Research Topics

COVID-19: Food system frailties and opportunities

Edited by
Claire Kremen, Elliot Berry, Rachel Bezner Kerr,
Patrick Meyfroidt, Ivette Perfecto, Todd Rosenstock,
José Antonio Teixeira and Hannah Wittman

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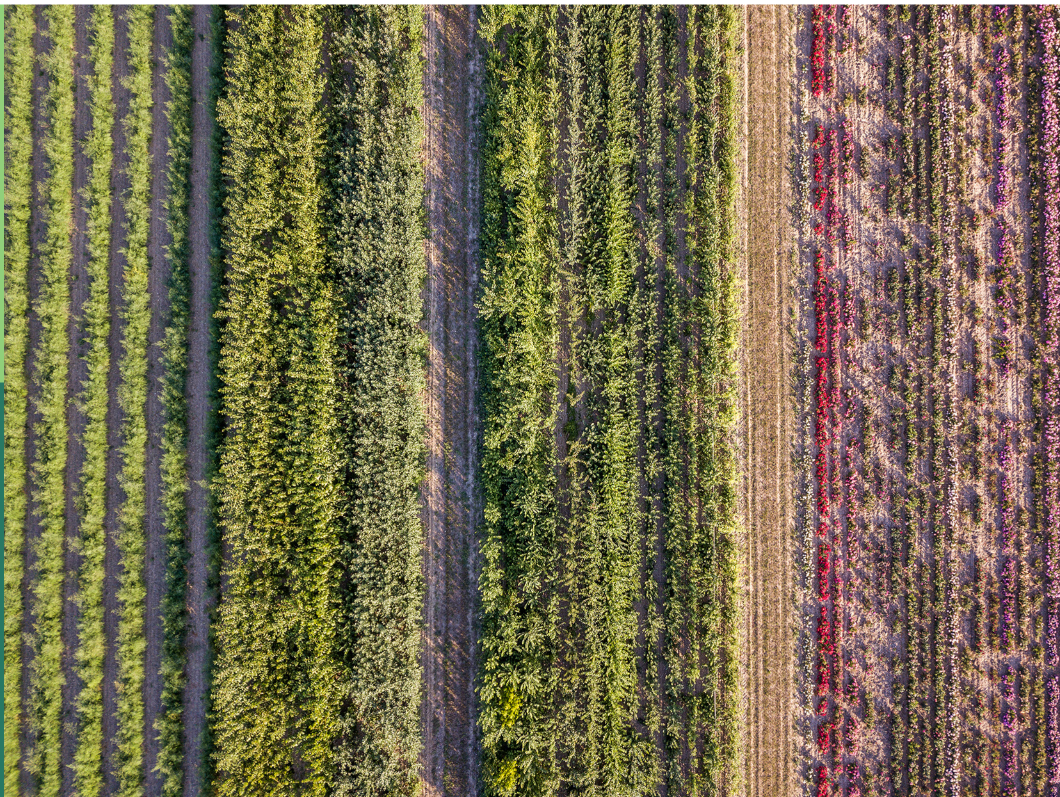

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COVID-19: Food system frailties and opportunities

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Rachel Bezner Kerr — Cornell University, United States
Patrick Meyfroidt — Université Catholique de Louvain, Belgium
Ivette Perfecto — University of Michigan, United States
Todd Rosenstock — Alliance Bioversity International and CIAT, France
José Antonio Teixeira — University of Minho, Portugal
Hannah Wittman — University of British Columbia, Canada

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Table of contents

06 Editorial: COVID-19: food system frailties and opportunities
Elliot M. Berry

09 Household Food Dynamics and Food System Resilience Amid the COVID-19 Pandemic: A Cross-National Comparison of China and the United States
Zhengxia Dou, Darko Stefanovski, David Galligan, Margaret Lindem, Paul Rozin, Ting Chen and Ariana M. Chao

20 Alternative Seafood Networks During COVID-19: Implications for Resilience and Sustainability
Joshua S. Stoll, Hannah L. Harrison, Emily De Sousa, Debra Callaway, Melissa Collier, Kelly Harrell, Buck Jones, Jordyn Kastlunger, Emma Kramer, Steve Kurian, M. Alan Lovewell, Sonia Strobel, Tracy Sylvester, Brett Tolley, Andrea Tomlinson, Easton R. White, Talia Young and Philip A. Loring

32 Food Containing Bioactive Flavonoids and Other Phenolic or Sulfur Phytochemicals With Antiviral Effect: Can We Design a Promising Diet Against COVID-19?
Martina Ghidoli, Federico Colombo, Stefano Sangiorgio, Michela Landoni, Luca Giupponi, Erik Nielsen and Roberto Pilu

47 Impact of Crop Diversity on Dietary Diversity Among Farmers in India During the COVID-19 Pandemic
Kaela Connors, Lindsay M. Jaacks, Poornima Prabhakaran, Divya Veluguri, G. V. Ramanjaneyulu and Aditi Roy

57 COVID-19 Impact on Poultry Production and Distribution Networks in Bangladesh
Abdullah Al Sattar, Rashed Mahmud, Md. Abu Shoieb Mohsin, Nurun Nahar Chisty, Md. Helal Uddin, Nusrat Irin, Tony Barnett, Guillaume Fournie, Eve Houghton and Md. Ahasanul Hoque

69 From Farm to Fork: Early Impacts of COVID-19 on Food Supply Chain
Shalika Vyas, Nitya Chanana, Madhur Chanana and Pramod K. Aggarwal

84 Systematic Review on Food Safety and Supply Chain Risk Assessment Post Pandemic: Malaysian Perspective
Md Saad Nurul Eiman, Firdaus Muhammad Nurul Azmi Aida, Trias Mahmudiono and Siva Raseetha

94 Building Resilient Value Chains After the Impact of the COVID-19 Disruption: Challenges for the Coffee Sector in Central America
Ingrid Fromm

103 Perceptions and Responses of Diversified Farm Producers in the Northern Great Plains to the Early Stage of the COVID-19 Pandemic
Roland Ebel, Selena Ahmed, Teresa Warne, Alexandria Moxley, Irene Grimberg, Meghann Jarchow and Fabian D. Menalled

120 A Shock to the System: What the COVID-19 Pandemic Reveals About Australia's Food Systems and Their Resilience
Natalie A. Jones, Jennifer Bellamy, William Bellotti, Helen Ross, Severine van Bommel and Yiyu Liu

138 Effect of COVID-19 Pandemic on Food Systems and Determinants of Resilience in Indigenous Communities of Jharkhand State, India: A Serial Cross-Sectional Study
Suparna Ghosh-Jerath, Ridhima Kapoor, Ayushi Dhasmana, Archna Singh, Shauna Downs and Selena Ahmed

162 Assessing the Impacts of the COVID-19 Pandemics on Sustainable Development Goals in Nepal
Toyanath Joshi, Rudra Prasad Poudel, Kamana Kafle, Bandana Bhattarai, Benu Prasad Prasai and Santosh Adhikari

167 Food Supply Chain Shocks and the Pivot Toward Local: Lessons From the Global Pandemic
E. Melanie DuPuis, Elizabeth Ransom and Michelle R. Worosz

181 An Assessment of the Impact of COVID-19 on the Agri-Food System in Caribbean Small Island Developing States
Oral Daley, Wendy-Ann P. Isaac, Afiya John, Ronald Roopnarine and Keon Forde

196 Diversified Farming Systems: Impacts and Adaptive Responses to the COVID-19 Pandemic in the United States, Norway and China
Inger Elisabeth Måren, Heidi Wiig, Kathryn McNeal, Sally Wang, Sebrina Zu, Ren Cao, Kathinka Fürst and Robin Marsh

213 Changing Conditions for Local Food Actors to Operate Towards Agroecology During the COVID-19 Pandemic
Markus Frank, Brigitte Kaufmann, Mercedes Ejarque, María Guadalupe Lamaison, María Virginia Nessi and Mariano Martin Amoroso

230 "Connecting With Good People and Good Plants": Community Gardener Experiences in New York State During the COVID-19 Pandemic
Tomasz B. Falkowski, Bethany Jorgensen, Donald A. Rakow, Ashmita Das, Stewart A. W. Diemont, Theresa Selfa and Austin B. Arrington

247 Perceived Effects of COVID-19 Pandemic on Food Security in Southeast Nigeria
Jane Munonye, Emeka Osuji, Michael Olaolu, Anthony Okoisu, Joy Obi, Gladys Eze, Sikiru Ibrahim-Olesin, Loveday Njoku, Mark Amadi, Chibuzo Izuogu and Gillian Azuamairo

265 The vulnerability of a centralized food system: An opportunity to improve food security in times of COVID-19-Peru perspective
Vicente Amirpasha Tirado-Kulieva, William Rolando Miranda-Zamora, Ernesto Hernández-Martínez, Tania Jakeline Choque-Rivera and Olivia Magaly Luque-Vilca

278 A longitudinal investigation of dietary diversity during the COVID-19 pandemic in Mandinka households in Kanifing, Brikama, and the West Kiang region in The Gambia
Richard Sidebottom, Solomon Bizuayehu Wassie, Carla Cerami, Momodou W. Jallow, Shailaja Fennell and Sarah Dalzell

297 Effects of COVID-19 on dietary behavior of urban consumers in Nairobi, Kenya
Christine G. K. Chege, Kevin Onyango, Joram Kabach and Mark Lundy

308 Foodborne zoonoses control in low- and middle-income countries: Identifying aspects of interventions relevant to traditional markets which act as hurdles when mitigating disease transmission
Eithne Leahy, Florence Mutua, Delia Grace, Elisabetta Lambertini and Lian Francesca Thomas

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EDITED AND REVIEWED BY
Jennifer Blesh,
University of Michigan, United States

*CORRESPONDENCE
Elliot M. Berry
elliotb@ekmd.huji.ac.il

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Editorial: COVID-19: food system frailties and opportunities

Elliot M. Berry*

Braun School of Public Health, Hebrew University-Hadassah Medical School, Jerusalem, Israel

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Editorial on the Research Topic
COVID-19: food system frailties and opportunities

One hundred years ago the Great War was followed by the Spanish Influenza pandemic which killed more people. Currently, we are witnessing the opposite: a pandemic followed by war in Ukraine which has lasted more than 590 days, at the time of writing. The COVID pandemic brought the world to its knees with shutdowns separating families, isolating the elderly and lonely, stopping commerce, closing school lunches and much more. Most of the world was caught unprepared. Food prices increased to 120% and supply chains were severely tested. Just as the pandemic was abating, the war involving major grain and fertilizer producers has considerably deteriorated the situation. The Food prices have now reached 160% and are still rising (Osendarp et al., 2022): food and energy have become weapons of war. In the winter, people have had to choose whether to "Eat or to Heat." It is extremely distressing that some 23 years into the 21st century we have already been visited by the four horsemen of the Apocalypse—Pestilence (COVID, MERS, SARS, Ebola, avian and swine flu, and more), War, Famine, and Death. To this list must be added the threat of climate change. However, the scientific and political collaborations, and the lessons learnt in surmounting COVID show that we do have the capabilities to overcome these major challenges. These efforts must be continued and extended to make the world safer for all humankind.

Therefore, this Frontiers Research Topic is of high relevance in considering the responses to enable strengthening food systems to cope with future crises to global food security. Twenty-two articles have been accepted by the editors for publication out of 29 that were submitted. The articles consider food systems world-wide—eight countries in Asia, seven from North America, three in Africa, two each from Central and South America and one from Australia and Europe.

The challenges to Food security affected initially its stability dimension and the ability to withstand shocks, but soon involved the whole pathway of availability (at national level), accessibility (household level), and utilization (individual) and also to include sustainability (Berry et al., 2015). The new food security dimension of agency (Clapp et al., 2022) was very engaged in the responses of the social media providing positive coping strategies (including humor) (Peng and Berry, 2021) and negative influences such as anti-vaccination messages (Wilhelm, 2023). The urgency of the situation, unfortunately, placed the on-going challenges of sustainability and climate change in the background, as well as the pandemic of obesity and malnutrition which affects far more people than were stricken by COVID.

Responses were considered at different levels—governments, non-profit organizations, the private sector and communities (Måren et al.) and involving most of the actors along the food chain, especially farmers (Connors et al.; Ebel et al.; Ghosh-Jerath et al.). The articles may also be grouped into three principal categories essential for dealing with the COVID pandemic, future zoonoses and general disaster risk reduction (Sendai framework, UNISDR, 2015): prevention and preparedness (5); resilience (10), and policy (7). Some articles cover more than one of these areas.

With regard to short term actions for pandemics, plans must be put in place for national food storage and local food distribution (DuPuis et al.) during lockdowns especially for at risk groups—homeless, unemployed, elderly, lonely and more. In India, farmers with more crop diversity were more resilient to disruptions in the markets (Connors et al.). An important practical step, for example, is to ensure the continuation of school meals programs.

National and supra-national organizations will have to guarantee that medical aid and vaccinations will be available to countries with weak public health infrastructures. As the pandemic is retreating, there should be national and international mechanisms to help economic recovery in low- and middle-income countries, where the resource-poor became unemployed (Joshi et al.) and more food insecure, especially in informal settlements around urban areas (Chege et al.).

Actions for the long term include: helping developing countries access the major securities of food, energy and water. Establishing national committees for contingency plans for emergency disasters, which should deal with all aspects of risk management. Health infrastructures must be strengthened regarding personal protective equipment, intensive care units and staff training. Global alert networks should operate for disease surveillance and control of animal markets (Leahy et al.). Further, it will be important to empower the civil society to counter misinformation on the social media, especially against anti-vaccination campaigns and anti-public health recommendations (Wilhelm, 2023). In Bangladesh, there was fake news that poultry could transmit the disease (Sattar et al.). There is a consensus that transparent communication with the general public is of utmost importance to ensure compliance with the public health and other measures necessary for crisis management, particularly when they affect personal liberty and movement.

Other considerations identified by the authors necessary to build resilient food systems, deal with unexpected compound risks from extreme weather events (Vyas et al.); attempts at dietary manipulation with flavonoids for protection (Ghidoli et al.); ensuring food safety hygiene of food handlers and food supply chain (Nurul Eiman et al.); developing cultural ecosystem services such as community gardens. These provided positive connection with other gardeners and safe spaces of refuge and joint activities such as composting, food donation (Falkowski et al.). Resilience to market disruption was linked to crop diversity in India (Connors et al.), and to sanitation in The Gambia (Sidebottom et al.).

In the global food system, many small farmers experienced economic difficulties (Daley et al.) and depended on off-farm incomes (Ebel et al.). Their work was hindered by restrictions in movement of farm labor and supplies (Ghosh-Jerath et al.). The shock of the pandemic did not affect the system equally. Some supply chains lost business while others experienced increased demands. Consumers were not fully confident in the supply chains (Jones et al.). Overall, exorbitant food prices tested the preparedness of family food security (Dou et al.; Munonye et al.). There were also the dangers of food hoarding as consumers attempted to increase their household food security in response to the unpredictable fluctuations and uncertainty in food supplies.

However, we believe that the global experiences during COVID may be leveraged to produce positive reactions at national and international levels for planning food systems toward the Sustainable Development goals. But for this to occur, requires a major re-thinking of the policies, methodologies and science involved in the multi-disciplinary activities of food systems (Béné, 2020). The move should be made toward complex adaptive systems where a perfect understanding of the individual parts does not automatically convey a perfect understanding of the whole system's behavior. These systems are dynamic and non-linear with both positive and negative feed-back loops, multiple interconnections; and synergies & trade-offs (Nayak and Waterson, 2019; Deconinck, 2021).

Among the opportunities identified in this Research Topic we note: transformation of food systems toward sustainability (Frank et al.) from agro-ecology, finding alternative practices by local food actors to form self-organized producer groups. To improve food security by decentralizing the food supply chain (Tirado-Kulieva et al.), whereby local producers and vendors collaborated to maintain food availability and multi-level interventions involved government, industry, academia and the general population. Alternative seafoods networks encouraged local and direct marketing, providing functional diversity in the food chain (Stoll et al.).

Opportunities arose to gain access to the diverse wild food environment and revitalize bio-cultural resources (Ghosh-Jerath et al.). There were also innovations using e-marketing, relying on family jobs and sharing information for positive resilience effects as found across the USA, China and Norway (Måren et al.).

We hope that this Research Topic will be used by all the actors in sustainable food systems, and especially policy makers, to learn lessons from this past pandemic (Klassen and Murphy, 2020), to be better prepared for the next one which will surely come. These, and more, are necessary to safeguard the survival of our planet (Smil, 2022; Rockström et al., 2023).

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Béné, C. (2020). Resilience of local food systems and links to food security–a review of some important concepts in the context of COVID-19 and other shocks. *Food Secur.* 12, 805–822. doi: 10.1007/s12571-020-01076-1

Berry, E. M., Dernini, S., Burlingame, B., Meybeck, A., and Conforti, P. (2015). Food security and sustainability: can one exist without the other? *Public Health Nutr.* 18, 2293–2302. doi: 10.1017/S136898001500021X

Clapp, J., Moseley, W. G., Burlingame, B., and Termine, P. (2022). The case for a six-dimensional food security framework. *Food Policy* 106, 102164. doi: 10.1016/j.foodpol.2021.102164

Deconinck, K. (2021). *Making Better Policies for Food Systems*. Berlin: OECD Publishing. doi: 10.1016/j.gfs.2022.100621

Klassen, S., and Murphy, S. (2020). Equity as both a means and an end: Lessons for resilient food systems from COVID-19. *World Dev.* 136, 105104. doi: 10.1016/j.worlddev.2020.105104

Nayak, R., and Waterson, P. (2019). Global food safety as a complex adaptive system: Key concepts and future prospects. *Trends Food Sci. Technol.* 91, 409–425. doi: 10.1016/j.tifs.2019.07.040

Osendarp, S., Verburg, G., Bhutta, Z., Black, R. E., de Pee, S., Fabrizio, C., et al. (2022). Act now before Ukraine war plunges millions into malnutrition. *Nature* 604, 620–624. doi: 10.1038/d41586-022-01076-5

Peng, W., and Berry, E. M. (2021). Coping with the challenges of COVID-19 using the sociotype framework: a rehearsal for the next pandemic. *Rambam Maimonides Med. J.* 12, e0005. doi: 10.5041/RMMJ.10425

Rockström, J., Gupta, J., Qin, D., Lade, S. J., Abrams, J. F., Andersen, L. S., et al. (2023). Safe and just Earth system boundaries. *Nature* 619, 102–111. doi: 10.1038/s41586-023-06083-8

Smil, V. (2022). *How the World Really Works: The Science behind how we got here and Where We're Going*. London: Penguin.

UNISDR (2015). *United Nations Office for Disaster Risk Reduction. Sendai Framework for Disaster Risk Reduction 2015-2030*. Geneva.

Wilhelm, E. A. (2023). New science for describing unhealthy online environments. *Physics* 16, 89. doi: 10.1103/Physics.16.89

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Household Food Dynamics and Food System Resilience Amid the COVID-19 Pandemic: A Cross-National Comparison of China and the United States

Zhengxia Dou[1]*, *Darko Stefanovski*[1], *David Galligan*[1], *Margaret Lindem*[2], *Paul Rozin*[3], *Ting Chen*[4]* and *Ariana M. Chao*[5]

[1] University of Pennsylvania School of Veterinary Medicine, Philadelphia, PA, United States, [2] University of Pennsylvania Libraries, Philadelphia, PA, United States, [3] University of Pennsylvania School of Arts and Sciences, Philadelphia, PA, United States, [4] Zhejiang Gongshang University, Philadelphia, PA, United States, [5] University of Pennsylvania School of Nursing, Philadelphia, PA, United States

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Edited by:
Hannah Wittman,
University of British Columbia, Canada

Reviewed by:
Steffanie Scott,
University of Waterloo, Canada
Zhenzhong Si,
University of Waterloo, Canada

***Correspondence:**
Zhengxia Dou
douzheng@vet.upenn.edu
Ting Chen
chenting_15@zjgsu.edu.cn

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The COVID-19 pandemic is a "perfect storm" that is testing the resilience and functional stability of the food system, as it ultimately affects household food dynamics and consumer food experiences. This cross-national survey-based study examined in real time how the COVID-19 pandemic impacted food-centric matters in 1,732 Chinese and 1,547 U.S. households during the stay-at-home directives. Both cohorts reported increased efficiency in the use of food, families spending more time cooking and eating together, and more prudent use of food with less waste. Food purchasing patterns shifted from frequent trips to the store to dramatic increases in online ordering. A small proportion (2% U.S. and 11% Chinese respondents) reported clinically significant weight gains of >4.5 kg. Household food security weakened, with large increases in people worrying about or experiencing food shortage. Collective grocery-shopping experiences by survey respondents indicated that the functional stability of food supply systems remained steady; all food types were somewhat available, except for noticeably higher prices widely reported by the Chinese cohort. This study offers insights into food system resilience when facing the pandemic and sheds light on future food patterns as well as long-term questions for additional research about how people make decisions and food behavioral changes at times of crisis.

Keywords: COVID-19, food security, food behavior, food system resilience, food availability, food supply disruption, household food dynamics, household food insecurity

INTRODUCTION

COVID-19, first documented in China in December 2019 [World Health Organization (WHO), 2020], has since spread rapidly around the globe. Stay-at-home orders and isolation have been in effect worldwide in an effort to slow down the spread of the disease. As a result, large portions of the population have stayed at home, and numerous businesses, including restaurants and eateries, have closed or suspended their services. Caught in the crisis, poorly prepared, and homebound for weeks or months, how did people fare in terms of sourcing food and keeping their families fed? How did household-level food security (or insecurity) change during the crisis? Alterations in food purchasing and eating patterns as well as routine activities may also be related to weight change, with several popular media outlets referring to a "quarantine 15" (e.g., https://nypost.com/2020/05/19/nearly-half-of-women-report-weight-gain-in-coronavirus-quarantine/). Growing media attention also highlights incidents of food flow disruption due to the pandemic, from vegetables rotting in fields and milk being dumped, food processing facilities running short of workers due to the disease, and to panic-buying in stores. Strains on multiple points of the food supply chain could affect food availability and prices in the retail sector, ultimately impacting people at the receiving end [World Bank, 2014; World Economic Forum (WEF), 2020]. With the food system subjected to the "perfect storm" of COVID-19, what insights may be drawn from people's experience at the market–consumer interface regarding the integrity and resilience of the food system?

A number of recent studies have shed light on addressing some of the issues raised above. For example, there appeared to be a phenomenal shift of household food sourcing from in-store shopping to online-based purchases (e.g., Gray, 2020; Si et al., 2020). Several studies also examined consumer food behavioral change in terms of food choices and eating habits. For instance, an Italian survey ($n = 1{,}929$) found that nearly half of the participants reported modified dietary habits, with many increasing the consumption of comfort food, e.g., chocolate and dessert items (Scarmozzino and Visioli, 2020). Changes in eating patterns and dietary intake while staying at home because of the pandemic have raised concerns about potential health and nutritional consequences (Belen Ruiz-Roso et al., 2020; Scarmozzino and Visioli, 2020; Sidor and Rzymski, 2020). Health-related implications can be further exacerbated by reduced physical activities due to the home quarantine (Ammar et al., 2020). Additionally, food security issues emerged as a top priority besides health and safety concerns associated with the COVID-19 disease. The potential for a "secondary pandemic" of hunger and food shortage has become a serious concern for the Global South's urban poor and vulnerable groups (Crush and Si, 2020). Furthermore, countries or regions that rely heavily on food imports to meet domestic needs under normal conditions, such as the Pacific islands and territories (Farrell et al., 2020), have reported alarm regarding their food security vulnerability given COVID-19's global spread and the multitude of disruptions.

A robust and resilient food system is fundamental to all people at all times but particularly at times of crisis. Food system resilience is the capacity to provide food security over time in the face of various changes or disturbances (Tendall et al., 2015). The COVID-19 pandemic exerts enormous pressure with disruption to food systems, testing its resilience on multiple fronts, such as the logistics (supply, transport, and distribution of food materials and products), management (rapid response and flexibility involving various policies and regulations), food availability, and accessibility at the consumer end. Hobbs (2020) provided an early assessment of the pandemic's impacts on food supply–demand dynamics in Canada. Food supply disruption was assessed and linked to factors such as labor shortage and transportation network breakdowns due to domestic as well as border-control issues, whereas consumer panic-buying, as well as a dramatic shift in consumption patterns from food services to home cooking, has brought about demand-side shock to the food supply chain as well (Hobbs, 2020). Richards and Rickard (2020) reported significant changes in the Canadian fruit and vegetable markets, shifting from foodservice sectors to almost entirely retail channels. Intervention policies for enhancing food supply and food system resilience to mitigate crisis shocks have been proposed, e.g., prioritizing local food supplies (Hobbs, 2020), favoring shorter supply chains (Abiral and Atalan-Helicke, 2020), and promoting home gardening and urban agriculture (Lal, 2020; Pulighe and Lupia, 2020).

The current study aims to address the critical issues raised above by examining the food experience of Chinese and U.S. households during the pandemic through real-time data collection using convenience and snowball sampling methods. Our first objective was to understand the impacts of the pandemic on household food dynamics, such as food purchasing and eating behavior, aspects of food security issues, as well as stress and self-reported body weight change. Our second objective was to assess food system resilience by examining food supply stability from the viewpoint of grocery shoppers. China and the U.S. are the largest countries most severely impacted by the COVID-19 pandemic as of mid-to-late April 2020, when the survey was conducted. Examining people's food experience in these countries can help us better understand the "food-print" of the COVID-19 pandemic. Such understanding is critical for developing innovative policies and mitigation strategies toward a better and more secure food future. Patterns derived from the survey can inform additional research for determining long-term consequences. Lessons drawn from the survey cohorts with further investigations in the U.S. and China, two countries that feature distinct food cultures with different food systems, may be applicable elsewhere.

METHODS

Survey Design

The survey consisted of 53 questions (single or multiple and numeric or descriptive choices) to collect data on the following: (i) demographics of respondents; (ii) parameters reflecting household food dynamics (food purchasing, at-home food-related activities, and food-use behavior); (iii) household-level food security parameters; (iv) food supply and availability indicators in marketplaces as experienced by survey respondents; and (v) other relevant matters (stress level, bodyweight change, etc.). The survey contained no identifier items, such as name, address, etc. The study was deemed exempt from requiring human subjects approval by the Institutional Review Board of the University of Pennsylvania.

The Chinese-language version was identical in content to the original (English) version except for a few items that were adapted to apply to Chinese participants, for example, race/ethnicity choices, household income range, height (in meters instead of feet), and weight (in kilograms instead of pounds). The two versions were hosted on the same internet platform.

Survey Distribution

After pilot testing, the survey was disseminated online. Distribution was through individual as well as institutional networks and snowballing via social media, e.g., Facebook and Twitter in the U.S., and the most popular social media platform, WeChat, in China. Cross-sectional data collection started on April 17, 2020, in the United States and April 22, 2020, in China. The number of daily responses spiked within 24 h in each country and slowed down substantially within 3–5 days. The slowing down was more rapid in China than in the U.S. Data collected during April 17–27 in the U.S. and April 22–27 in China were extracted for analysis in this study. Valid responses (answering at least two survey questions) were from 705 zip code regions in the U.S. and 30 out of 34 Provincial districts in China.

Data Analysis

Raw data were exported to and analyzed in Stata (Stata Corp., College Station, TX). All analyses were conducted with two-tailed tests of hypotheses and a p-value < 0.05 as the criteria for statistical significance. Descriptive analyses included computation of means (with 95% confidence intervals [95%CI]), standard deviations, medians, interquartile ranges (IQR) of continuous variables, and tabulation of categorical variables. Frequency counts and percentages were used for categorical variables. Inference statistical analyses were conducted using the chi-square test for comparison of categorical variables and ANOVA or t-test for continuous outcomes.

RESULTS

Characteristics of the U.S. and Chinese Cohorts

Valid survey respondents totaled 1,547 in the U.S. and 1,732 in China. Characteristics of the two cohorts are presented in **Supplementary Table 1**. At the time of the survey, the Chinese respondents had stayed at home for about 7.5–10 weeks; 62.4% had a household member(s) losing income because of the pandemic. In comparison, the U.S. respondents had stayed at home for 4–6 weeks; 35.7% had a household member(s) losing income. A greater proportion of the U.S. cohort reported that household members tested COVID-19 positive (0.41%) or had COVID-19-like symptoms (11.4%), compared to the Chinese cohort (0 and 1.99%). Of other demographic parameters, the U.S. respondents consisted primarily of women with age groups more or less evenly distributed, whereas the Chinese cohort was younger with a narrower gender gap (**Figure 1**, **Supplementary Table 1**). That the Chinese participants were mostly young people can be attributed to the survey distribution mechanisms, which relied heavily on networks of university faculty via snowballing through their college and graduate students who were scattered throughout the country while staying-at-home with their families during the pandemic. This is one of the potential limitations associated with convenience sampling through online-based survey studies, leading to sampling bias. For example, in a recent survey by Zhao et al. (2020) investigating the dietary diversity of the Chinese population during the pandemic, 83.6% of the participants (n = 1,938) were in the younger group (18–45 years of age) while only 16.4% were >45 years of age. It is also noteworthy that the majority of the U.S. cohort (>70%) were in charge of household grocery shopping or meal planning/cooking (**Supplementary Table 1**), whereas the Chinese cohort had about 1/3 indicating this role. The latter is consistent with the age characteristics exhibited in **Figure 1**, as in Chinese families, the younger generation typically enjoys continued support from their parents in terms of cooking and other household chores. It is not clear whether or how the skewed sample distribution with the Chinese cohort impacted the accuracy of the survey outcome. The extent of such impact, if any, may be relatively small considering the "up-close" relationship spatiotemporally within households during the stay-at-home pandemic.

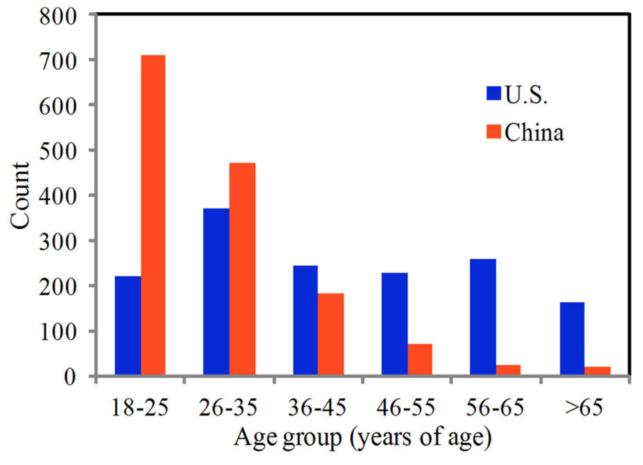

FIGURE 1 | Age group distribution of survey participants. The U.S. cohort (N = 1,547) was more or less evenly distributed whereas the Chinese cohort (N = 1,732) consisted of proportionally more people in the younger range of age.

Household Food Dynamics

Food sourcing changed dramatically during the pandemic, and this was consistent for both cohorts. First, restaurant food ordering for take-out or delivery during the pandemic decreased in frequency (**Supplementary Figure 1A**). Money spent on such food had the same pattern of decreases (**Supplementary Figure 1B**). Second, the vast majority (74% for both cohorts) reported making fewer grocery-shopping trips during the pandemic than before (**Supplementary Figure 2**). Meanwhile, online grocery shopping for delivery or curbside pickup became popular, about 1/3 of U.S. respondents reported doing so for the first time. Notably, the single largest proportion of the Chinese cohort reported community- or neighborhood-based group grocery ordering for delivery (**Figure 2**). In their recent report, Si et al. (2020) explicitly described how consumers

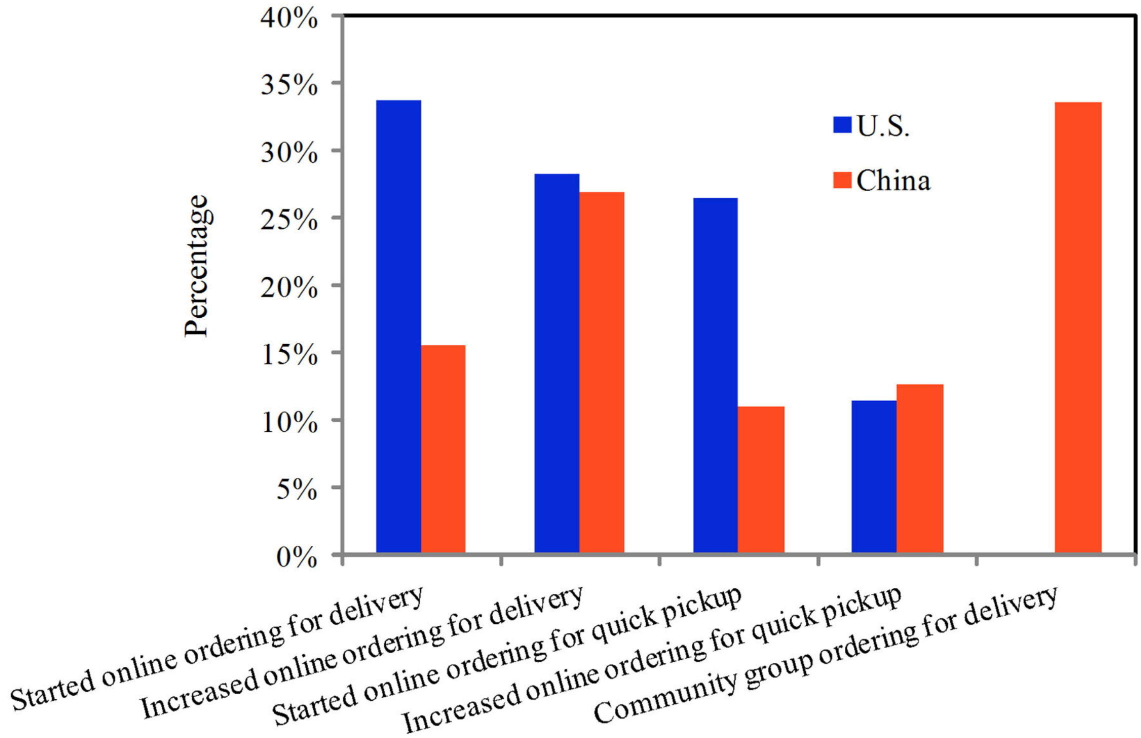

FIGURE 2 | Online grocery-shopping increased dramatically during the COVID-19 pandemic. Many reported ordering groceries online for delivery or curbside pickup for the first time. About 1/3 of the Chinese cohort reported community-based group ordering for delivery.

in Wuhan, the epicenter of the COVID-19 outbreak in China, coordinated via grassroots community organizing efforts to obtain food during the strictly enforced lockdown. Our survey, with participants from 30 out of 34 Provincial-districts in China indicated that the community- or neighborhood-based group ordering as a major food-sourcing mechanism not only occurred in Wuhan but also mushroomed across the country during the pandemic. Understandably, many people in the Chinese and U.S. cohorts reported purchasing extra amounts of various foods when grocery shopping (**Supplementary Figure 3**).

Food behavior and perceptions changed, with both cohorts valuing food more during the pandemic than before. For example, many reported throwing away less food (**Supplementary Table 2**). In modern societies, food wastage can be reduced, but total elimination is unlikely (Papargyropoulou et al., 2014; Quested and Murphy, 2014). For the survey respondents in both countries, spoiled fruits and vegetables topped the list of foods thrown away during the pandemic (**Supplementary Table 3**). This may be attributed to the extra-quantity purchases as well as the perishable nature of fresh produce. In line with the heightened awareness of food being precious, most U.S. and many Chinese respondents indicated making a second meal or snack of leftovers from restaurant food, as well as being more prudent in meal planning or spending less money on meals (**Supplementary Table 2**). A positive behavioral change with reduced food wastage was also reported by Jribi et al. (2020) for a smaller sample ($n = 284$) in Tunisia.

Importantly, a great many respondents indicated making home-cooked meals more often (62% U.S. and 60% China) and reported household members spending more time cooking or eating together (48% U.S. and 73% China) while staying at home (**Supplementary Table 2**). Meanwhile, the use of ready-to-eat food items, such as frozen dinners, was less frequent. The vast majority indicated no change regarding types of food consumed during the pandemic as compared to before, although the number of people reporting eating more of various foods exceeded those reporting eating less (**Supplementary Figure 4**). In comparison, a survey ($n = 411$) by Celik and Dane (2020) focusing on consumer food preference found that the first and second preferences were meat and bakery foods before the pandemic but fruits and vegetables during the pandemic. By and large, changes in household food dynamics and food attitudes and behavior were mostly positive/desirable, with patterns consistent for both the U.S. and Chinese cohorts. Some of the changes may persist, as about half of each cohort indicated that the pandemic might have changed how they will treat/handle food in the future (**Supplementary Table 2**).

Household Food (in)Security

Household food security situation changed dramatically in terms of survey respondents' perception as well as actuality indicators. Among U.S. respondents, less than 4% reported ever worrying about feeding themselves or household members in the year prior to the pandemic; but during the pandemic (i.e., at the time of survey) 38% reported becoming worried. The number of worried

TABLE 1 | Household food insecurity situation worsened during the COVID-19 pandemic.

	United States			China		
	N	Lowest income[a]	Lost income[b]	*N*	Lowest income[a]	Lost income[b]
Worries about not being able to feed family before pandemic	45	13 (28.9%)	27 (60.0%)	188	51 (27.1%)	140 (74.5%)
Worries about not being able to feed family since pandemic	507	39 (7.7%)	213 (42.0%)	360	92 (25.6%)	265 (73.6%)
Skipping a meal or going to bed hungry due to food shortage before pandemic	16	6 (37.5%)	11 (68.8%)	81	34 (42.0%)	63 (77.8%)
Skipping a meal or going to bed hungry due to food shortage since pandemic	33	4 (12.1%)	17 (51.5%)	52	23 (44.2%)	46 (88.5%)
Access to food from government or charity organization during pandemic	91	5 (5.5%)	41 (45.1%)	124	29 (23.4%)	88 (71.0%)
Access to free meals provided to school children during pandemic	112	4 (3.6%)	41 (36.6%)	57	15 (26.3%)	36 (63.2%)

Number of people reported worrying about or experiencing food shortage went up in both U.S. and Chinese cohorts, particularly those in the lowest income category or with the household member(s) losing income during the pandemic. More than 10% of all survey participants reported having access to free food from the government or other organizations.

[a] *<$25,000 per U.S. household, <50,000 RMB per Chinese household.*

[b] *Household member(s) lost income during the COVID-19 pandemic.*

respondents was 45 vs. 509 for before vs. during the pandemic, respectively (**Table 1**). Twice as many people reported skipping a meal or going to bed hungry due to food shortage (16 vs. 33 for before vs. during the pandemic, respectively). Fortunately, having access to free foods from government or charity organizations, for the households in general (91 entries) or for school children (112 entries) in particular, helped relieve household food shortage during the pandemic. Households that meet their food needs via various coping strategies, such as skipping a meal or acquiring food through food assistance programs, are considered food-insecure per USDA definition (USDA ERS, 2019). With the Chinese respondents, the food security situation deteriorated due to the pandemic but to a lesser extent than the U.S. cohort (**Table 1**). Notably, there exist various assessment systems with more comprehensive food (in)security indicators, e.g., USDA ERS (2019), Household Food Insecurity Access Scale (HFIAS) (2020). Our survey included a few selected parameters (discussed above), rather than more complete and inclusive indicators, based on the consideration of balancing the breadth and scope of the questionnaire (totaling 53 items) with participants' weariness and response rate.

Not surprisingly, households that were food insecure were in the lowest income category (<$25,000 per U.S. household, <50,000 RMB per Chinese household) or had family members who lost income during the pandemic (**Table 1**). In a survey (conducted on March 19–24, 2020) investigating household food security issues at the very early stage of the stay-at-home orders, Wolfson and Leung (2020) reported that the COVID-19 pandemic was "disproportionately affecting low-income, food-insecure households that already struggle to meet basic needs." Similarly, Barker and Russell (2020) reported that the lockdown in Britain rendered a large proportion of the population economically vulnerable with demand for emergency food relief quadrupled. There is clearly a need for rapid mobilization of effective intervention mechanisms to avert food shortage and to protect those who are most vulnerable at times of crisis like COVID-19 (see more in section Discussion). It is necessary to note that the income categories in our survey were chosen rather arbitrarily than matching existing standards, e.g., the World Bank (2020) with specific income-level definitions. Additionally, households with the same (low) income can still differ in relevant capacity to obtain food and feed themselves, depending on location, cost of living, and other factors.

Food-Mind-Body

The pandemic brought abrupt and unimaginable interference to people's lives. In these challenging times, both cohorts found solace in food. About 70% of both cohorts indicated food being a pleasure/comfort element, a stress reducer, and a way to cope with boredom during the pandemic. Still, the U.S. respondents were bearing considerable stress while staying-at-home (**Table 2**): about 30% indicating "rather much" or "very much" stress. In contrast, the Chinese cohort had just 7% indicating "rather much" or "very much" stress whereas 61% indicated "only a little" or "not at all" (**Table 2**). The level of stress was associated with age, household income level, and family members losing income during the pandemic (**Supplementary Table 4**).

Regarding body weight change (**Table 2**), the highest proportion of each cohort (39.5% U.S., 46.5% China) reported no change in weight; for the remainder, people reporting weight gains outnumbered those reporting weight loss. What differentiated the two cohorts was a greater extent of weight gain with the Chinese respondents, 11% gaining >4.5 kg (10 pounds) and 14% gaining 2.3–4.5 kg (5–10 lbs). In comparison, only 2% of the U.S. cohort reported gaining >4.5 kg and 11% gaining 2.3–4.5 kg. Weight change was related to stress level; association with age or income level was inconsistent for the two cohorts (**Supplementary Table 4**). Decreased physical (exercise) activities were reported by a large portion of each cohort (43.3% U.S., 47.8% China; **Table 2**). Interestingly, in a survey conducted

TABLE 2 | Stress level and body weight change during the COVID-19 pandemic as reported by U.S. and Chinese participants.

	United States No. (%)	China No. (%)	*p*-value for U.S. vs. China
"Do you feel stressed these days"?	$N = 1{,}327$	$N = 1{,}611$	$P < 0.001$
Not at all	93 (7.0%)	546 (33.9%)	
Only a little	362 (27.3%)	515 (32.0%)	
To some extent	459 (34.6%)	440 (27.3%)	
Rather much	263 (19.8%)	83 (5.2%)	
Very much	150 (11.3%)	27 (1.7%)	
"What has happened to your weight during the pandemic"?	$N = 1{,}326$	$N = 1{,}615$	$P < 0.001$
Gained >10 lb (4.5 kg)	27 (2.0%)	173 (10.7%)	
Gained 5–10 lb (2.3–4.5 kg)	143 (10.8%)	221 (13.7%)	
Gained <5 lb (2.3 kg)	267 (20.1%)	307 (19.0%)	
Stayed the same	523 (39.4%)	752 (46. 6%)	
Lost <5 lb (2.3 kg)	186 (14.0%)	78 (4.8%)	
Lost 5–10 lb (2.3–4.5 kg)	61 (4.6%)	29 (1.8%)	
Lost >10 lb (4.5 kg)	14 (1.1%)	10 (0.6%)	
Don't know	105 (7.9%)	45 (2.8%)	
"During the pandemic, have your physical activities changed (and exercise)?"	$N = 1{,}325$	$N = 1{,}610$	$P < 0.001$
Increased	391 (29.5%)	325 (20.2%)	
No change	360 (27.2%)	516 (32.1%)	
Decreased	574 (43.3%)	769 (47.8%)	

All analyses were conducted with two-sided tests of hypotheses and a p-value < 0.05 indicating statistical significance.

in Italy, 19.5% reported gaining weight, with 42% indicating greater intake of comfort food (chocolate, dessert, ice cream, etc.), which were attributed to higher anxiety (Scarmozzino and Visioli, 2020). Negative impacts of COVID-19 related home confinement on physical activities and food consumption patterns. e.g., overeating and eating frequency. were also reported by Ammar et al. (2020) in a survey ($n = 1{,}047$) of African, Asian, and European participants.

Food Supply and Availability

The COVID-19 pandemic is a test for the functional stability of the food supply chain and ultimately the resilience of the food system. The survey asked what people experienced regarding food availability and choices when grocery shopping (shelf-empty, limited choices, store limited how much one could buy, compared to fully stocked, etc.) for nine food types (animal source food, fresh produce, processed foods, etc.) as well as two types of beverages. According to the U.S. respondents, most foods were available but many had limited options (**Figure 3A**); reports of empty shelves were generally low (<10% of respondents) except for rice/flour/dried beans and manufactured grain products for which 26.8 and 20.3% of respondents encountered empty shelves, respectively. Results from the Chinese cohort show that, by and large, all food types were well "stocked" (**Figure 3B**), with some choice limitations but relatively fewer reports of empty shelves. Food availability scores (1 for shelf-empty, 4 for fully stocked) were >2 (U.S.) and >3 (China) for all food categories (**Supplementary Table 5**), indicating that all food types were somewhat available. That the Chinese food availability scored higher than the U.S. may be attributed to a more versatile and diverse food retail sector in China, particularly involving urban food outlets (Anonymous, 2020). Zhong et al. (2019) discussed food security policies instituted in the city of Nanjing, China. The researchers described the utility of a public-private hybrid model, with mixed ownership of food wholesale and retail markets as well as capitals, in preventing market failure in food system operation. To our knowledge, similar food security policies have been applied in principle in many Chinese cities. Proactive and progressive food policies in urban planning are extremely important at times of crisis to foster urban food security.

Food prices held steady based on the experience of the U.S. cohort (**Figure 4A**); 70–90% of the respondents reported no price change, although 25.6% reported noticeably higher prices for meat/fish/eggs. Results from the Chinese cohort indicated price volatility; noticeably higher prices were reported by many for nearly all food types. About half of the Chinese cohort reported noticeably higher prices especially for meats/fish/eggs, fruits, and vegetables (**Figure 4B**).

To gauge people's general confidence in food supply security, we asked the following: "how did you feel about food supply and availability in your area or the nation in general?" The U.S. cohort exhibited a dramatic shift from broadly optimistic or no concern (83%) before the pandemic, to the vast majority (74%) being somewhat concerned or very concerned since the pandemic (**Figure 5A**). In contrast, nearly 90% of the Chinese respondents indicated a high level of confidence (optimistic or no concern) before and during the pandemic (**Figure 5B**). This is consistent with the pandemic-related stress levels mentioned earlier, with the U.S. cohort being more stressed/worried than the Chinese counterpart. This may be explained in part by the fact that the vast majority of the Chinese cohort participants are young (**Figure 1**); they are yet to establish large families and/or financial responsibilities. This may also reflect a growing sense of "optimism" or self-confidence that has spread among the Chinese people, particularly younger generations, resulting from the country's decades-long economic growth. Age, income level, and loss of income by household members during the pandemic were associated with the confidence of the U.S. but not the Chinese cohorts (**Supplementary Table 5**).

It is necessary to note that the various observations, patterns, and changes described above are the results aggregated from the reporting of survey participants at a specific timeframe, that is, after staying-at-home for 4–6 weeks (U.S. respondents) or 8–10 weeks (Chinese respondents). As the COVID-19 disease spread and the quarantine continued, the situation changed; different policies and control/containment measures were instituted; food

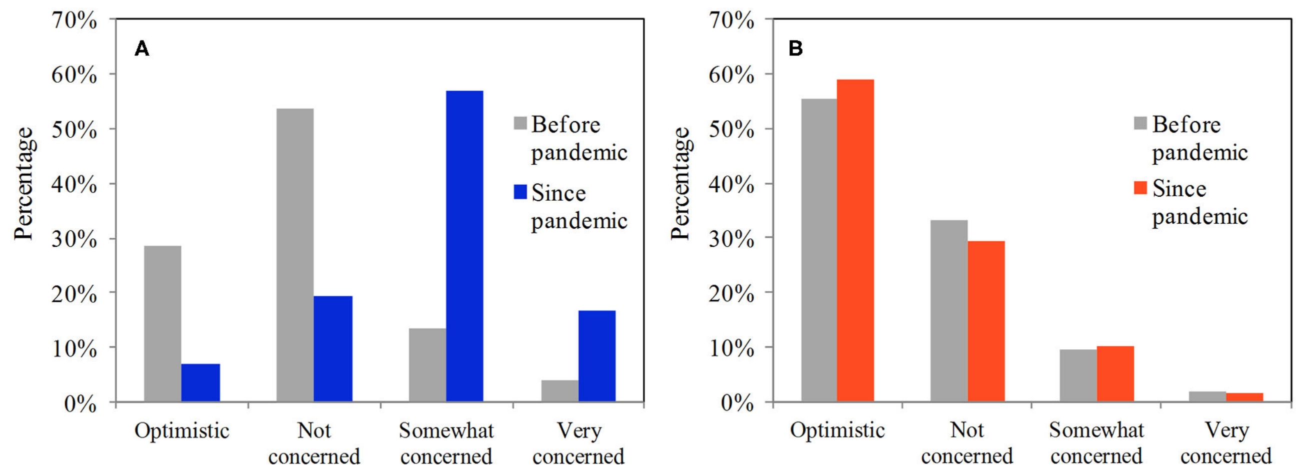

FIGURE 3 | Perception of food security during as compared to before the COVID-19 pandemic. The U.S. cohort exhibited a sharp decrease in confidence in food supply and availability in their area or the nation in general **(A)**, whereas the Chinese cohort retained their confidence **(B)**.

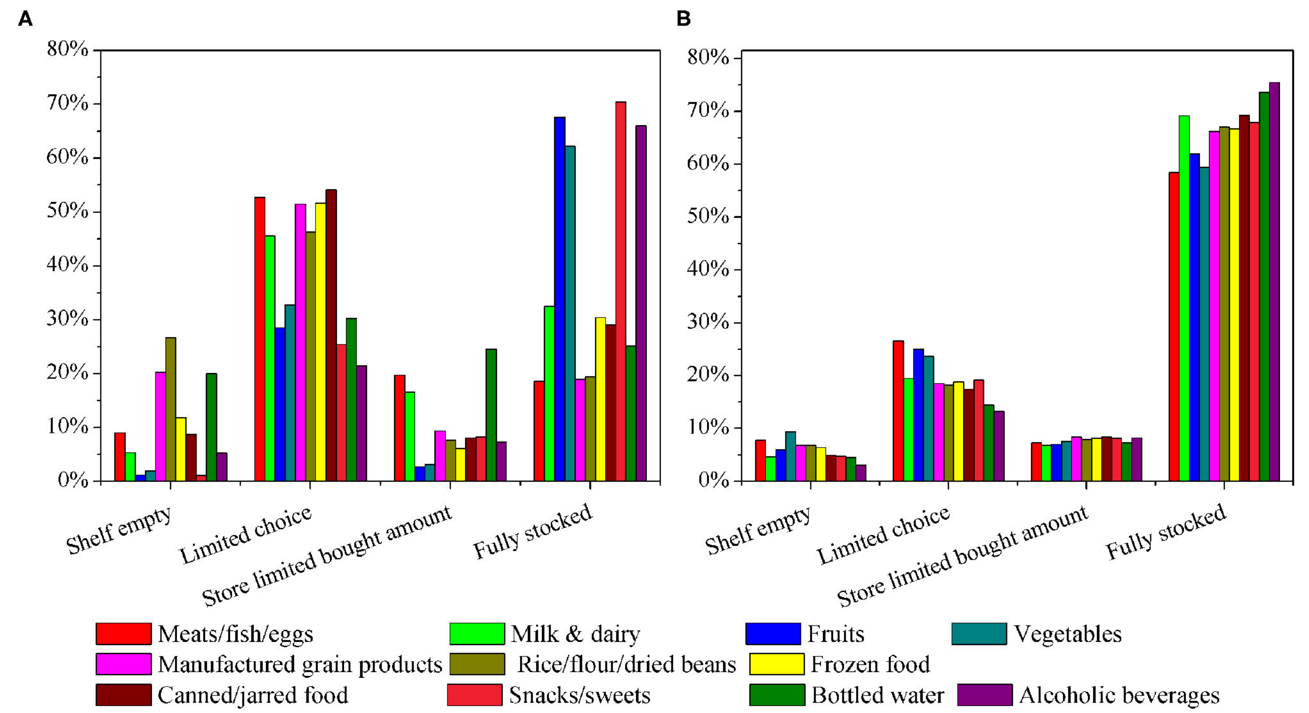

FIGURE 4 | Food availability as experienced when grocery-shopping by survey respondents from the U.S. **(A)** vs. China **(B)**. Foods were categorized into 9 groups. Two types of beverages were also included in survey questionnaire. Food availability was more variable for the U.S. than the Chinese datasets ($P < 0.001$).

supply operations overcame some problems but met newly emerged challenges. Consequently, people's perception of the situation surrounding them would change; their food attitude and behavior would be dynamic as well. This survey, through the lens of thousands of U.S. and Chinese respondents in the given timeframe, reveals the food-print of the COVID-19 pandemic in multiple dimensions. Analyzing the observed shifts and patterns, assessing food system resilience under extreme stress, and identifying opportunities for improvement would be of great significance to societies.

DISCUSSION

The COVID-19 pandemic exerts enormous pressure with disruption on food systems, testing its resilience and functionalities in multiple aspects, e.g., supply and distribution,

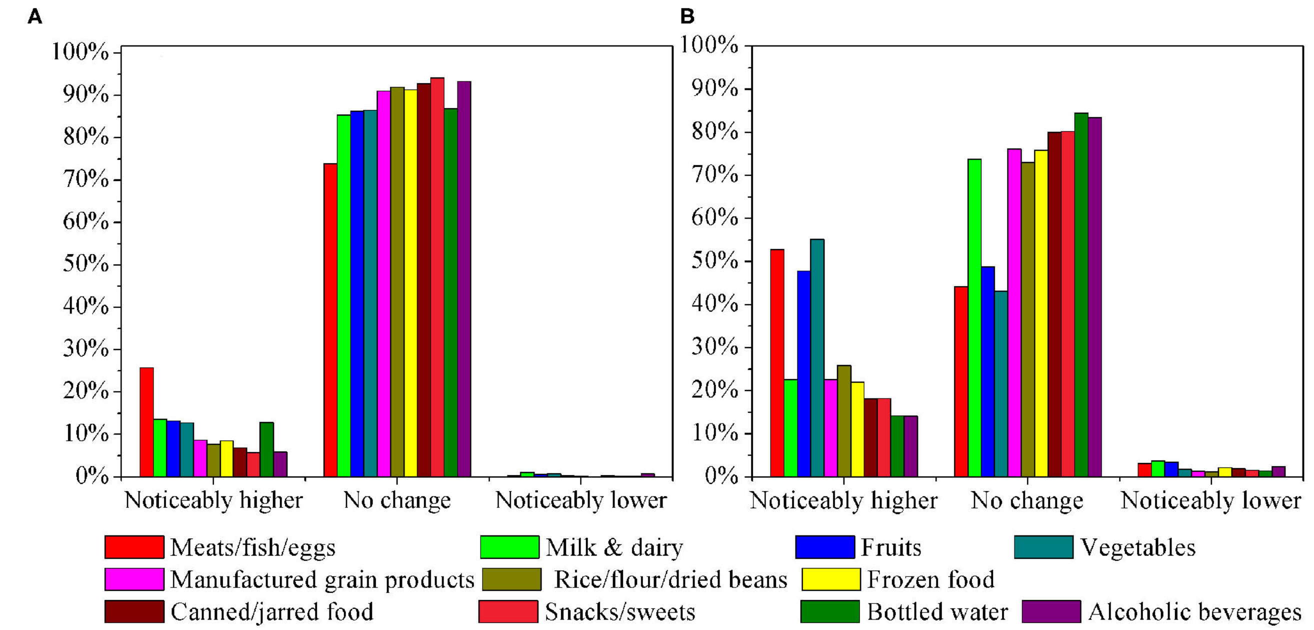

FIGURE 5 | Food price change during as compared to before the COVID-19 pandemic, according to U.S. **(A)** and Chinese **(B)** survey participants when grocery-shopping. Proportionally, noticeably higher prices were reported by more Chinese than U.S. participants ($P < 0.001$) for all food types, particularly meats/fish/eggs, fruits, and vegetables.

rapid response, and flexibility. Our survey results indicated that the U.S. and Chinese food systems retained their integrity and functionality regarding overall food availability, viewed from the lens of survey respondents. But the collage of snapshots provided by the U.S. and Chinese cohorts revealed caveats and constraints; some, for instance, showed choice limitation and price volatility. Modern food supply chains are complex with many actors, moving parts, and connecting points (Cutter, 2017; Umar et al., 2017). At times of crisis like the COVID-19 pandemic, rapid response and quick activation of intervention mechanisms at the national scale require flexibility in rule- and regulation-decision changes as well as adaptable implementation by business operations. For example, to divert food previously purposed for bulk distribution (schools, restaurants, etc.) to retail channels now requires government approval of labeling and packaging changes as well as execution capacity at packaging facilities. In fact, during the pandemic, many entities in the U.S. worked in partnership to overcome barriers, bridge gaps, and alleviate the shock and smooth the flow of foods [(Bipartisan Policy Center (BPC), 2020)]. Further work is needed to systematically examine what worked, where things went wrong, and what new mechanisms and strategies are needed to boost the resilience of the food systems toward a better and more secure food future. This would be the learning component that is critical in the food system resilience action cycle described by Tendall et al. (2015). From a policy perspective, various strategies have been proposed, e.g., streamlining supply chain monitoring and proactive measures to prevent and deal with potential threats to the supply chain (Gray, 2020), effective interventions to promote and enable urban agriculture and home gardening as well as shorter supply chains (Hobbs, 2020; Lal, 2020; Pulighe and Lupia, 2020), and innovative public-private programs to diversify food market channels and broaden food delivery and accessibility mechanisms (Zhong et al., 2019), just to name a few. Additionally, how to leverage Internet-enabled food supply and distribution for enhanced food system resilience deserves further attention. It is also interesting to note that how the phenomenon of online grocery-shopping will evolve post-pandemic may have important ramifications on matters pertaining to the infrastructure of the retail sector, their service mode, food safety, and public health. Further investigation is warranted.

Household food security is one of the key outcomes of food system resilience (Tendall et al., 2015; Smith and Frankernberger, 2018; Ansah et al., 2019; Meyer, 2020). The impact of the COVID-19 pandemic was most acutely felt by the U.S. and Chinese families with the lowest income or those who had household members losing income during the pandemic. Deterioration in household food security was reflected by large increases in people of the U.S. cohort worrying about feeding their families as well as indications of food shortage in homes. According to Feeding America (a U.S.-based organization with a national network of >200 food banks providing food assistance to those in need pandemic or not), people seeking food assistance increased by 70% during the COVID-19 pandemic [(Bipartisan Policy Center (BPC), 2020)]. How to improve the resilience of those most vulnerable and food-insecure households and to avert food shortage at times of crisis remains a global as well as local challenge. Building an expansive and effective network of government agencies, private firms, non-profit organizations, as well as grassroots entities (e.g., community- or church-based initiatives and citizen volunteers with a variety of field gleaning, food rescue, and distribution activities) can be essential toward mitigating household food insecurity at times of crisis.

Despite widespread media reports of the "quarantine 15," most survey respondents indicated no change in their weight. However, some reported clinically significant weight gains of greater than 4.5 kg in a short period of time. This group of individuals who rapidly gained weight may constitute a higher risk group that may benefit from targeted diet and exercise counseling. Some of them might have previously been on diets but had their routines drastically altered due to the pandemic. This entails further study. Moreover, individuals differ in psychological resilience (Lamond et al., 2009); they may respond to or deal with crises differently. For example, the young majority of the Chinese cohort might be less prone (more resilient) to stress or life-changing uncertainties. Instead, they might have derived more joy from delicious home-made meals while staying with parents during the pandemic, which in turn may help explain the greater weight gain (in proportion and amount) described earlier. In addition to personal traits and experiences, people's resilience at times of crisis can be deeply rooted in a historical, societal, and cultural background [e.g., Mintz and Du Bois, 2002; Clauss-Ehlers, 2008; Pogosyan, 2017; Centers for Disease Control and Prevention (CDC), 2020]. Exploring such elements and their connections and influences, although beyond the scope of the current study, would be of great interest in future research.

The positive changes of increased efficiency in the use of food and families spending more time cooking and eating together are in part direct consequences of the stay-at-home orders, as individuals may now have more disposable time to spend on food preparation and less eating out or ordering in. Positive food attitudes in the more prudent use of food with less wastage may be attributed to the heightened awareness of food being in limited supply, close encounters and personal experience of choice limitations at food stores, as well as uncertainties people were facing regarding the trajectory of COVID-19 and food availability in the future. These serve as examples of negative drivers providing an opportunity for positive changes (Scheffer et al., 2012). The durability of the positive changes and how widespread the phenomenon might be across large populations deserve further study. Pandemic or not, the world must find ways to feed the growing populations more sustainably [(Food and Agriculture Organization of the United Nations (FAO), 2019)]. Reducing food loss and waste throughout the food chain, particularly at the consumer level, is paramount (Dou et al., 2016). Finding ways to sustain the positive change and to broaden relevant reach is important in societies' endeavor of pursuing a resilient and sustainable food future.

We acknowledge the potential limitations of the methodology associated with convenience sampling, such as sampling is not representative and findings are not generalizable (Bornstein et al., 2013; Etikan et al., 2016). Meanwhile, we recognize that the classic issues related to the methodology (e.g., lack of representativeness) might not be as critical in the present situation, because the pandemic's impacts are so widespread and pervasive and essentially encompassing everyone in the societies. Regardless, additional work is needed with more rigorous and strategic sampling for better representation of the population and an in-depth understanding of how people make food behavior changes at times of crisis and relevant consequences thereafter.

CONCLUSION

Using convenience-snowball sampling for real-time data collection, we were able to capture people's food experience as they encountered it amid the COVID-19 pandemic while staying-at-home. The pandemic had profound impacts on how people sourced, valued, and used food. Household food security deteriorated during the pandemic; food-insecure was most acutely felt by the U.S. and Chinese families with the lowest income or those who had household members losing income during the pandemic. There were also indications of positive changes in household food dynamics, including closer family bonding around the dinner table and, perhaps, better nutrition from increased time spent on meal planning and preparing at home, as well as making more out of the food they have and wasting less. Survey findings offer insight into the resilience of the food systems across multiple functional indicators, such as food choices, availability, price stability, system-responsiveness, and flexibility. This study also sheds light on long-term questions to be explored in further research about future food patterns as well as how people make food behavior changes at times of crisis and relevant consequences.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/**Supplementary Material**.

ETHICS STATEMENT

The study was deemed exempt from requiring human subjects approval by the Institutional Review Board of the University of Pennsylvania. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

ML helped with the initial literature search and also shaped the language of the questionnaire to fit grade level 8–9 and up. DS took charge of survey platform logistics and conducted data analysis. TC performed data management. TC and ZD coordinated survey dissemination in China. ZD directed the study and wrote the manuscript. AC made major contributions in study design and manuscript revision. All authors reviewed and approved the manuscript prior to submission and were involved in survey design, development, and distribution.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2020.577153/full#supplementary-material

REFERENCES

Abiral, B., and Atalan-Helicke, N. (2020). Trusting food supply chains during the pandemic: reflections from Turkey and the U.S. *Food Foodways* 28, 226–236. doi: 10.1080/07409710.2020.1790147

Ammar, A., Brach, M., Trabelsi, K., Chtourou, H., Boukris, O., Masmoudi, L., et al. (2020). Effects of COVID-19 home confinement on eating behaviour and physical activity: results of the ECLB-COVID19 International Online Survey. *Nutrients* 12, 1583. doi: 10.3390/nu12061583

Anonymous (2020). *Lessons From China: Ensuring No One Goes Hungry During Coronavirus Lockdowns*. Available online at: https://theconversation.com/lessons-from-china-ensuring-no-one-goes-hungry-during-coronavirus-lockdowns-135781 (accessed August 19, 2020)

Ansah, I. G. K., Gardebroek, C., and Ihle, R. (2019). Resilience and household food security: a review of concepts, methodological approaches and empirical evidence. *Food Secur*. 11, 1187–1203. doi: 10.1007/s12571-019-00968-1

Barker, M., and Russell, J. (2020). Feeding the food insecure in Britain: learning from the 2020 COVID-19 crisis. *Food Secur*. 12, 865–870. doi: 10.1007/s12571-020-01080-5

Belen Ruiz-Roso, M., de Carvalho Padilha, P., Mantilla-Escalante, D. C., Ulloa, N., Brun, P., Acevedo-Correa, D., et al. (2020). Covid-19 confinement and changes of adolescent's dietary trends in Italy, Spain, Chile, Colombia and Brazil. *Nutrients* 12, 1807. doi: 10.3390/nu12061807

Bipartisan Policy Center (BPC) (2020). *BPC Food Summit*. Available online at: https://bipartisanpolicy.org/event/bpc-food-summit/ (accessed August 25, 2020)

Bornstein, M., Jager, J., and Putnick, D. L. (2013). Sampling in developmental science: situations, shortcomings, solutions, and standards. *Dev. Rev*. 33, 357–370. doi: 10.1016/j.dr.2013.08.003

Celik, B., and Dane, S. (2020). The effects of COVID-19 pandemic outbreak on food consumption preferences and their causes. *J. Res. Med. Dent. Sci*. 8, 176–180.

Centers for Disease Control and Prevention (CDC) (2020). *Coronavirus Disease 2019 (COVID-19): Coping With Stress*. Atlanta, GA: CDC. Available online at: https://www.cdc.gov/coronavirus/2019-ncov/daily-life-coping/managing-stress-anxiety.html. (accessed August 26, 2020)

Clauss-Ehlers, C. (2008). Sociocultural factors, resilience, and coping: support for a culturally sensitive measure of resilience. *J. Appl. Dev. Psychol*. 29, 197–212. doi: 10.1016/j.appdev.2008.02.004

Crush, J., and Si, Z. (2020). COVID-19 containment and food security in the Global South. *J. Agric. Food Syst. Commun. Dev*. 9, 149–151. doi: 10.5304/jafscd.2020.094.026

Cutter, S. L. (2017). The perilous nature of food supplies: natural hazards, social vulnerability, and disaster resilience. *Environ. Sci. Policy Sustain. Dev*. 59, 4–15. doi: 10.1080/00139157.2017.1252603

Dou, Z., Ferguson, J. D., Galligan, D. T., Kelly, A. M., Finn, S. M., and Giegengack, R. (2016). Assessing U.S. food wastage and opportunities for reduction. *Glob. Food Secur*. 8, 19–26. doi: 10.1016/j.gfs.2016.02.001

Etikan, I., Musa, S. A., and Alkassim, R. S. (2016). Comparison of convenience and purposive sampling. *Am. J. Theor. Appl. Stat*. 5, 1–4. doi: 10.11648/j.ajtas.20160501.11

Farrell, P., Thow, A. M., Wate, J. T., Nonga, N., Vatucawaqa, P., Brewer, T., et al. (2020). COVID-19 and Pacific food system resilience: opportunities to build a robust response. *Food Secur*. 12, 783–791. doi: 10.1007/s12571-020-01087-y

Food and Agriculture Organization of the United Nations (FAO) (2019). *The State of Food and Agriculture 2019: Moving Forward on Food Loss and Waste Reduction*. Rome: FAO. Available online at: https://reliefweb.int/report/world/state-food-and-agriculture-2019-moving-forward-food-loss-and-waste-reduction (accessed August 27, 2020)

Gray, R. S. (2020). Agriculture, transportation, and the COVID-19 crisis. *Can. J. Agric. Econ*. 68, 239–243. doi: 10.1111/cjag.12235

Hobbs, J. E. (2020). Food supply chains during the COVID-19 pandemic. *Can. J. Agric. Econ*. 68, 171–176. doi: 10.1111/cjag.12237

Household Food Insecurity Access Scale (HFIAS) (2020). Available online at: https://inddex.nutrition.tufts.edu/data4diets/indicator/household-food-insecurity-access-scale-hfias. (accessed August 20, 2020).

Jribi, S., Ben Ismail, H., Doggui, D., and Debbabi, H. (2020). COVID-19 virus outbreak lockdown: what impacts on household food wastage? *Environ. Dev. Sustain*. 22, 3939–3955. doi: 10.1007/s10668-020-00740-y

Lal, R. (2020). Home gardening and urban agriculture for advancing food and nutritional security in response to the COVID-19 pandemic. *Food Secur*. 12, 871–876. doi: 10.1007/s12571-020-01058-3

Lamond, A. J., Depp, C. A., Allison, M., Langer, R., Reichstadt, J., Moore, D. J., et al. (2009). Measurement and predictors of resilience among community-dwelling older women. *J. Psychiat. Res*. 43, 148–154. doi: 10.1016/j.jpsychires.2008.03.007

Meyer, M. A. (2020). The role of resilience in food system studies in low- and middle-income countries. *Glob. Food Secur*. 24, 1–9. doi: 10.1016/j.gfs.2020.100356

Mintz, S. W., and Du Bois, C. M. (2002). The anthropology of food and eating. *Ann. Rev. Anthropol*. 31, 99–119. doi: 10.1146/annurev.anthro.32.032702.131011

Papargyropoulou, E., Lozano, R., Steinberger, J. K., Wright, N., and bin Ujang, Z. (2014). The food waste hierarchy as a framework for the management of food surplus and food waste. *J. Clean. Prod*. 76, 106–115. doi: 10.1016/j.jclepro.2014.04.020

Pogosyan, M. (2017). What makes families resilient? Nurturing strength amid adversity. *Psychol. Today*. Available online at: https://www.psychologytoday.com/us/blog/between-cultures/201710/what-makes-families-resilient (accessed August 27, 2020)

Pulighe, G., and Lupia, F. (2020). Food first: COVID-19 outbreak and cities lockdown a booster for a wider vision on urban agriculture. *Sustainability* 12, 5012. doi: 10.3390/su12125012

Quested, T., and Murphy, L. (2014). *Household Food and Drink Waste: A Product Focus*. Final Report. Waste and Resources Action Programme (WRAP), Banbury, United Kingdom.

Richards, T. J., and Rickard, B. (2020). COVID-19 impact on fruit and vegetable markets. *Can. J. Agric. Econ*. 68, 189–194. doi: 10.1111/cjag.12231

Scarmozzino, F., and Visioli, F. (2020). Covid-19 and the subsequent lockdown modified dietary habits of almost half the population in an Italian sample. *Foods* 9, 675. doi: 10.3390/foods9050675

Scheffer, M., Carpenter, S. R., Lenton, T. M., Bascompte, J., Brock, W., Dakos, V., et al. (2012). Anticipating critical transitions. *Science* 338, 344–348. doi: 10.1126/science.1225244

Si, Z., Qi, D., Dai, N., Zhong, T., Crush, J. (2020). *"COVID-19 and Grassroots Community Organizing in Wuhan, China" COVID-19 and Food Security Research Brief No. 5*, Waterloo, ON. Available online at: https://hungrycities.net/covid-19-and-food-security-publications/

Sidor, A., and Rzymski, P. (2020). Dietary choices and habits during COVID-19 lockdown: experience from Poland. *Nutrients* 12, 1657. doi: 10.3390/nu12061657

Smith, L. C., and Frankernberger, T. R. (2018). Does resilience capacity reduce the negative impact of shocks on household food security? Evidence from the 2014 floods in Northern Bangladesh. *World Dev*. 102, 358–376. doi: 10.1016/j.worlddev.2017.07.003

Tendall, D. M., Joerin, J., Kopainsky, B., Edwards, P., Shreck, A., Le, Q. B., et al. (2015). Food system resilience: defining the concept. *Glob. Food Secur*. 6, 17–23. doi: 10.1016/j.gfs.2015.08.001

Umar, M., Wilson, M., and Heyl, J. (2017). Food network resilience against natural disasters: a conceptual framework. *SAGE Open* 7:UNSP 2158244017717570. doi: 10.1177/2158244017717570

USDA ERS (2019). *Food Secrity in the U.S.* Available online at: https://www.ers.usda.gov/topics/food-nutrition-assistance/food-security-in-the-us/key-statistics-graphics/. (accessed August 22, 2020)

Wolfson, J. A., and Leung, C. W. (2020). Food insecurity and COVID-19: disparities in early effects for US adults. *Nutrients* 12, 1648. doi: 10.3390/nu12061648

World Bank (2014). *The Economic Impact of the 2014 Ebola Epidemic.* Washington, DC: The World Bank. Available online at: https://openknowledge.worldbank.org/bitstream/handle/10986/20592/9781464804380.pdf?sequence=6 (accessed August 27, 2020)

World Bank (2020). *GDP Per Capita (current US$).* Washington, DC: The World Bank. Available online at: https://data.worldbank.org/indicator/NY.GDP.PCAP.CD (accessed August 27, 2020)

World Economic Forum (WEF) (2020). *What Past Disruptions Can Teach Us About Reviving Supply Chains After COVID-19.* Geneva: WEF. Available online at: https://www.weforum.org/agenda/2020/03/covid-19-coronavirus-lessons-past-supply-chain-disruptions/ (accessed August 27, 2020)

World Health Organization (WHO) (2020). *Novel Coronavirus (2019-nCoV) SITUATION REPORT-1 JANUARY 2020*. Geneva: United Nations Economic and Social Council. Available online at: https://reliefweb.int/report/china/2019-novel-coronavirus-situation-report-1-january-27-2020WHO (accessed August 27, 2020)

Zhao, A., Li, Z., Ke, Y., Huo, S., Ma, Y., Zhang, Y., et al. (2020). Dietary diversity among Chinese residents during the COVID-19 outbreak and its associated factors. *Nutrients* 12, 1699. doi: 10.3390/nu12061699

Zhong, T., Si, Z., and Crush, J. (2019). Achieving urban food security through a hybrid public-private food provisioning system: the case of Nanjing, China. *Food Secur*. 11, 1071–1086. doi: 10.1007/s12571-019-00961-8

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Alternative Seafood Networks During COVID-19: Implications for Resilience and Sustainability

Joshua S. Stoll[1]*, Hannah L. Harrison[2], Emily De Sousa[2], Debra Callaway[3], Melissa Collier[4], Kelly Harrell[5], Buck Jones[6], Jordyn Kastlunger[7], Emma Kramer[8], Steve Kurian[9], M. Alan Lovewell[10], Sonia Strobel[11], Tracy Sylvester[12], Brett Tolley[13], Andrea Tomlinson[14], Easton R. White[15], Talia Young[16] and Philip A. Loring[17,18]

[1] School of Marine Sciences, University of Maine, Orono, ME, United States, [2] Department of Geography, Environment, and Geomatics, University of Guelph, Guelph, ON, Canada, [3] Walking Fish Cooperative, Beaufort, NC, United States, [4] West Coast Wild Scallops, Courtenay, BC, Canada, [5] Sitka Salmon Shares, Anchorage, AK, United States, [6] Columbia River Inter-Tribal Fish Commission, Portland, OR, United States, [7] Tuna Harbor Dockside Market, San Diego, CA, United States, [8] Straight to the Plate, Girdwood, AK, United States, [9] Wild for Salmon Inc., Bloomsburg, PA, United States, [10] Real Good Fish, Moss Landing, CA, United States, [11] Skipper Otto Community Supported Fishery, Vancouver, BC, Canada, [12] Wooden Island Wild, Woods Hole, MA, United States, [13] North American Marine Alliance, Gloucester, MA, United States, [14] New Hampshire Community Seafood, Portsmouth, NH, United States, [15] Department of Biological Sciences, University of New Hampshire, Durham, NH, United States, [16] Department of Environmental Studies, Haverford College, Haverford, PA, United States, [17] Arrell Food Institute, University of Guelph, Guelph, ON, Canada, [18] Department of Geography, Environment, and Geomatics, University of Guelph, Guelph, ON, Canada

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***Correspondence:**
Joshua S. Stoll
joshua.stoll@maine.edu

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Export-oriented seafood trade faltered during the early months of the COVID-19 pandemic. In contrast, alternative seafood networks (ASNs) that distribute seafood through local and direct marketing channels were identified as a "bright spot." In this paper, we draw on multiple lines of quantitative and qualitative evidence to show that ASNs experienced a temporary pandemic "bump" in both the United States and Canada in the wake of supply chain disruptions and government mandated social protections. We use a systemic resilience framework to analyze the factors that enabled ASNs to be resilient during the pandemic as well as challenges. The contrast between ASNs and the broader seafood system during COVID-19 raises important questions about the role that local and regional food systems may play during crises and highlights the need for functional diversity in supply chains.

Keywords: community supported fisheries, COVID-19, fisheries, resilience, seafood, systemic shock, trade

INTRODUCTION

Seafood is among the most traded food commodities in the world. In 2018, 38% of the global fish supply was exported at a value of US$164 billion (Food Agricultural Organization of the United Nations, 2020). By value, this represents an inflation adjusted increase of 168% in the last 40 years. Multiple factors are contributing to the continued growth and globalization of the seafood system, including neoliberal trade policies that incentivize export of seafood and advancements in technological capacity that enable wide distribution of highly perishable products (Anderson et al., 2010). The expansion of seafood trade has resulted in a range of socioeconomic benefits, including increased employment opportunity and food security (Asche et al., 2015). However, it also makes the seafood system more vulnerable to systemic shocks that disrupt the flow of product and the livelihoods that depend on it (Cottrell et al., 2019). The global financial crisis of 2007–2008, for example, resulted in an estimated 7% decline in seafood exports worldwide, including a 9% decline in the United States and Canada (US$632 million; Food Agricultural Organization of the United Nations, 2010). A decade later, the seafood system again faces a systemic shock, this time due to the COVID-19 pandemic (Love et al., 2021). Shocks like these are becoming an increasingly common feature of food systems, including those associated with seafood (Cottrell et al., 2019)—a trend that can be expected to continue, given the challenges presented by climate change (Rockstrom et al., 2020) and increased globalization in food systems (Kummu et al., 2020). Such disturbances will continue to have major implications for the well-being of the 60 million people worldwide who are directly employed by fisheries and aquaculture as well as those who are involved in processing, distribution, and sales and depend on seafood for nutrition (Food Agricultural Organization of the United Nations, 2020). As such, systemic shocks like the COVID-19 pandemic provide an important opportunity to study food system resilience and learn from segments of it that exhibit shock-tolerance. By food system resilience we mean the "capacity over time of a food system and its units at multiple levels, to provide sufficient, appropriate and accessible food to all, in the face of various and even unforeseen disturbances" (Tendall et al., 2015, p. 19).

Alternative Seafood Networks Contribute to Systemic Resilience

As seafood systems become increasingly globalized, evermore product flows out and away from the places where it is caught or farmed. However, during systemic shocks, food systems—including those associated with seafood—can experience "deadlock" where segments of the supply chain are unable to function because other segments of the supply chain are not operating and these segments cannot function because still other segments are not operating (Garnett et al., 2020). Such paralysis, even if temporary, can have serious socioeconomic implications. For example, an estimated 40% of survey participants in a study conducted in seven countries in Latin America and the Caribbean reported being without food during the COVID-19 lockdown (Hill and Narayan, 2020 as reported in World Bank, 2020). In the United States, US Census Bureau Household Pulse Survey shows that the percent of adults in the country that sometimes or often do not have enough to eat in the last seven days has increased from 8% before the pandemic to 11% by February 1, 2021 (US Census Bureau, 2021).

Local and regional seafood systems are not immune to shocks, including but not limited to those caused by extreme weather events (Marín et al., 2010) and anthropogenic catastrophes (Cockrell et al., 2019). Furthermore, these place-based systems are not fully decoupled from global seafood systems (Bronnmann et al., 2020; Farrell et al., 2020). Nevertheless, key distinctions between them exist in terms of their relationship and geographic orientation to consumers. In particular, what local and regional seafood systems lack in their overall geographic reach and total market potential, they make up in their direct connection and proximity to consumers (Stoll et al., 2020). This "relational" orientation between harvesters and consumers sets local and regional seafood systems apart from their global counterparts. Since these systems are not fully dependent on long or complex supply chains, the physical and social connectedness associated with them may also help to insulate local and regional seafood systems from the deadlock caused by systemic global shocks. We therefore propose that there is likely an inverse, yet complementary, relationship between local and global seafood systems during periods of systemic shock. Specifically, we predict that during these episodes of systemic shock, we can expect to see a short-term re-localizing phenomenon unfold (**Figure 1**)—one which contributes important systemic resilience to seafood systems at large.

To explore this dynamic, we draw on data from the United States and Canada during the early months of the COVID-19 pandemic. COVID-19 initially impacted seafood trade by altered consumer behavior in China, the largest importer of seafood worldwide (Love et al., 2021). The impacts of COVID-19 subsequently propagated worldwide. The first cases of COVID-19 were observed in the United States and Canada in early January of 2020. On March 11 the World Health Organization declared the spread of the COVID-19 virus a global pandemic and the United States and Canadian governments responded by temporarily closing businesses deemed non-essential and encouraged stay-at-home practices. Less than two weeks later, on March 21, the Canada-US and US-Mexico borders were closed to non-essential travel. Social distancing and other public health measures immediately altered consumer behavior, with the restaurant and food services sector particularly hard hit (White et al., 2021). In March 2020, for example, the US Farm Bureau reported a 27% increase in grocery store sales compared to the previous year and a 25% decrease in restaurant and other food establishments (U.S. Farm Bureau, 2020). Nearly all segments of the seafood system were impacted in some way by COVID-19 (Sorensen et al., 2020; Love et al., 2021; White et al., 2021). Examples include delayed fishing seasons, outbreaks in processing plants, and depressed prices due to reduced global demand.

The focus of this research is on a segment of the seafood system called alternative seafood networks (ASNs) (**Figure 2**) Alternative seafood networks refer to a range of "boat to fork" seafood distribution models that contribute to local and regional seafood systems (Witter and Stoll, 2016; Witter, 2020). Like alternative food networks in the agricultural sector (c.f. Whatmore et al., 2003; Goodman et al., 2012), which emerged in response to problems in terrestrial food systems, ASNs aim to address perceived economic, social, and environmental issues associated with the global seafood system—including but not limited to concerns about overfishing, industrialization, privatization, and the disappearance of small-scale and community-based fishing operations (Brinson et al., 2011; Campbell et al., 2014; McClenachan et al., 2014; Stoll et al., 2015). The literature also refers to ASNs as direct marketing arrangements (Stoll et al., 2015), community supported fisheries (Bolton et al., 2016), and relational seafood supply chains (Stoll et al., 2020). While further research is needed to define the parameters of ASN, we use the term ASN broadly to describe individual and collective efforts by fishers and fishing families

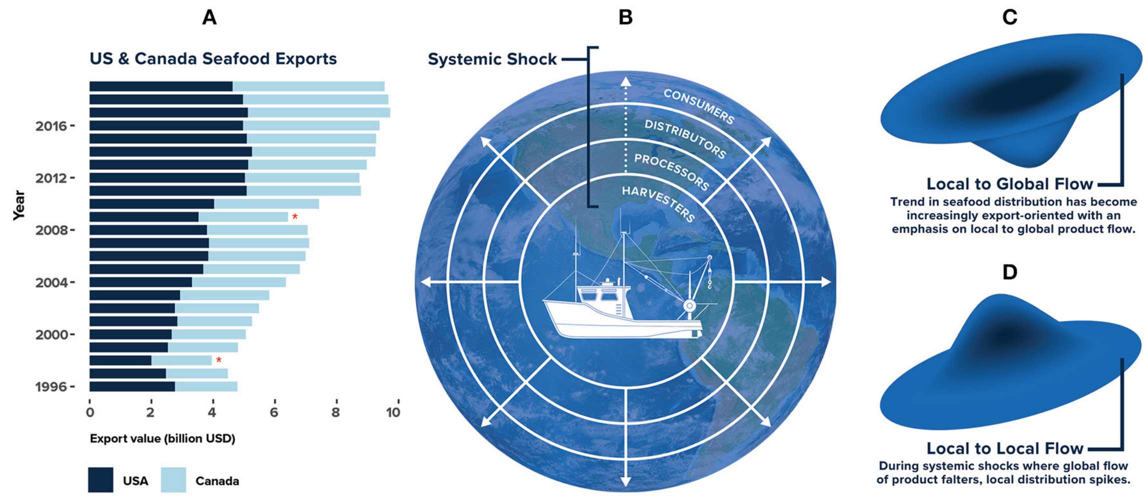

FIGURE 1 | (A) Fisheries in the United States and Canada have become increasingly trade-oriented, but in the last 25 years, multiple systemic shocks have caused global trade to drop sharply, including during the ongoing COVID-19 pandemic (United Nations, 2020). Asterisks correspond to global recessions. **(B)** Systemic shocks impact all levels of the food system, from producers to consumers, and can lead to "deadlock" in the system. **(C)** Globalization in the seafood system leads to a local-to-global pattern where product is distributed out and away from the places where it is caught, creating a void of seafood. **(D)** During the early months of COVID-19 pandemic, however, global seafood supply chains faltered, leading to greater dependence on local food systems and a surge or "bump" in local and direct distribution.

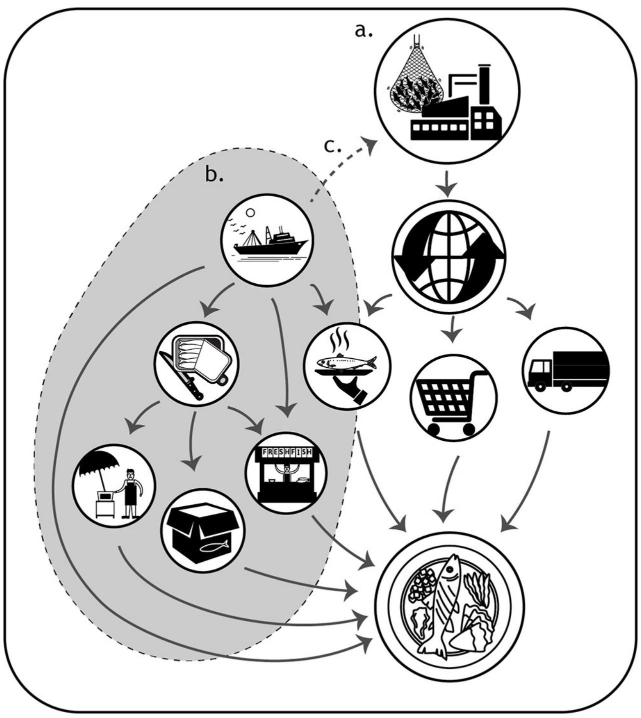

FIGURE 2 | A simplified depiction of Alternative Seafood Networks and their orientation to the global seafood supply chain. **(a)** The predominant system is based on transactional relationships and moves seafood into the global marketplace. **(b)** ASNs diverse distribution channels provide ways for small-scale operators to directly connect with consumers through local and direct-to-consumers sales. Note the redundancy of linkages. **(c)** Small-scale operators that sell through ASNs also often depend on the predominant seafood system for selling a portion of their catch.

to use relational seafood supply chains to distribute their catch directly to consumers.

Alternative seafood networks exist worldwide and were identified as a "bright spot" in both high- and low-income countries during the early months of the COVID-19 pandemic (Bennett et al., 2020; Gephart et al., 2020; Loring et al., 2020; O'Malley, 2020). For example, in the northeast, United States, Smith et al. (2021) found that 60% of the 258 fishers they surveyed reported adapting to local and direct seafood sales during the pandemic. Similarly, in a survey of small-scale fisheries across Europe from more than 105 fishing organizations from 12 countries, Pita (2020) found that 48% of respondents had shifted to direct-to-consumer sales through ASNs. Even some multinational corporations pivoted toward local and direct models of seafood distribution (Cooke Aquaculture, 2020)[1].

In this paper, we present multiple lines of quantitative and qualitative evidence to show that ASNs experienced a short-term pandemic "bump" in both the United States and Canada in the wake of supply chain disruptions and government mandated social protections. We then analyze the factors that enabled ASNs to be resilient during the early months of the pandemic and discuss the implications for seafood systems. We frame our analysis of ASNs around the concept of systemic resilience, which describes the ability of actors in a complex system to effectively respond and recover from shock and surprise (Walker and Salt, 2012; Ungar, 2018). Generally, systemic resilience involves some sequence of actions through which agents (people, firms, or industries) adapt to new circumstances and secure

[1]We note that our focus is on alternative seafood networks as opposed to efforts by multinational corporations to shift to e-commerce platforms and direct-to-consumer sales.

the resources required for recovery (Ungar, 2018). Response diversity, flexibility, social capital, and learning are among the primary system properties known to confer systemic resilience (Carlisle, 2014; Leslie and McCabe, 2014). Systemic resilience also operates at multiple levels (Berkes and Ross, 2013); people may draw resilience from larger social networks or the state, and they may also, through their actions, contribute resilience to those higher levels. Here, we are particularly interested in the individual and structural circumstances that enabled or inhibited local agents' ability to adapt to the new societal and supply chain challenges created by COVID-19, effectively allowing the inverse pattern of response noted above. Our findings have important implications both for how we understand the role of heterogeneity in food systems, particularly with respect to the scale and organization of production and distribution of food, as well as for policy options for enhancing the systemic resilience of seafood systems moving forward.

METHODS

This study uses mixed methods to examine changes experienced by ASNs during the early months of the COVID-19 pandemic. Specifically, we draw on multiple types of quantitative and qualitative data from different sources: Google search terms, website analytics, SafeGraph, and in-depth qualitative interviews. In gathering and analyzing data for this study, we also included a mixed authorship team, composed of academic and practitioner knowledge holders. This team was composed deliberately to be inclusive of gender, a wide range of geographies, and Indigenous and non-Indigenous participants. This team was recruited with intentions to conduct research with, instead of on, ASNs, and in recognition that knowledge emerges from society and the specific relationships we, as researchers, have to people and the environment. Adding non-traditional authors to our writing team represents a small way to acknowledge the important contributions that practitioners have had on our thinking, ability to collect critical data, and integral support to the research process. This decision also reflects our philosophy that shared authorship is also about distributing the privilege and legitimacy that comes with publishing.

Co-authorship

To acknowledge the different, but complementary ways in which researchers and practitioners create and disseminate knowledge, authorship on this manuscript was based on intellectual contribution rather than the particular tasks each author completed for the research (e.g., writing, revising, etc.; see Castleden et al., 2010). Our team included 14 individuals who are involved in ASNs in a professional capacity (including two with a dual role in academia; hereafter referred to as "practitioners") and four researchers who do not have a financial interest in ASNs (hereafter referred to as "researchers"). The researcher sub-team was responsible for the initial conception of the paper, primary data collection, analysis, and drafting the manuscript. The practitioner sub-team provided website analytics data and feedback on the results and multiple drafts of the manuscript. By assembling this mixed authorship team, we acknowledge the important role practitioners often play in enabling research and create space for those with grounded experiences to confirm that their lived experiences are represented appropriately.

Quantitative Analysis

We analyzed ASNs using three quantitative datasets: Google search terms, SafeGraph foot traffic, and website analytics.

Google Search Terms

Google search term data associated with seafood and food systems were analyzed for a 5-year period from June 2016 to July 2020. Search terms included in the search were "seafood," "direct seafood," "local fish", "home delivery seafood", "seafood box," "local seafood, "local food", and "community supported agriculture." We note that we did not include the search term "community supported fishery" because there was not enough data.

Foot Traffic

SafeGraph is a data company that aggregates anonymized location data from numerous applications in order to provide insights about physical places. During the early months of the pandemic, SafeGraph made their foot traffic data publicly available. We used these data to compare foot traffic at fish and seafood markets to foot traffic associated with ASN (January–June, 2020). To do this, we used the North American Industry Classification System (NAICS) to identify fish and seafood markets (NAICS code 445220) and then used the Local Catch Network Seafood Finder, which lists ASN from across the United States and Canada, to identify the subset of businesses that are ASN. Following White et al. (2021), we filtered out businesses that were mislabeled as seafood markets and those with <300 days of foot traffic data since the start of 2019. Data were normalized by dividing the number of daily visits by the number of devices present per the recommendation of SafeGraph. The number of businesses fluctuated over time as well, so we normalized visits by the number of businesses included each day, resulting in an average number of visits per business per day.

Website Analytics

Daily website analytics for eight ASNs in the United States ($n = 6$) and Canada ($n = 2$) was collected for the time period of January 1, 2019 to June 30, 2020. Businesses were selected purposefully to ensure geographic coverage across the United States and Canada (East and West Coasts) and to account for different types of ASN described by Bolton et al. (2016): (1) harvester focused; (2) consumer focused; and (3) species focused. Additional attention was given to selecting different size ASN—from those distributing to dozens of consumers to thousands. Because the website analytics data used in the analysis is from a non-random sample, results are intended to show a general trend. Data were downloaded from Google Analytics and Squarespace Analytics ($n = 8$) and analyzed in R (Version 3.6.1). Data were normalized to allow for business-to-business comparison using a z-score calculation [$z = (x - \mu)/\sigma$], where x represents the raw data, μ represents the population mean, and σ represents the population standard deviation. Change in consumer interest was calculated on a year-over-year basis for 2019 and 2020.

Qualitative Analysis

Thematic networks are used to organize salient themes and provide structure in the depiction of those themes and how they were derived (Attride-Stirling, 2001). Though similar to methods of qualitative analysis found in grounded theory (Corbin and Strauss, 2008), thematic networks are not intended to "discover the beginning of arguments or the end of rationalizations" (Attride-Stirling, 2001, p. 388), but are rather a technique for organizing text and developing rationalizations and their significance (Attride-Stirling, 2001). Thematic networks are constructed using three "levels" of data organization: basic themes, organizing themes, and global themes.

In total, 48 semi-structured interviews were conducted with 16 people via telephone or online video conferencing between March and August of 2020. Interview participants were solicited via recruitment through the Local Catch Network and other similar outreach channels. All participants self-identified as being directly involved in an ASN. While there is not an established set of parameters or criteria for ASN, all participating operations reported selling at least a portion of their seafood through direct market channels (i.e., direct marketing, subscriptions, community supported fisheries, cooperative buying, fishermen's markets, or other alternatives). Interviews were recorded and transcribed, then analyzed using NVIVO qualitative analysis software.

To identify basic themes in the data, we followed the analytical steps laid out by Attride-Stirling (2001) and began by reducing the text via a presence/absence coding scheme. We focused the presence/absence on factors that supported or hindered resilience in ASNs. Once all transcripts were coded, codes were refined to consolidate any redundancy and clarify code definitions. Codes were organized around emerging themes, then refined to clarify discrete boundaries between ideas. The emergent themes were organized into coherent groupings, resulting in organizing themes of several social and structural factors. We further consolidated those themes into key organizing themes of structural and response diversity, which fit best under a global theme of resilience. To connect empirical evidence from the interviews to the global theme, we linked exemplifying pieces of interview text to the thematic network at the basic coding level (**Supplement 1**). It is important to note that in the present approach to thematic coding, prevalence of occurrence of individual codes does not imply relative importance, and hence is not reported here.

To develop the policy recommendations table, we posed the following question to the practitioner authors: what social, political, economic, environmental, regulatory, and/or cultural changes are needed to institutionalize the short-term "pandemic bump" that CSFs have observed and lead to transformative change in the seafood system? We collected 27 responses to this question and synthesized responses thematically.

RESULTS

Alternative Seafood Networks During Systemic Shock

Our research suggests that in the early months of the COVID-19 pandemic there was a rapid increase in demand for local and directly sourced seafood in the United States and Canada, at a time when many other segments of the broader food system were disrupted (Garnett et al., 2020; Love et al., 2021). This finding is supported by multiple lines of quantitative and qualitative evidence. We find that Google searches for terms related to local and direct seafood distribution surged in the beginning of March. For example, from mid-March until the end of June, the searches for terms like "direct seafood" (not shown) (+88%), "seafood delivery" (+209%), and "local fish" (+4%) (not shown) all increased and then started to return to normal during the summer (**Figure 3**). This pandemic "bump" is reflected in Google searches for terms related to the local food system more broadly such as "local food" (+47) and "community supported agriculture" (+124%) (not shown), but not general terms like "seafood" (−6%) (**Figure 3**). These results are consistent with website analytics data across the United States and Canada. Across a geographically distributed but non-random subset of ASNs ($n = 8$), we find no year-over-year difference in ASN website traffic in January or February 2020 compared to the previous year. However, corresponding with the implementation of government ordered health measures related to COVID-19, there is a large mean year-over-year increase in March (+276%), April (+982%), May (+1,312%), and June (+339%) (**Figure 3**). This pattern is observed in all eight of the ASN across geographic regions, scales, and types.

SafeGraph foot traffic data provides modest evidence that ASN did not decline as rapidly as conventional fish and seafood markets during the early months of the COVID-19 pandemic. The mean number of people visiting approximately 3,000 fish and seafood markets in the United States decreased by 30% in 2020 as COVID-19 cases started increasing (**Figure 4A**), although this also varies by state (White et al., 2021). There was some recovery starting in mid-April, but foot traffic never reached levels seen in the previous year (**Figure 4A**). Although a small sample size ($n = 16$), ASNs listed on the Local Catch Network did not experience a sharp decline and followed a very similar pattern to 2019 (**Figure 4B**).

Interview data with ASN operators further corroborate our findings. A total of 48 interviews were conducted with 16 ASN operators. In total, 15 of 16 ASNs (93%) reported a major increase in demand for their products through both in-person and online outlets. As one respondent observed:

In the beginning I think a lot of us were nervous that we weren't going to be able to get rid of [our product] … And then the thing was for a couple of weeks, people started kind of panic buying in the beginning, and it was like "Oh no, we actually can't keep up with what people are wanting." But then once it started to level out we've been able to get rid of everything (Participant 1, April 28, 2020).

Although ASN operators are optimistic that demand for local and directly sourced seafood will be sustained, some interviewees

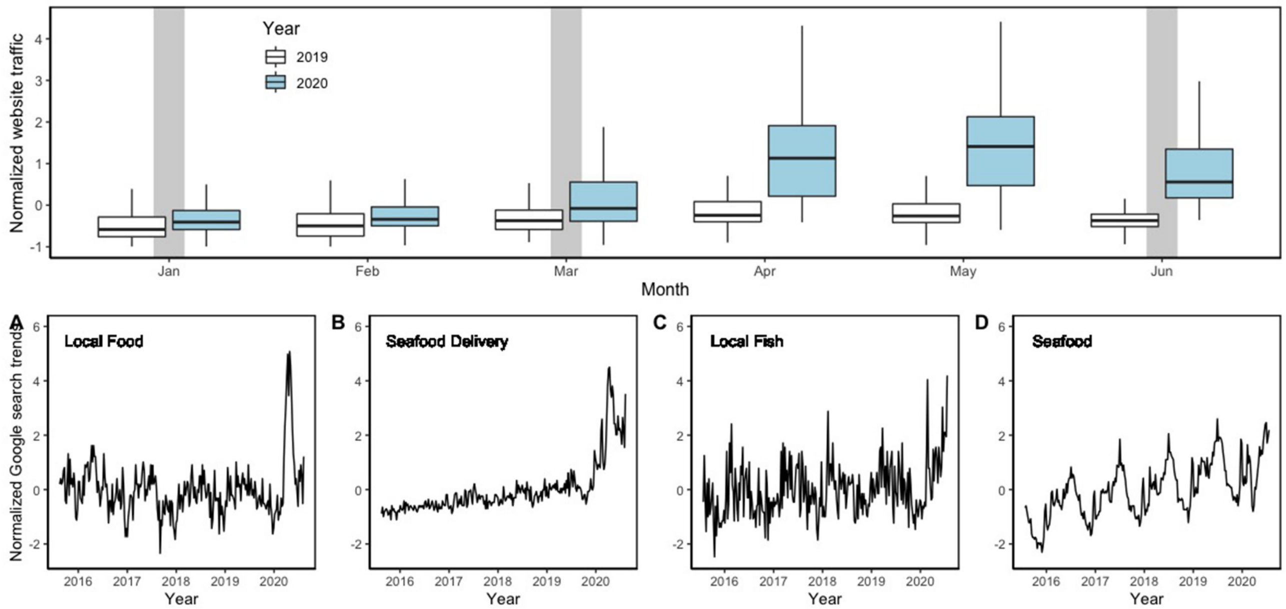

FIGURE 3 | (Top) Google Analytics web traffic data for select alternative seafood networks ($n = 8$). (Bottom) Google search trends for example phrases related to local food systems and direct producer-to-consumer sales (White et al., 2021) similarly describe an increase in web searches for the term "seafood recipes" **(A–C)**. Note that a similar pattern does not exist for the more general term "seafood" **(D)**.

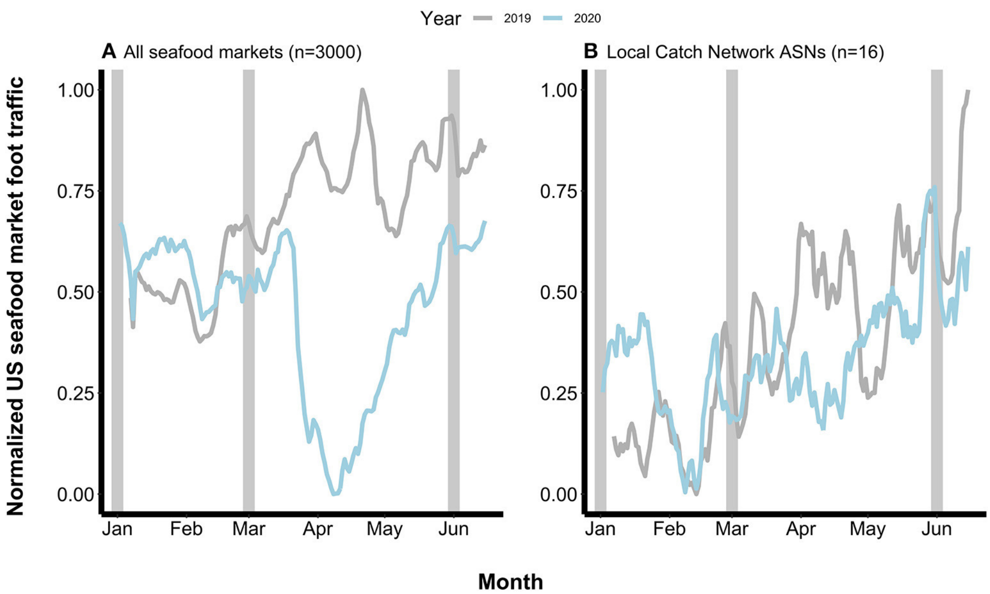

FIGURE 4 | Rolling mean of normalized seafood market foot traffic for **(A)** all seafood markets in the US and **(B)** only those seafood markets found in the Local Catch Network (https://finder.localcatch.org/). The vertical gray bars designate the initial introduction of social-distancing guidelines and subsequent reopening efforts.

began reporting a decline in the initial "bump" in demand in June and July as retail locations reopened more broadly.

Resilience of ASNs During Systemic Shock

Research participants identified multiple drivers and determinants of their resilience and ability to adapt their business practices during the early months of the COVID-19 pandemic (**Figure 5** and **Supplement 1**). Generally, these fell into two categories: structural factors and response diversity. Structural factors describe the fixed or hard-to-change features of society, such as infrastructure and policy, which create vulnerabilities to impacts and path

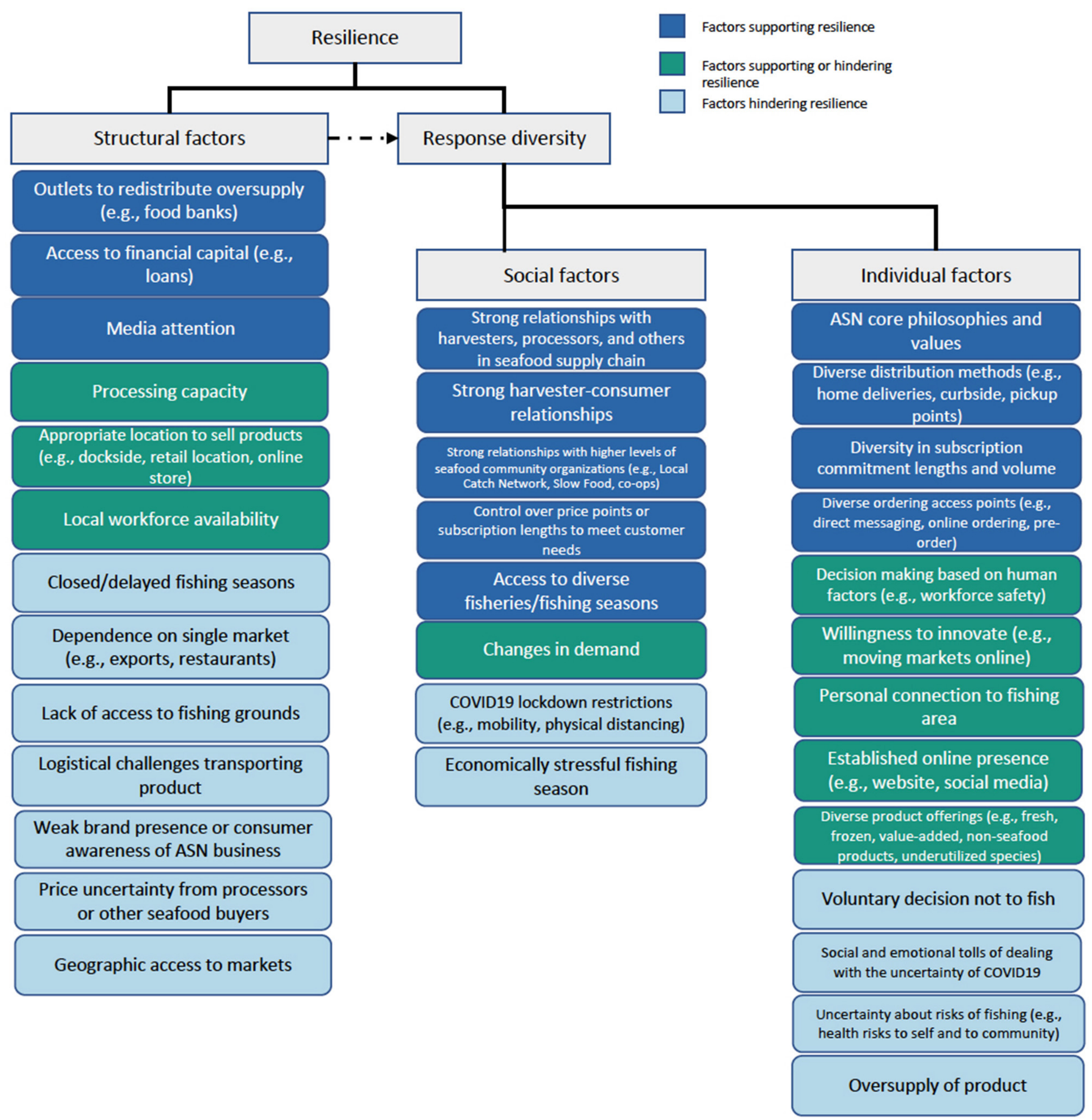

FIGURE 5 | Structural and response factors that supported or hindered ASN resilience during the COVID-19 pandemic. Factors in dark blue were identified as being important to supporting ASN resilience across research participant contexts. Factors in green were either supportive or hindering ASN resilience depending on the context of individual ASNs. Factors in light blue were identified as hindering ASN resilience across research participant contexts.

dependence as people mount their responses to change and surprise (Loring et al., 2011). Response diversity, on the other hand, describes the breadth of existing and new strategies that people mount in response to some challenge (Leslie and McCabe, 2014), which as we discuss below and is influenced by a variety of factors at the individual- and societal-levels.

With respect to structural factors, study participants identified many circumstances that support or reduce resilience (**Figure 5**), such as having access to diverse supply chain configurations (e.g., distribution methods, consumer-harvester interaction interfaces, consumer bases), and diversified fishing portfolios containing multiple species and fishing seasons. Participants also identified specific circumstances that inhibited or made more difficult their efforts to adapt to pandemic-induced challenges such as limited options to transport seafood products, closed or restricted fishing seasons, lack of processing infrastructure and freezer space, or lack of a well-established online retail system and brand.

One structural challenge to ASNs resilience was decline of restaurant sector due to the pandemic. Though ASNs reported a significant increase in demand from individual consumers, adapting to serve those markets came at a cost. To remain in business, ASNs were forced to pivot their consumer base away from restaurant-based markets and other retail outlets that had closed, such as farmers markets. These closures created an overall decline in demand and drop in price, resulting in the closure or delay of some fisheries (e.g., white fish fishery in the Great Lakes). In some places it also caused a loss of processing capacity when large processors temporarily closed due to a lack of product to process. As one ASN owner described:

Having that really direct connection takes out a lot of variability or uncertainty. You know the more hands you put in the middle the more uncertainty there is. Right? The more, you know, you just don't know for example if this processor or that processor is going to shut down. Or if you're dealing with wholesalers or distributors in between you just don't know, you can't control those things. The direct relationship between the fishing family and the end consumer builds trust, builds flexibility on the part of the customer (Participant 9, April 22, 2020).

Other structural resilience challenges arose due to price uncertainty from large-scale processors, to whom many ASNs sold the excess of their catch, though the rising demand from new individual customers acted as a buffer for some ASN models. Processing capacity and availability, either within the ASN or through a larger commercial processor, became tenuous as processing spaces closed their doors or limited their intake—a challenge for a small ASN with no privately-owned processing space. Similarly, accessing appropriate retail space such as docks or other physical locations that allowed for social distancing and sanitation measures was also critical for ASNs to maintain sales.

Alternative seafood network operators also identified physical infrastructure and available workforce as critical to their ability to adapt to new buying and selling strategies, keep their workforce and customers safe, and rapidly scale their business model in response to increasing demand. Alternative seafood network operators also noted the absence of physical infrastructures such as those described above as a hindrance to resilience. Difficulty in finding local employees (or the secondary barrier of processors not having enough employees, and thus closing) and working around COVID-19 distancing and health safety concerns (e.g., insufficient space, etc.) were significant challenges that limited ASN ability to adapt to new production and sales conditions. As one harvester described:

I'm always a really big fan of selling whole fish. One of our infrastructure struggles is finding processors. We've had our favorite one shut down and he didn't reopen, so for us not knowing the market is one thing but getting it processed for high demand would actually be a challenge. At that point I would really encourage my customers to buy whole fish (Participant 3, May 5, 2020).

Some ASN operators identified the lack of access to fishing grounds, or feeling unsafe to travel to their fishing grounds, as a problem. Those who could access the fishing grounds identified geographic access to markets as a challenge in remote areas where fishers faced increased logistical barriers to getting their product to markets when transportation and travel became restricted. Secondary to challenges of access were challenges around maintaining a steady supply of product, particularly for those ASN harvesters who were unable to return to their harvesting grounds or missed important fishing seasons/openers. Here, ASNs often relied upon the aforementioned strong social networks between harvesters to maintain their seafood supply chains (e.g., access to harvested seafood through their co-op). As an ASN owner-harvester explained, "It's really been helpful that the co-op is providing me with basically it's like fish on tap, where I can go back and get more if I run out" (Participant 2, May 17, 2020).

Regarding response diversity, we found that factors at the individual and societal level influenced the range of options that ASN operators were able to mobilize in response to the pandemic. Participants described drawing extensively upon social networks and their own personal psychological resilience to get through the early months of the pandemic. Inter-harvester relationships and relationships to higher-level organizations such as fisheries co-ops were cited by many participants as being essential to their ability to distribute their catch.

These relationships were also viewed by many as being important for facilitating new markets. For example, ASN harvesters who live away from the fishing grounds in the off-season were able to develop new markets in places that were otherwise not served by their fishery. Respondents also described the positive social and psychological impact of their relationships with consumers, and highlighted the opportunity for face-to-face interactions (e.g., during curb-side pickups or home deliveries), especially during COVID-19 where such interactions have been limited in daily life.

This emphasis on relationships is closely coupled with the underlying philosophies that shape ASNs and was key to informing how they operated during the pandemic. For example, ASNs often prioritize sustainable food systems, human and community health, and well-being alongside profitability (Witter and Stoll, 2016). These topics are often tightly coupled, but during the early months of the pandemic, ASNs grappled with the tradeoffs between the need to provide seafood and the risks associated with contracting or spreading the virus, particularly to rural and remote fishing communities. As one ASN operator explained, "I do feel like I have a right to get to our fishing boat and go catch fish. And as fishermen we are essential workers. But do I want to exercise that right? Do I want to put my kids on an airplane, fly myself and my partner and my kids up [to Alaska where we fish] and be a vector for this town that I love so much?" (Participant 2, April 27, 2020).

Setting appropriate price points and managing consumers' fears and anxiety about committing to a subscription or share-based model during times of economic uncertainty was also a challenge. Alternative seafood network owners reported being oriented around providing high quality seafood products for reasonable prices, but faced declining disposable income in their consumer bases as people struggled with financial security during the pandemic.

Respondents also identified relationships to place as being important in both developing new markets and selling place-based products. For example, ASN harvesters who live away from the fishing grounds in the off-season were able to develop new markets in places that were otherwise not served by their fishery. Their personal connection to their home area and their fishery was important to connecting consumers to the value and origin of their product. Harvesters also reported feelings of satisfaction through connecting with their customers and sharing with them a nutritionally and emotionally valuable food product. This factor linked closely to ASNs having core underlying philosophies that inform their business decisions and offered flexibility in considering what an ASN should achieve and how a sustainable business model should look during the pandemic. For example, prioritizing sustainable food systems and human and community health and well-being alongside profitability.

Conversely, social and emotional tolls from the uncertainty of the COVID-19 pandemic's impact on their fisheries and markets hindered many with worries about risks and responsibilities of contracting or spreading the virus, particularly to rural and remote fishing communities. Setting appropriate price points and managing consumer fears/anxiety of commitment to a subscription or share-based model ASNs during times of economic turmoil has also been a challenge. As one harvester explained:

We've actually dropped the prices on a lot of things. I know like tuna and opah went from being like $14.00, $15.00 to now everything is like $10.00/lbs and some of the whole fish is cheaper, whole or a couple dollars less filet, just again people are I think wanting to move stuff but also make sure that people are able to buy because as much as we're struggling, so are the people that are supporting us (Participant 9, May 11, 2020).

Likewise, many discussed their own willingness to be flexible, e.g., moving their operations online, as well as having online marketing platforms and presences in the first place, as essential to accommodating social distancing requirements and accessing new consumers.

Strengthening Alternative Seafood Networks

Alternative Seafood Networks operators identified several key barriers to ASN development and growth, notably a lack of appropriate infrastructure such as docks or other unloading areas, reliable postal services, or seafood processing locations. Others identified challenging regulatory environments that make it difficult to obtain appropriate permits, licenses, or other permissions required to direct-market seafood to local consumers or retailers. Underlying these challenges was also a reported lack of state/provincial or federal recognition of ASNs and small-scale fisheries and the role they provide to local food security. **Table 1** provides a synthesis of policy changes to address these challenges identified during interviews.

TABLE 1 | Policy opportunities to strengthen alternative seafood networks.

Type of infrastructure	Action/Investment
Physical	Make local and state/provincial investments in scale-appropriate infrastructure (e.g., working waterfronts, postal service, food hubs, etc.) that is conducive for direct-sale of seafood products through multiple channels and locations.
Social	Provide affordable, accessible health care for essential food production workers in the seafood industry that reflect the seasonality of fishing.
Social/ Economic	Develop fair and affordable financial tools to help young and new fishermen enter highly competitive and costly fisheries.
Economic	Establish financial incentives for domestic seafood purchasing and consumption, with priority on sustainability of stocks and fair labor practices.
Regulatory	Streamline and simplify regulatory requirements for fishermen to sell their catch directly to consumers or local retail outlets. Streamlined regulatory requirements exist for land-based farmers, but are currently much more arduous for seafood producers.
Regulatory/ Marketing	Acknowledge the diversity of domestic seafood markets (ASNs, large-scale), and expand the definition of what "local" means in terms of labeling so as to include products harvested elsewhere by local residents.
Marketing	Provide leadership at the state/provincial and federal level to highlight and promote the value of North America's commercial fishing fleets and emphasize local, U.S./Canadian caught/raised seafoods (i.e., national seafood council) and consumption of local, sustainably-harvested, underutilized species.

DISCUSSION

Our research provides evidence of a temporary re-localization in the seafood system during the early months of the COVID-19 pandemic, in which demand for local and directly sourced seafood spiked abruptly. This finding is consistent with recent studies that find evidence that fishers shifted to local and direct sales as a key adaptation strategy during the early months of the pandemic (Pita, 2020; Smith et al., 2021). To date, ASNs have been described as an important strategy for small- and mid-size seafood operations to build firm-level resilience (Kittinger et al., 2015; Stoll et al., 2020). However, the relative shock-tolerance that ASNs exhibited during the COVID-19 pandemic also suggests that they may contribute to the "systemic resilience" of the broader seafood economy. That is, ASN participants may be uniquely capable of mobilizing the necessary response diversity that allows producers and consumers to circumvent supply chain deadlocks during times of stress. Indeed, it is worth noting that the pattern of re-localization during shocks that we document in this paper is not a new phenomenon. For example, in 1917, during World War I, the Canadian Ministry of Agriculture encouraged citizens to establish "victory gardens" as part of the tactical strategy to increase food sovereignty and win the war. Woodrow Wilson, president of the United States between 1913 and 1921, launched a similar campaign. More contemporary examples also exist. For example, Gómez and Lien (2017) have previously observed that the global financial crisis of 2007–2008 played a critical role in catalyzing local food distribution in southern Europe. Similarly, during the 2007–2008 global financial crisis, the iconic lobster fishery in Maine, which had been becoming progressively more globalized (Stoll et al., 2018), pivoted their efforts toward local and domestic seafood distribution. Likewise, this pattern of food systems localization has also been reported to us anecdotally from multiple Latin American locales during the pandemic, including Puerto Rico (Marco Hanke, pers. commun., 17 August, 2020, Chile (Marah Hardt, pers. commun., 06 July 2020), Mexico (Ines Lopez, pers. commun., 31 August, 2020), and the Caribbean Islands (Felicity Burrows, pers. commun., 21 July 2020). Within Indigenous contexts, local pivots in fisheries may also open the door to Indigenous self-determination and food sovereignty through small-scale artisanal fisheries in North America (Lowitt et al., 2019).

Some of the drivers and determinants of resilience observed here match with findings of other research, including the importance of existing infrastructure, experience with alternative fisheries and marketing strategies, and a willingness to be flexible on the part of individual operators (Hamilton et al., 2003; Huntington et al., 2017). Particularly noteworthy, we believe, is the apparent role of psychological resilience and agency at the individual level, e.g., fishers' commitment to fishing and to core values for fishing, in supporting the continued function of the seafood system at higher levels. This is an important contribution to how we understand the role of individual coping and well-being in the resilience of fisheries and the larger social-ecological systems within which they are embedded (Adger, 2000). Resilience at the individual level has been discussed previously, but largely in terms of people's ability to cope and maintain their own well-being during crisis (Coulthard, 2012; Broch, 2013). Here, we have an example of individuals contributing positive resilience, that is, the ability to not just bounce back but bounce forward (Manyena et al., 2011), in a way that is transferring resilience to higher levels in regional food systems and the seafood sector at large.

Troell and colleagues previously hypothesized that the aquaculture sector could add resilience to the global seafood system by increasing the diversity of fished species and production locales (Troell et al., 2014). While we are unaware of studies that have tested their hypothesis for aquaculture or any other subsector of the seafood industry, here we present findings that suggest ASNs may contribute to the systemic resilience of the global seafood system. In part, they do by adding diversity to the production systems and supply chains and allow fishers to circumvent deadlocks in global supply chains by moving product through local markets. We also find that individual agency plays an important role, agency that is empowered by fishers' psychological resilience and commitment to the unique value sets around fisheries that ASNs embody, values such as fair access and simple supply chains. This suggests that when considering how to improve global seafood systems moving forward, it is insufficient to look at diversification in production and supply chains without looking at the system of values that motivate the actors making and participating in those changes. Further research is needed to understand how ASN are able to persist over time in the face of ongoing and future crises.

Alternative seafood network operators identified a number of structural and response factors that, depending on their local context, helped or hindered their resilience to impacts from the COVID-19 pandemic as well as possible policy options that could address some obstacles to resilience (**Table 1**). Those policy opportunities were directed toward physical, social, socioeconomic, economic, and regulatory infrastructure. For example, operators identified that lack of physical infrastructure, such as working waterfronts or seafood processing capacity, posed a challenge to ASNs who need space to deliver their product and prepare it for sale. Prioritizing investment at multiple levels to develop and support existing local-level seafood infrastructure would provide appropriate locations and capacity for ASNs to scale their operations to meet demand and seasonal abundance (see Lowitt et al., 2020). Similarly, respondents identified that excessive regulatory "red tape" was often challenging and expensive to navigate, creating disincentives for some seafood harvesters to seek out appropriate permissions to direct market their products. Alternative seafood network operators identified that streamlining and simplifying direct-marketing permissions (e.g., permits, licenses, etc.) and the process by which they are obtained would make this process more accessible to a wider variety of seafood producers and bring direct-marketing of seafood in line with the more streamlined processes that exist for the direct sale of land-based agricultural products.

Finally, to more fully understand the role that ASNs play in the broader seafood system, better data on the sector are critically needed (O'Hara, 2020). At present, there is no national-level data in either the United States or Canada to describe the number of ASNs, their geographic distribution or their total socioeconomic contribution. However, sales associated with local and regional types of agricultural distribution in the United States alone are estimated to be US$9 billion, including US$2.8 billion in sales directly to consumers (USDA, 2019). Addressing this data gap is not beyond the realm of possibility as parallel data for the agricultural sector have been collected since 1976 in the United States through the Farmer-to-Consumer Direct Marketing Act. Such data are critical to further understand the role of ASNs in shock-tolerance and the importance of functional diversity in supply chains, as demonstrated during the COVID-19 pandemic.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: https://trends.google.com/trends/?geo=US; https://github.com/eastonwhite/COVID19_US_Fisheries. The qualitative data sets used in this study are not available due to confidentiality rules.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of Guelph Research Ethics Board. The patients/participants provided their written informed consent to participate in this study.

AUTHOR'S NOTE

To listen to the PubCast of this paper – an abridged and annotated audio-book style recording, go to: https://soundcloud.com/conservechange/alternative-seafood-networks-during-covid-19.

AUTHOR CONTRIBUTIONS

JS, HH, ED, and PL conceived of the study. HH, ED, and PL performed qualitative interviews. HH and ED analyzed qualitative data. JS and EW performed quantitative analysis. JS, HH, ED, and PL drafted the manuscript. DC, MC, KH, BJ, JK, EK, SK, ML, SS, TS, BT, AT, EW, and TY contributed web analytics and interview data, and reviewed, and commented on the manuscript. PL, ED, and HH were supported in part by the Social Sciences and Humanities Research Council and the Arrell Food Institute. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2021.614368/full#supplementary-material

REFERENCES

Adger, W. N. (2000). Social and ecological resilience: are they related? *Prog. Hum. Geogr.* 24, 347–364. doi: 10.1191/030913200701540465

Anderson, J. J., Asche, F., and Tveteras, S. (2010). "World fish markets," in *Handbook of Marine Fisheries Conservation and Management*, eds R. Q. Grafton, R. Hillborn, D. Squires, M. Tait, and M. Williams (Oxford University Press), 113–122.

Asche, F., Bellemare, M. F., Roheim, C., Smith, M. D., and Tveteras, S. (2015). Fair enough? Food security and the international trade of seafood. *World Dev.* 67, 151–160. doi: 10.1016/j.worlddev.2014.10.013

Attride-Stirling, J. (2001). Thematic networks: an analytic tool for qualitative research. *Qual. Res.* 1, 385–405. doi: 10.1177/146879410100100307

Bennett, N., Finkbeiner, E., Ban, N., Dyhia, B., Jupiter, S., Kittinger, J., et al. (2020). The COVID-19 pandemic, small-scale fisheries and coastal fishing communities. *Coast. Manage.* 48, 336–347. doi: 10.1080/08920753.2020.1766937

Berkes, F., and Ross, H. (2013). Community resilience: toward an integrated approach. *Soc. Nat. Resour.* 26, 5–20. doi: 10.1080/08941920.2012.736605

Bolton, A. E., Dubik, B. A., Stoll, J. S., and Basurto, X. (2016). Describing the diversity of community supported fishery programs in North America. *Mar. Policy* 66, 21–29. doi: 10.1016/j.marpol.2016.01.007

Brinson, A., Lee, M.-Y., and Rountree, B. P. (2011). Direct marketing strategies: the rise of community supported fishery programs. *Mar. Policy* 35, 542–548. doi: 10.1016/j.marpol.2011.01.014

Broch, H. B. (2013). Social resilience - local responses to changes in social and natural environments. *Marit. Stud.* 12:6. doi: 10.1186/2212-9790-12-6

Bronnmann, J., Smith, M. D., Abbott, J., Hay, C. J., and Næsje, T. F. (2020). Integration of a local fish market in Namibia with the global seafood trade: implications for fish traders and sustainability. *World Dev.* 135:105048. doi: 10.1016/j.worlddev.2020.105048

Campbell, L. M., Boucquey, N., Stoll, J., Coppola, H., and Smith, M. D. (2014). From vegetable box to seafood cooler: applying the community-supported agriculture model to fisheries. *Soc. Nat. Resour.* 27, 88–106. doi: 10.1080/08941920.2013.842276

Carlisle, L. (2014). Diversity, flexibility, and the resilience effect: lessons from a social-ecological case study of diversified farming in the northern Great Plains, USA. *Ecol. Soc.* 19, 45–45. doi: 10.5751/ES-06736-190345

Castleden, H., Morgan, V. S., and Neimanis, A. (2010). Researchers' perspectives on collective/community co-authorship in community-based participatory indigenous research. *J. Empiric. Res. Hum. Res. Ethics* 5, 23–32. doi: 10.1525/jer.2010.5.4.23

Cockrell, M. L., O'Farrell, S., Sanchirico, J., Murawski, S. A., Perruso, L., and Strelcheck, A. (2019). Resilience of a commercial fishing fleet following emergency closures in the Gulf of Mexico. *Fish. Res* 218, 69–82. doi: 10.1016/j.fishres.2019.04.017

Cooke Aquaculture (2020). *Cooke Reeling-in Customers Online by Delivering Unique Seafood Boxes*. Available online at: https://www.cookeseafood.com/2020/05/25/cooke-reeling-in-customers-online-by-delivering-unique-seafood-boxes/

Corbin, J., and Strauss, A. (2008). *Basics of Qualitative Research, 3rd Edn*. Thousand Oaks, CA: Sage.

Cottrell, R. S., Nash, K. L., Halpern, B. S., Remenyi, T. A., Corney, S. P., Fleming, A., et al. (2019). Food production shocks across land and sea. *Nat. Sustain.* 2, 130–137. doi: 10.1038/s41893-018-0210-1

Coulthard, S. (2012). Can we be both resilient and well, and what choices do people have? Incorporating agency into the resilience debate from a fisheries perspective. *Ecol. Soc.* 17:4. doi: 10.5751/ES-04483-170104

Farrell, P., Thow, A. M., Wate, J. T., Nonga, N., Vatucawaqa, P., Brewer, T., et al. (2020). COVID-19 and Pacific food system resilience: opportunities to build a robust response. 12, 783–791. doi: 10.1007/s12571-020-01087-y

Food Agricultural Organization of the United Nations (2010). *The State of World Fisheries and Aquaculture 2010*. Rome.

Food Agricultural Organization of the United Nations (2020). *The State of World Fisheries and Aquaculture 2020*. Rome.

Garnett, P., Doherty, B., and Heron, T. (2020). Vulnerability of the United Kingdom's food supply chains exposed by COVID-19. *Nat. Food* 1, 315–318. doi: 10.1038/s43016-020-0097-7

Gephart, J., Cottrell, R. S., Froehlich, H. E., Nussbaumer, E., Stoll, J. S., and White, E. (2020). *Covid-19 Seafood Impacts (Version 1.0), 1st Edn*. Zenodo.

Gómez, S., and Lien, M. E. (2017). Recovering food commons in post industrial Europe: cooperation networks in organic food provisioning in Catalonia and Norway. *J. Agric. Environ. Ethics* 30, 625–643. doi: 10.1007/s10806-017-9691-6

Goodman, D., DuPuis, E., and Goodman, M. (2012). *Alternative Food Networks: Knowledge, Practice, and Politics*. London: Routledge. doi: 10.4324/9780203804520

Hamilton, L., Brown, B., and Rasmussen, R. O. (2003). West Greenland's cod-to-shrimp transition: local dimensions of climatic change. *Arctic* 56, 271–282. doi: 10.14430/arctic623

Hill, R. V., and Narayan, A. (2020). *How Is COVID-19 Likely to Affect Inequality?* A Discussion Note (Unpublished). Washington, DC: World Bank.

Huntington, H., Begossi, A., Gearheard, S. F., Kersey, B., Loring, P., Mustonen, T., et al. (2017). How small communities respond to environmental change: patterns from tropical to polar ecosystems. *Ecol. Soc.* 22:9.

Kittinger, J. N., Teneva, L. T., Koike, H., Stamoulis, K. A., Kittinger, D. S., Oleson, K. L. L., et al. (2015). From reef to table: social and ecological factors affecting coral reef fisheries, artisanal seafood supply chains, and seafood security. *PLoS ONE* 10:e0123856. doi: 10.1371/journal.pone.0123856

Kummu, M., Kinnunen, P., Lehikoinen, E., Porkka, M., Queiroz, C., Roos, E., et al. (2020). Interplay of trade and food system resilience: gains on supply diversity over time at the cost of trade independency. *Glob. Food Secur.* 24:100360. doi: 10.1016/j.gfs.2020.100360

Leslie, P., and McCabe, T. (2014). Response diversity and resilience in social-ecological systems. *Curr. Anthropol.* 2, 114–143. doi: 10.1086/669563

Loring, P., De Sousa, E., Harrison, H., and Stoll, J. (2020). As coronavirus threatens seafood economy, community fisheries find ways to stay afloat. *The Conversation*. Winnipeg, MB: Fernwood Publishing.

Loring, P., Fazzino, D., Agapito, M., Chuenpagdee, R., Gannon, G., and Isaacs, M. (2011). "Fish and food security in small-scale fisheries," in *Transdisciplinarity for Small-Scale Fisheries Governance*, Vol. 21, eds R. Chuenpagdee and S. Jentoft (Cham: Springer), 55–73. doi: 10.1007/978-3-319-94938-3_4

Love, D., Allison, E., Asche, F., Belton, B., Cottrell, R. S., Froehlich, H., et al. (2021). Emerging COVID-19 impacts, responses, and lessons for building resilience in the seafood system. *Glob. Food Secur.* 28, 1–22. doi: 10.1016/j.gfs.2021.100494

Lowitt, K., Levkoe, C. Z., Lauzon, R., Ryan, K., and Sayers, C. D., (2019). "Indigenous self-determination and food sovereignty through fisheries governance in the Great Lakes region," in *Civil Society and Social Movements in Food System Governance, 1st Edn.,* eds P. Andrée, J. K. Clark, C. Z. Levkoe, and K. Lowitt (London: Routledge), 145–163. doi: 10.4324/9780429503597-8

Lowitt, K., Levkoe, C. Z., Spring, A., Turlo, C., Williams, P. L., Bird, S., et al. (2020). Empowering small-scale, community-based fisheries through a food systems framework. *Mar. Policy* 120:104150. doi: 10.1016/j.marpol.2020.104150

Manyena, B., OBrien, G., OKeefe, P., and Joanne, R. (2011). Disaster resilience: a bounce back or bounce forward ability? *Int. J. Justice Sustain.* 16, 417–424. doi: 10.1080/13549839.2011.583049

Marín, A., Gelcich, S., Araya, G., Olea, G., Espíndola, M., and Castilla, J. C. (2010). The 2010 tsunami in Chile devastation and survival of coastal small-scale fishing communities. *Mar. Policy* 34, 1381–1384. doi: 10.1016/j.marpol.2010.06.010

McClenachan, L., Neal, B. P., Al-Abdulrazzak, D., Witkin, T., Fisher, K., and Kittinger, J. N. (2014). Do community supported fisheries (CSFs) improve sustainability? *Fish. Res.* 157, 62–69. doi: 10.1016/j.fishres.2014.03.016

O'Hara,. J. K. (2020). Farmers markets and seafood: where is it feasible? *Mar. Resour. Econ.* 35, 411–426. doi: 10.1086/710051

O'Malley, J. (2020). How COVID-19 is threatening Alaska's wild salmon fishing season. *New York Times*. Available online at: https://www.nytimes.com/2020/06/23/dining/alaska-salmon-coronavirus.html?smid=tw-share.

Pita, C. (2020). "People, COVID-19 and beyond: impacts, adaptation, and innovation among small-scale fisheries," in Small is Bountiful Conference. Available online at: http://toobigtoignore.net/opportunity/join-us-for-world-ocean-day-2020/

Rockstrom, J., Edenhofer, O., Gaertner, J., and DeClerck, F. (2020). Planet-proofing the global food system. *Nat. Food* 1, 3–5. doi: 10.1038/s43016-019-0010-4

Smith, S. L., Golden, A. S., Ramenzoni, V., Zemeckis, D. R., and Jenson, O. P. (2021). Adaptation and resilience of commercial fishers in the Northeastern United States during the early stages of the COVID-19 pandemic. *PLoS ONE* 5:e0243886. doi: 10.1371/journal.pone.0243886

Sorensen, J., Echard, J., and Weil, R. (2020). From bad to worse: the impact of COVID-19 on commercial fisheries workers. *J. Agromed.* 25, 388–391. doi: 10.1080/1059924X.2020.1815617

Stoll, J. S., Bailey, M., and Jonell, M. (2020). Alternative pathways to sustainable seafood. *Conserv. Lett.* 13:e12683. doi: 10.1111/conl.12683

Stoll, J. S., Crona, B. I., Fabinyi, M., and Farr, E. R. (2018). Seafood trade routes for lobster obscure teleconnected vulnerabilities. *Front. Mar. Sci.* 5, 587–588. doi: 10.3389/fmars.2018.00239

Stoll, J. S., Dubik, B. A., and Campbell, L. M., (2015). Local seafood: rethinking the direct marketing paradigm. *Ecol. Soc.* 20, 1–14. doi: 10.5751/ES-07686-200240

Tendall, D. M., Joerin, J., Kopainsky, B., Edwards, P., Shreck, A., Le, Q. B., et al. (2015). Food system resilience: defining the concept. *Glob. Food Secur.* 6, 17–23. doi: 10.1016/j.gfs.2015.08.001

Troell, M., Naylor, R. L., Metian, M., Beveridge, M., Tyedmers, P. H., Folke, C., et al. (2014). Does aquaculture add resilience to the global food system? *Proc. Natl. Acad. Sci. U.S.A.* 111, 13257–13263. doi: 10.1073/pnas.1404067111

Ungar, M. (2018). Systemic resilience: principles and processes for a science of change in contexts of adversity. *Ecol. Soc.* 23, 34–17. doi: 10.5751/ES-10385-230434

United Nations (2020). *UN Comtrade Database*. Available online at: https://comtrade.un.org/data/

US Census Bureau (2021). *Household Pulse Survey Data Table. Week 23 Household Pulse Survey: January 20–February 1*. Available online at: https://www.census.gov/programs-surveys/household-pulse-survey/data.html

USDA (2019). *2017 Census of Agriculture*. Available online at: https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_US/usv1.pdf

Walker, B., and Salt, D. (2012). *Resilience Practice: Building Capacity to Absorb Disturbance and Maintain Function*. Island Press.

Whatmore, S., Stassart, P., and Renting, H. (2003). What's alternative about alternative food networks? *Environ. Plan. A* 35, 389–391. doi: 10.1068/a3621

White, E. R., Froehlich, H. E., Gephart, J. A., Cottrell, R. S., Branch, T. A., Bejarano, R. A., et al. (2021). Early effects of COVID-19 interventions on US fisheries and seafood. *Fish Fish.* 22, 232–239. doi: 10.1111/faf.12525

Witter, A. (2020). *Boat to Fork: Seafood Value Chains and Alternative Food Networks*. Ph.D. thesis, The University of British Columbia, Vancouver. 1–207.

Witter, A., and Stoll, J. (2016). Participation and resistance Alternative seafood marketing in a neoliberal era. *Mar. Policy* 80, 130–140. doi: 10.1016/j.marpol.2016.09.023

World Bank (2020). *Poverty and Shared Prosperity 2020: Reversals of Fortune*. Washington, DC: World Bank. doi: 10.1596/978-1-4648-1602-4

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REVIEW
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Food Containing Bioactive Flavonoids and Other Phenolic or Sulfur Phytochemicals With Antiviral Effect: Can We Design a Promising Diet Against COVID-19?

Martina Ghidoli[1†], *Federico Colombo*[1†], *Stefano Sangiorgio*[1], *Michela Landoni*[2], *Luca Giupponi*[1,3], *Erik Nielsen*[4] *and Roberto Pilu*[1,3*]

[1] *Department of Agricultural and Environmental Sciences - Production Landscape, Agroenergy, Università degli Studi di Milano, Milan, Italy,* [2] *Department of Bioscience, Università degli Studi di Milano, Milan, Italy,* [3] *Centre of Applied Studies for the Sustainable Management and Protection of Mountain Areas – CRC Ge.S.Di.Mont., Università degli Studi di Milano, Edolo, Italy,* [4] *Department of Biology and Biotechnology Università degli Studi di Pavia, Pavia, Italy*

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***Correspondence:**
Roberto Pilu
salvatore.pilu@unimi.it

†These authors have contributed equally to this work

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Since in late 2019, when the coronavirus 2 (SARS-CoV-2) pathogen of coronavirus disease 2019 (COVID-19) started to spread all over the world, causing the awful global pandemic we are still experiencing, an impressive number of biologists, infectious disease scientists, virologists, pharmacologists, molecular biologists, immunologists, and other researchers working in laboratories of all the advanced countries focused their research on the setting up of biotechnological tools, namely vaccines and monoclonal antibodies, as well as of rational design of drugs for therapeutic approaches. While vaccines have been quickly obtained, no satisfactory anti-Covid-19 preventive, or therapeutic approach has so far been discovered and approved. However, among the possible ways to achieve the goal of COVID-19 prevention or mitigation, there is one route, i.e., the diet, which until now has had little consideration. In fact, in the edible parts of plants supplying our food, there are a fair number of secondary metabolites mainly belonging to the large class of the flavonoids, endowed with antiviral or other health beneficial activities such as immunostimulating or anti-inflammatory action that could play a role in contributing to some extent to prevent or alleviate the viral infection and/or counteract the development of SARS induced by the novel coronavirus. In this review, a number of bioactive phytochemicals, in particular flavonoids, proven to be capable of providing some degree of protection against COVID-19, are browsed, illustrating their beneficial properties and mechanisms of action as well as their distribution in cultivated plant species which supply food for the human diet. Furthermore, room is also given to information regarding the amount in food, the resistance to cooking processes and, as a very important feature, the degree of bioavailability of these compounds. Concluding, remarks and perspectives for future studies aimed at increasing and improving knowledge and the possibility of using this natural complementary therapy to counteract COVID-19 and other viral pathologies are discussed.

Keywords: flavonol, flavanone, phytochemicals, functional foods, COVID-19, diet

INTRODUCTION

At the end of 2019, the World Health Organization (WHO) reported numerous cases of low respiratory tract infections in Wuhan (Hubei province, China) caused by a novel virus. The novel virus is a member of the *Coronaviridae* family and it was identified as Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) due to its high similarity with another previously isolated coronavirus, SARS-CoV (1–4). Due to its spread all over the world, in March 2020, the WHO declared a pandemic (5). Over the recent decades, an increase in diseases caused by new coronaviruses has been reported in humans and animals (6). Among these, SARS-CoV (2002–2003) and MERS-CoV (2012) caused serious health problems and demonstrated the lethality of coronaviruses if they cross the species barrier and subsequently infect humans (7, 8). Currently, the SARS-CoV-2 generated the unprecedented COVID-19 (Coronavirus Disease of 2019) outbreak. This pathogen can affect several tissues at multiple levels in humans: from the cells of nose and throat down to the lung, and also invading the kidneys and the nervous system, where it can lead to severe illness and death (9, 10). The subjects at highest risk of developing severe COVID-19 symptoms are the elderly and those with major chronic diseases, such as diabetes, cancer and hypertension (11). MERS-CoV binds to dipeptidyl-peptidase 4 (DPP4) receptors to infect human cells (6), while both the original SARS-CoV and the novel virus SARS-CoV-2 bind to the angiotensin-converting enzyme 2 (ACE2). However, SARS-CoV-2 has a greater binding affinity to ACE2, presenting an higher infectivity compared to the previous SARS-CoV (12–16). Similarly to SARS-CoV, also in SARS-CoV-2, two open-reading-frames (ORF1a and ORF1b) are translated into two viral enzymes fundamental for virus replication: 3C-like protease (3CLpro) and papain-like protease (PLpro) (17). In this context, an essential role in the infection is played by the spike glycoprotein (S), located on the viral phospholipidic membrane surface (**Figure 1**). In particular, the receptor-binding domain (RBD) of the spike protein of SARS-CoV-2 binds strongly to ACE2 receptors after the activation by two host serine proteases (TMPRSS2 and furin). The entry of the virus into host cells causes an increase of the natural inflammatory response (defined as a cytokine storm), leading to serious problems particularly in the respiratory tract.

In synergy with therapeutic treatments and vaccines, we propose that the diet might play a significant role to prevent or to mitigate the symptoms of this illness. In fact, it is known that many phytochemicals have great potential in preventing viral infection, modulating immune responses, and decreasing the inflammatory response (18, 19). These natural molecules are present not only in a few medicinal plants, but also in many edible parts (seeds, fruits and vegetables) of cultivated plants which form part of the human diet. Consequently, we have available various "functional foods" that could complement our daily diet, with positive effects on both prevention and reduction of the severity of COVID-19 symptoms (**Table 1**).

Several foods, particularly fruits and vegetables, are rich in different natural compounds with beneficial effects on human health. In particular, various aromatic and a few sulfur compounds are known for their key roles as antioxidants, antivirals and anti-inflammatories (38). These bioactive phytochemicals may thus alleviate SARS-CoV-2 symptoms, decreasing the inflammatory responses (39, 40).

In this review, we present many natural plant-derived compounds whose intake can be implemented in the human diet and illustrate their antiviral potential or beneficial properties which may counteract COVID-19 progression. Furthermore, within the same species, the varieties characterized by a higher content of these phytochemicals are described. In particular, the focus is on the flavonoids flavonones and flavonols which are reported to be able to significantly counteract coronavirus infection and thus may also play a central role in protection against the novel COVID-19.

FLAVONOIDS

Flavonoids are secondary metabolites synthesized by plants. They are divided into different classes: anthocyanins, flavanols, dihydroflavonols, flavanones, flavones, flavonols, isoflavonoids, chalcones, and dihydrocalcones (18).

The maize flavonoid biosynthesis involves over 20 loci, and historically was the first elucidated plant metabolic pathway, due to the facility with which it enabled work with non-lethal mutants, and corn revealed itself to be the ideal model plant for a variety of different genetic studies.

The pathway starts from the condensation of four molecules of coumaroyl-CoA with 3-malonyl-CoA, which produces naringenin chalcone by the enzyme chalcone synthase, CHS (**Figure 2**). Naringenin chalcone is subsequently isomerized by chalcone isomerase (CHI) to naringenin, a key intermediate of the biosynthetic pathway. Naringenin is then transformed to dihydrokaempferol, which in turn is the substrate for three enzymes: (1) dihydroflavonol reductase (DFR) which leads to pelargonidin synthesis; (2) flavonol synthase (FLS) that transforms dihydrokaempferol to kaempferol; (3) flavanone 3-hydroxylase (F3′H) that catalyzes the formation of dihydroquercetin. Similarly, dihydroquercetin leads to the synthesis of cyanidin by dihydroflavonol reductase (DFR) or to the formation of quercetin by FLS. F3′H is also a key enzyme for the synthesis of phlobaphenes (41). These red pigments are formed from polymers of luteoforol and apiferol, which in turn derive from eriodictyol and naringenin, through the action of the DFR enzyme. Moreover, eriodictyol can be converted to dihydroquercetin by the activity of F3H (42). All these structural genes are regulated by the presence of two multigene families, c1/pl1/p1 genes, belonging to the family of MYB transcription factors and r1/b1 genes, belonging to MYC transcription factors (43–45). Usually, an active form of each family (acting as dominant) must be present to lead anthocyanin biosynthesis in different plant tissues according to the presence of different alleles.

There are various studies that highlight the wide range of biological activities of flavonoids, such as antiviral (46), antioxidant (47), anticancer (48), antimicrobial (49), and anti-inflammatory (50). As antivirals, several flavonoids have been reported to inhibit the targets of SARS and MERS coronaviruses

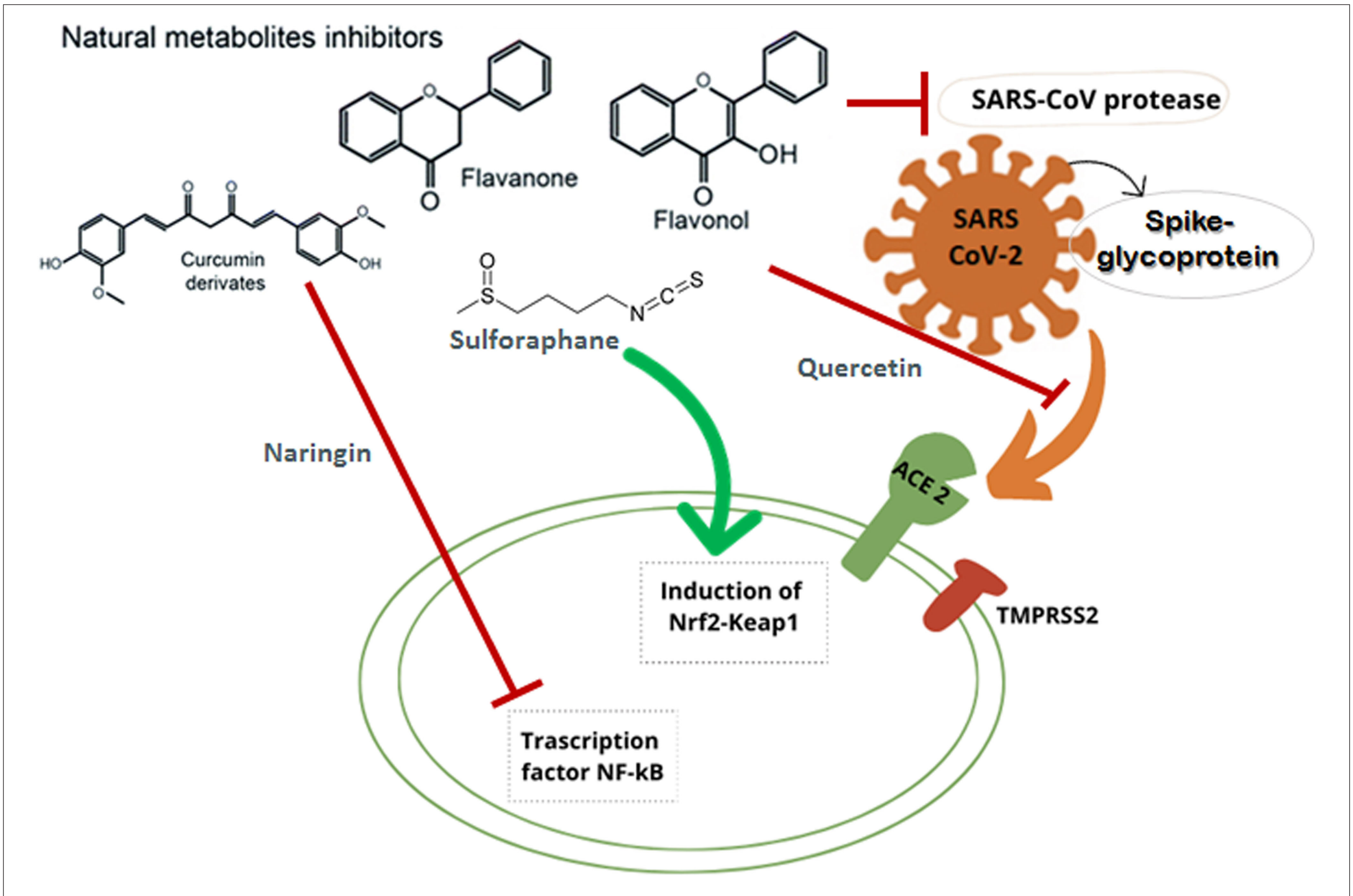

FIGURE 1 | Schematic representation of the main mechanisms of action against SARS CoV-2 of different secondary plant metabolites: flavanones, flavonols, aromatic compounds, and sulfur compounds.

(51) in different ways: blocking the enzymatic activities of viral proteases (3CLpro and PLpro), interfering with spike glycoproteins or suppressing the activity of ACE2 receptors (52, 53), which not only play an important role in cardiovascular diseases, but can be a key factor in viral infections and pneumonia (54). In particular, the hydroxyl group of flavonoids at 7-position appears essential to attack the binding site against 3CLpro and PLpro.

Different studies have focused primarily on the interference of flavonoids with the main viral proteases of SARS and MERS coronaviruses by using tools such as common enzymatic activity measurement, FRET (fluorescence resonance energy transfer) based methods and molecular docking (55–57). 3CLpro and PLpro are both key targets as they process many viral polyproteins that are involved in RNA replication and transcription within host cells (58).

However, the majority of the studies dealing with the health beneficial properties of flavonoids are conducted *in vitro* on the basis that these compounds show poor stability, low bioavailability, and poor distribution when tested *in vivo* (52). Among the tools and strategies used to increase these functions, the most promising are the insertion of structural modifications of the molecules (59), the use of absorption enhancers and nanotechnology (60, 61).

In the next step, epidemiological work should focus on clinical trials on COVID-19 patients in order to point out a reduction of the virus multiplication in the patient's body and a decrease in clinical signs (62). Furthermore, the advantage of implementing the diet with flavonoids is related to their high safety profile and lack of major side effects (62).

In this context, several authors have recently suggested kaempferol, quercetin, naringenin, curcumin, catechin, and epicatechin-gallate as recommended compounds found in plants that may act against COVID-19 proteases (18, 19, 26).

Quercetin

Quercetin is one of the most important flavonoids and belongs to the class of flavonols (**Table 1**). Quercetin is the aglycone form of several glycoside flavonoids: rutin and quercitin are the most common. In fact, sugars such as glucose, rhamnose, galactose, and rutinose are usually bound to these natural compounds to form glycosides. Quercetin is naturally present in several fruits and vegetables, and also in medicinal herbs (63, 64). Its highest concentration is present in capers (*Capparis spinosa* L.), which

TABLE 1 | Main foods rich in bioactive molecules and their effectiveness against CoVs.

Bioactive plant molecules	Compound	Main Source	Food Concentration (mg/100 g)	Effectiveness Against CoVs	References
Flavonoids	Quercetin	Capers Buckwheat Onions	Capers (raw) 234 Buckwheat 184–535 Onions 120	SARS-CoV-2 proteases (3CLpro, PLpro), ACE2 receptor, glycoprotein-RBD Spike	(20–23)
	Kaempferol	Capers Saffron Brassicaceae	Capers (raw) 259 Saffron 205 Brassicaceae 30–60	SARS-CoV-2 protease, glycoprotein-RBD Spike, NF-kB	(24, 25)
	Naringenin	Citrus fruits Tomatoes	Grapefruit 53 Orange 11 Tangerine 11 Tomato 5–12	SARS-CoV-2 protease (3CLpro), ACE2 receptor, NF-kB	(26–28)
	Hesperetin	Citrus fruits	Orange 20–60 Tangerines 8–46 Lemon 4–41 Grapefruit 2–17	SARS-CoV-2 protease (3CLpro), glycoprotein-RBD Spike, ACE2 receptor	(29)
Other aromatic compounds	Curcumin	Turmeric	3,000	SARS-CoV-2 protease (3CLpro), glycoprotein-RBD Spike, ACE2 receptor	(30, 31)
	Phloretin	Apple Kumquat Pear Strawberry	40	Activation Nrf2 pathway, epigenetic regulation	(30, 32, 33)
	Epigallocatechin gallate (EGCG)	Tea	Green tea 7,380 White tea 4,245 Black tea 936	ACE2 receptor, NF-kB, epigenetic regulation	(34, 35)
Sulfur compounds	Sulforaphane	Brassicaceae	Broccoli 1,400	Activation Nrf2 pathway, epigenetic regulation	(36, 37)

contain 234 mg of flavonol per 100 g of edible portion. Due to its beneficial properties, quercetin is used as a food supplement and can counteract various diseases, acting as antiviral, anticancer, antioxidant, antidiabetic, antiulcer, antiallergy, antihypertensive, anti-inflammatory, and was reported to protect the human body from cardiovascular and gastrointestinal diseases (65). Recently, Solnier et al. have proposed quercetin as a good anti-SARS-CoV-2 candidate (19). In fact, several flavonols showed antiviral activity against coronaviruses (such as SARS-Cov and MERS-CoV) through the inhibition of 3CL and PLpro proteases (51). Since the former SARS-CoV and the new SARS-CoV-2 show high sequence similarity in the spike glycoproteins, flavonols may be also expected to prevent the entry of SARS-CoV-2 into host cells. Moreover, it has been demonstrated that the spike protein of the novel virus binds the ACE2 receptor with higher affinity compared to SARS-CoV (58). Therefore, the inhibition of ACE2 through a competing binding, appears to be a good approach to prevent SARS-CoV-2 infections. In this framework, experimental results have demonstrated that quercetin exerts strong inhibitory effects on ACE2 *in vitro*, and also *in vivo* when tested in rats (52–54, 66). Furthermore, the screening of a library of 150 compounds, allowed the identification of quercetin as a potent inhibitor of SARS-CoV-2 3CLpro (67). Taken together, these results suggest that quercetin may prevent the entry of SARS-CoV-2 in the host cell, binding the S protein and inhibiting ACE2 receptors.

Kaempferol

Another important flavonol is kaempferol (**Table 1**), a secondary metabolite found in a wide variety of edible plants and food-derived products (24), such as kale, common bean, cabbage, broccoli, endive, and leek. The highest level of this compound was found in capers and saffron (259 and 205 mg/100 g, respectively). The glycoside form of kaempferol is astragalin, well-known for its multiple therapeutic properties (68) such as antioxidant (69, 70), anti-inflammatory (71), anticancer (72), neuroprotective (73), and antiviral (25).

Naringenin

A natural compound that belongs to the flavanone class is naringenin (**Table 1**). Naringenin is present in a wide variety of fruits and vegetables, but the highest concentrations are reported in grapefruit, tangerines, oranges, and tomatoes. Naringenin mainly occurs as glycosides such as naringin or prunin (74). The presence of this flavanone in human diet is relatively high (75), but its bioavailability is limited (nearly 5.81%). Moreover, it appears that the glycosylated form naringin is less bioavailable than the respective aglycone (76). However, in order to solve the problem of naringenin's limited bioavailability, some formulations such as nanoparticles loaded with naringenin have been developed (77). After the absorption via active transport and passive diffusion (78), naringenin attaches to albumin and is finally transported to different organs: brain, liver,

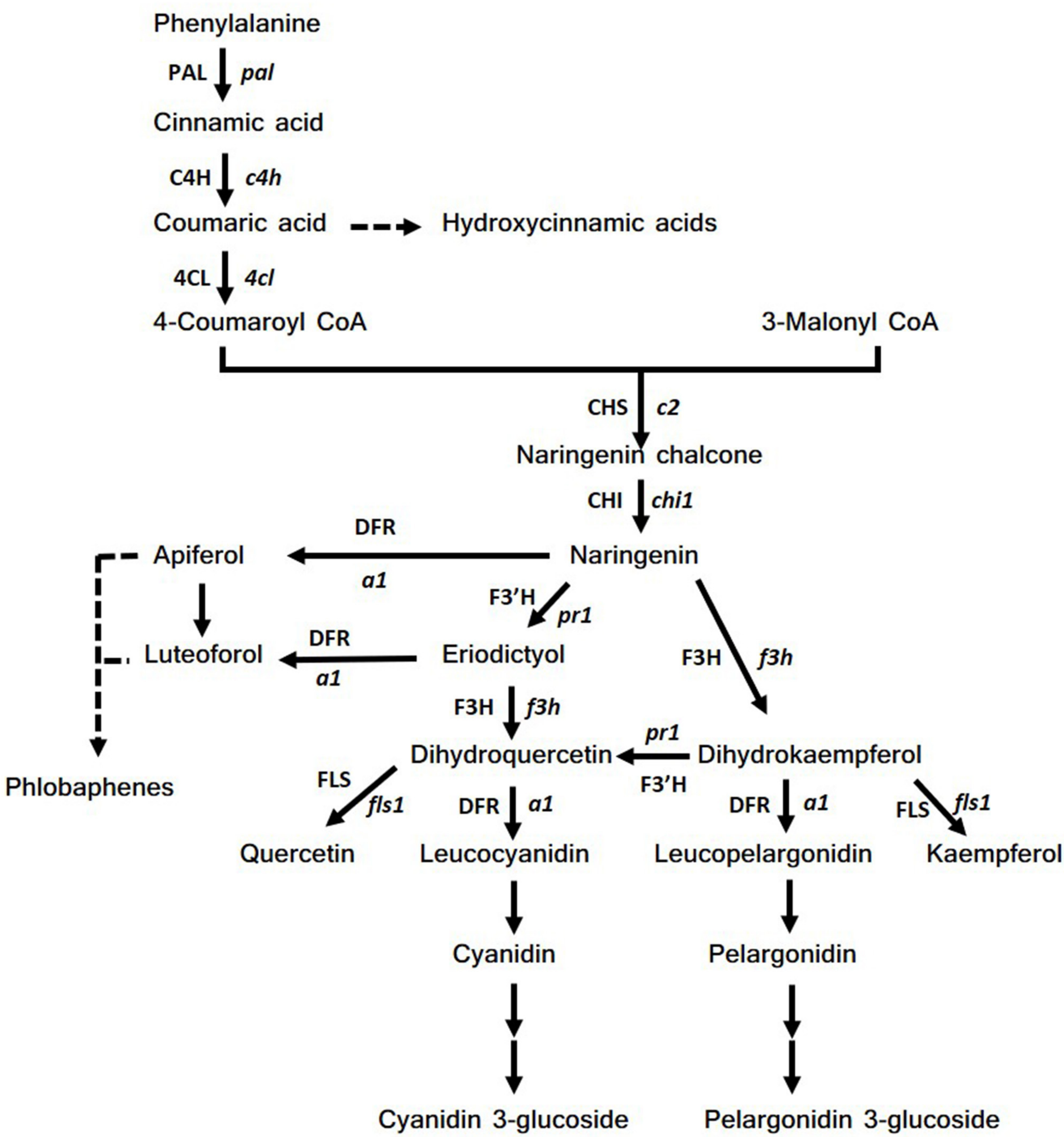

FIGURE 2 | Scheme of flavonoids biosynthetic pathway. Abbreviations of genes (enzymes): pal (PAL), phenylalanine ammonia lyase; c4h (C4H), cinnamic acid 4-hydroxylase; 4cl (4CL), 4-coumarate-CoA ligase; c2 (CHS), chalcone synthase; chi1 (CHI), chalcone isomerase; f3h (F3H), flavanone 3 hydroxylase; pr1 (F3′H), flavonone 3'-hydroxylase; a1 (DFR), dihydroflavonol synthase.

kidneys, and heart (79). Like other flavonoids, naringenin was found to be endowed with beneficial strong antioxidant, anti-inflammatory and antiviral properties (80–82). In particular, the antioxidant role of this flavanone was shown to be carried out by eliminating free radicals and preventing DNA oxidative damage (83–85) while the strong anti-inflammatory activity is due to the inhibition of the NF-kB (nuclear factor kappa B) signaling pathway (86) since NF-kB promotes the expression of many fundamental inflammatory proteins (87). The antiviral activity of naringenin was tested against some viruses: HCV, Dengue virus (DENV), Chikungunya virus (CHIKV), and Zika virus (ZIKV) (26). In this context, the beneficial properties and the possible therapeutic effects of naringenin against SARS-CoV-2 have been recently reviewed (26), pointing out that it may exert therapeutic effects against COVID-19 through the inhibition of the main protease 3CLpro and the reduction of ACE2 activity. Moreover, one additional mechanism by which this flavanone can counteract the effects of SARS-CoV-2 infection can be attributed to the attenuation of inflammatory responses.

Hesperetin

Another flavonone similar to naringenin is hesperetin (**Table 1**), mainly found in the glycoside form (hesperidin) in citrus fruits, where it is particularly abundant in the peel and in the white part of the fruit. Therefore, the consumption of the whole fruit would ensure a greater intake than the juice alone (88, 89). As recently reviewed (90), the content of hesperidin for 100 mL of juice varies according to the fruit: in oranges it ranges from 20 to 60 mg, in lemons from 4 to 41 mg, in tangerines the content is between 8 and 46 mg, while in grapefruit it is lower (2–17 mg). Among all flavonoids, researchers have recently focused the attention on hesperidin because the low binding energy of hesperidin to the spike glycoprotein and to the protease 3CLpro suggests an effective antiviral action (29). In addition, hesperidin is considered an important antioxidant compound (29), able to counteract the damaging effects of oxygen free radicals, triggered by infection and inflammation.

OTHER AROMATIC COMPOUNDS

Curcumin

Curcumin is a natural phenolic compound found in turmeric (*Curcuma longa* L.), a plant native to India and Southeast Asia where curcumin is used as a traditional medicine to treat various disorders. In Europe, this molecule is used as a food dye for its yellow color and it is classified as a food additive. Curcumin is characterized by multiple beneficial properties, acting as anti-inflammatory, antineoplastic, antiangiogenic, but also as an antiviral (influenza virus, hepatitis C virus, HIV), antibacterial (*Streptococcus* spp., *Staphylococcus* spp. and *Pseudomonas* spp.) and antifungal (*Candida* spp., *Aspergillus* spp., *Cryptococcus* spp., and *Dermatophytes* spp.) natural compound (91). It is active against various human viruses, bacteria and fungi. Nowadays, foods with high curcumin content have been evaluated as SARS-CoV-2 inhibitors (**Table 1**). Despite its poor bioavailability, some nanoparticle-based approaches have recently been developed (92–94). Furthermore, it was shown that different compounds can increase curcumin bioavailability. In particular, when combined with piperine, the major active component of black pepper, curcumin can increase its bioavailability as much as 20-fold (95).

Phloretin

Another natural phenol is phloretin (**Table 1**). Phloretin is a dihydrochalcone and phlorizin is its main glucoside. Both compounds are naturally present in apples, kumquat, pear, strawberry, and vegetables (96, 97). Phloretin is a flexible molecule able to efficiently bind biological macromolecules. It is endowed with antiviral as well as anticancer, antifungal, anti-inflammatory, and antibacterial properties, thus conferring important health-beneficial effects (32). Furthermore, this compound can increase the fluidity of membranes and enhance the penetration of administered drugs into cells (98, 99).

EGCG

An additional compound under research for its beneficial properties on human health which may be interesting under the antiviral activity aspect is epigallocatechin gallate (EGCG) (**Table 1**). EGCG is a type of catechin and it is abundant in green tea (100), while small quantities are also present in onions, plums, and apple skin. EGCG is a strong antioxidant and antitumor molecule and has the potential to prevent and counteract several human diseases with chronic metabolic and inflammatory components, such as diabetes, stroke, obesity, Parkinson's, and Alzheimer's diseases (101–103). Probably due to its ability to interact with DNA methyltransferases (DNMT), ACE-2 and helicase, EPGCG is also an antiviral molecule able to counteract diseases caused by a wide variety of viruses: herpes simplex virus (HSV), human papillomavirus (HPV), adenovirus, hepatitis B and C viruses (HBV and HCV, respectively), dengue virus (DENV), Zika virus (ZIKV), West Nile viruses (WNV), Chikungunya virus (CHIKV), Ebola virus (EBOV), human immunodeficiency virus (HIV), and influenza virus (104–108).

SULFUR COMPOUNDS

Sulforaphanes

Sulforaphanes are not phenolic compounds, but possess antiviral potential. They belong to the isothiocyanate group of nitrogen-containing plant secondary metabolites and are classified as sulfur compounds (**Table 1**). Sulforaphanes are stored as glucoraphanin, their inactive form (109). This natural compound is principally found in cruciferous vegetables (such as broccoli), is used in prevention and support of chronic diseases and is supposed to be involved in human aging (110). Moreover, it has been suggested that sulforaphane, like other natural phytochemicals, may be used in SARS-CoV-2 treatment (36). Cruciferous plants are able to release glucoraphanin, converted by the plant into sulforaphane, which in turn activates Nrf2 (111), an important transcription factor that induces an antiviral action and prevents oxidative stress (112). Nrf2 activity decreases with age, causing the elderly to be more susceptible to oxidative stress-mediated diseases (36).

STRATEGIES TO OBTAIN FLAVONOL RICH FOODS

To our knowledge, caper (*Capparis spinosa* L.) is one of the edible species capable of accumulating the highest levels of quercetin (quercetin-3-rutinoside, named rutin), a flavonol compound with various curative properties (113, 114). Another plant capable of accumulating high levels of rutin in the seed is buckwheat (Fagopyrum spp.) and in particular *Fagopyrum tataricum* Gaertn that, compared to *Fagopyrum esculentum* Moench, is able to accumulate 40–50 $\times$ higher amounts of rutin (115, 116). In both cases this flavonol is synthesized via the flavonoid biosynthetic pathways where the main genes are PAL, C4H, 4CL, CHS, CHI, F3′H, F3H, FLS, and UFGT (**Figure 2**); these genes are very highly conserved among different plants and after the first characterization in maize they were studied in different species such as Arabidopsis, petunia, snapdragon and buckwheat (42, 117, 118). Therefore, it seems that the ability to accumulate large quantities of quercetin is determined by the inactivity of a key gene for anthocyanin biosynthesis, the DFR gene. In fact, the activity of DFR would lead to the synthesis of anthocyanins and/or phlobaphenes by subtracting the common precursor naringenin (**Figure 2**). As a consequence, both caper and buckwheat are not able to accumulate large amounts of anthocyanins in their tissues, as can also be observed for example in flowers that have colorless or weakly pigmented petals. To strengthen this hypothesis, the mutation in *anthocyaninless1 a1* (DFR) maize gene, in a genetic background prone to anthocyanin synthesis, has been reported to cause suppression of anthocyanin production followed by an accumulation of quercetin in the aleurone layer conferring a brownish color (119) (**Figure 3**). Hence the strategies that can be used to increase the flavanone content in food can be summarized as below:

1) the rediscovery of traditional varieties (landraces) naturally rich in these molecules.
2) the use of classical breeding techniques to specifically drive the accumulation of these molecules.
3) a biotechnological approach such as CRISPR/Cas9 to inactivate the DFR gene in pigmented varieties.

All these methods can be used in synergy to increase the flavonol content in foods.

The species/varieties rich in flavanones such as quercetin or naringenin will be described in the next paragraph. The strategy 1 is the simplest and most user-friendly since it is based on the selection of pre-existing varieties, while the second strategy, concerning breeding techniques, takes several years, and the third, based on the novel NBTs (new breeding techniques), currently has to comply with the same European regulations as those for GMOs (120).

Considering corn as a case study, both traditional and new corn varieties obtained by breeding (121–123) are rich in flavonoids, mainly anthocyanins and phlobaphenes [reviewed by (42, 124, 125)]. These varieties, in addition to being rich in anthocyanin pigments, are able to accumulate discrete quantities of flavonols as previously reported by Lago et al. (124), Cassani et al. (125), and Landoni et al. (126). However, in order to further increase significantly the content of flavonols (in particular quercetin), it would be enough to introduce the a1 mutation by recurrent backcrossing.

VARIETIES RICH IN FLAVONOIDS

Many cultivated plants are rich in bioactive compounds and mineral elements with potential health benefits (127). A strong variability in the flavonoid content is present among different species and varieties. In **Supplementary Table 1** we present different cultivars of fruits and vegetables highlighting the different contents of quercetin, kaempferol, hesperidin and naringenin which have been found in them.

Regarding quercetin, as already mentioned, capers are the richest food, reaching 2,340 mg/kg (20). Onions are also a good source of quercetin: white varieties had a level of 900–1,830 mg/kg, while the red variety Karmen had a content of over 2,500 mg/kg (128). Although pink onions were also rather rich in this compound, the registered level was lower compared to the others. Quercetin is also present in lovage and dill, two aromatic herbs widely used in cooking (129). In Bronte pistachios, quercetin is mainly contained in the skin, so the availability during consumption is relatively low, considering that the peel is only 10% of the whole nut (130). A comparison of the phenolic profiles from available literature data about radicchio *(Cichorium intybus)* cultivars allowed the selection of three autochthonous varieties *("Verdon da Cortèl," "Treviso Precoce," "Chioggia")* cultivated in the Veneto region of Italy. The variability between cultivars ranged from 40 to 250 mg/kg) (131). The most abundant forms of quercetin present in radicchio are quercetin glucuronide (3-O; 7-O) and quercetin-3-O-glucoside. Furthermore, the glycoside form of quercetin (rutin, quercetin-3-O-rutinoside) is present in buckwheat and asparagus. The selected varieties of buckwheat contained rutin in concentrations ranging from 590 to 769 mg/kg (116). A great intraspecific variability was observed in asparagus: the highest rutin values were recorded in green cultivars (119–163 mg/kg), while the lowest in the white (2 mg/kg). Purple varieties had intermediate levels of rutin (15–20 mg/kg) (132).

As to the other flavonol, kaempferol, it is present in its aglycone form in saffron (2,050 mg/kg) (133) and in its glycosylated forms in capers and radicchio (23, 131, 134).

The flavonones hesperetin and naringenin are present in citrus fruits in their glycosylated forms hesperidin and naringin (**Supplementary Table 1**). They are mainly found in the peel and albedo (white part) of citrus fruits at higher values compared to the juice. In fact, the consumption of fresh fruit allows a greater intake (29). The highest hesperidin levels in 100 mL of juice were recorded in oranges (20–60 mg), but also in mandarins and clementines (8–46 mg) (29). According to Alam et al., the concentration of naringenin in 100 mL of mandarin juice was 300 mg (135). The concentration of this compound in mandarins was 10 times higher compared to grapefruit and over a hundred times higher than that of oranges. In tomatoes, three cultivars appeared to have the highest naringin concentrations: Daniella 12.55 mg/kg, Ramillete 8.14 mg/kg and Canario 8.46 mg/kg. Moreover, these varieties also appeared to have also the highest values of the flavonol quercetin (136).

DISHES RICH IN FLAVONOIDS: BIOAVAILABILITY AND COOKING PROCESSES

Establishing the bioavailability of bioactive compounds is a fundamental step in determining the effects of phytochemicals on human health (137). From a nutritional point of view, bioavailability is defined as the fraction of a given molecule contained in food that the body can utilize (138, 139).

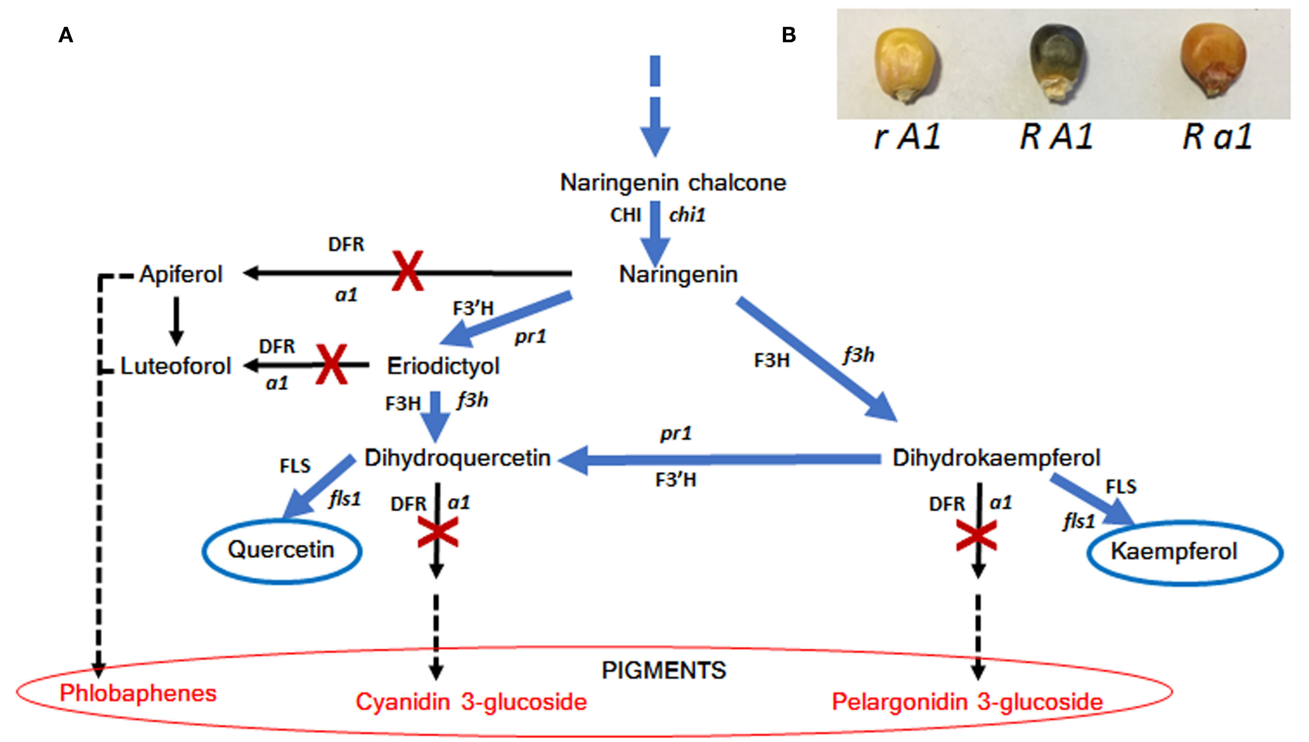

FIGURE 3 | Schematic representation of how plants accumulate quercetin and kaempferol by stopping the activity of DFR **(A)** and **(B)** effect of a1 (DFR) mutation on maize seed pigmentation. Genes (enzymes) are abbreviated as follows: c2 (CHS), chalcone synthase; chi1 (CHI), chalcone isomerase; f3h (F3H), flavanone 3-hydroxylase; pr1 (F3′H), flavonone 3′-hydroxylase; a1 (DFR), dihydroflavonol synthase. In **(B)** R represent red color 1, a regulatory gene conferring anthocyanin pigmentation in the aleurone seed layer.

Bioavailability is the result of different processes: digestion, absorption, metabolism and elimination of a compound after food ingestion (137). Flavonoids are first metabolized by phase I and phase II metabolism which take place in the gastrointestinal tract and liver, and subsequently by microbial metabolism in the colon (140). Finally, urinary excretion and plasma concentrations of flavonols in humans could be used in epidemiological studies as biomarkers of intake (141). However, the bioavailability of these compounds varies between individuals and many factors such as age, sex, genotype, but also food composition may affect these metabolic processes (140).

Although some vegetables mentioned in **Supplementary Table 1** can be used as fresh products, the majority of flavonoid rich foods require a cooking process before being consumed (142). Such a process can modify the chemical-physical properties of any phytochemical as well as its bioavailability. The first losses of flavonoids may occur in the pre-cooking stages in cases where parts of the product are removed. Onion peeling resulted in a 39% loss of flavonoids and asparagus chopping produced an 18.5% decrease of the rutin content (143, 144). Considerable losses were also recorded in the peeling and dicing of tomatoes (145). Thermal processes (blanching, drying, pasteurization, microwaving etc) also have an impact on the flavonoid content which depends on the magnitude and duration of heating (142). The data reported by Ioannou and Ghoul revealed a different sensitivity to heat treatment for the different flavonoids in aqueous solution. In general, a significant degradation was observed for temperatures above 100°C (142). A higher stability compared to the aglycon form was however observed in rutin (146, 147). During boiling, a fraction of the flavonoids is released into the cooking water causing losses of 20.5% for onions and 43.9% for asparagus (144). Furthermore, onion frying processes diminish flavonoid content (25–33%) (148, 149), while microwaving and steaming do not have a significant effect (149, 150). In contrast, baking increases the total flavonol content in onions (7%) (150). The degradation of flavonoids depends also on other factors such as pH and the presence or absence of oxygen. In fact, the presence of oxygen accelerates the degradation of rutin and quercetin due to the formation of ROS (146, 147).

Ioannou et al. showed the effects of temperature, oxygen and light on naringin content (151). This compound is degraded at temperatures above 100°C, with an oxygen content over 85% or upon exposure to light. In fact, a decrease in the naringin content was recorded by applying 108°C (400 W microwave power). However, by setting the extraction temperature at 80°C, an increase in naringin was observed (151).

A mixture of flavonoids-rich foods is present in the sofrito, widely used in the Mediterranean diet (152). Sofrito is composed of several ingredients rich in phenolic compounds, such as tomatoes, onions and olive oil (153). Naringenin is the main flavonone present in fresh tomatoes and tomato sauces (154, 155)

TABLE 2 | Dishes rich in quercetin.

Dish	Ingredients	Indicative quantity (g/serving)	Quercetin content (mg/100 g)	Quercetin content (mg/serving)	Processing	Quercetin loss (%)	Quercetin intake after processing and cooking (mg/serving)	Quercetin intake after processing and cooking) (% RDA)	References
Salad	Radicchio (cv. Chioggia)	100	17	17	Fresh	–	17	0.34	(143)
	Onion (cv. Karmen)	40	254.9	102	Peeling, trimming	39%	62.2	12.44	
	Tomato (cv. Daniella)	100	43.6	43.6	Fresh	–	43.6	8.72	
	Capers	10	234	23.4	Fresh	–	23.4	4.68	
	Olive oil	q.s	–	–	–	–	–	–	
	Salt	q.s	–	–	–	–	–	–	
TOT			549.5	186	–	–	146.2	26.18	
Pasta with tomato sauce	Tomato sauce (cv. Daniella)	200	43.6	87.2	–	–	87.2	17.44	(159)
	Onion (cv. Karmen)	40	254.9	102	Peeling, trimming	39%	77.8	15.56	(143)
	Capers	10	234	23.4	Fresh	–	23.4	4.68	
	Pasta	80	–	–	–	–	–	–	
	Olive Oil	q.s	–	–	–	–	–	–	
	Salt	q.s	–	–	–	–	–	–	
TOT			488.9	125.4	–	–	101.2	37.68	
Polenta taragna	Buckwheat flour (cv. Valtellinese)	50	764	382	–	29%	271.2	54.24	(160)
	Corn flour	20	–	–	–	–	–	–	
	Water	300	–	–	–	–	–	–	
	Salt	q.s	–	–	–	–	–	–	
TOT			764	382			271.2	54.24	

[RDA inferred from (158)].

and its content in sofrito is higher compared to tomatoes. By adding 120 g of sofrito to different dishes (such as pasta), a phenolic compound intake of 15–25 mg occurs (152). Adding capers to the sofrito could be a good strategy to increase the content of quercetin and kaempferol. If we consider the possible daily intake of 20 capers (10 g), this will provide from 20 to 80 mg of quercetin (23).

In this context, the varieties richest in these bioactive natural compounds can be implemented in human diet in order to try to protect to some extent from COVID-19.

Considering only quercetin, one of the most abundant dietary flavonoids with a daily average intake of 25–50 g (156), several papers cited in the flavonoid section of this review claimed its physiological effects on inflammation and immune function in murine systems [reviewed by Li et al., (157)]. These effects are linked to a daily intake ranging from 10 to 160 mg per kg. In particular, considering the effect on pro-inflammatory and anti-inflammatory cytokines production, linked to the response to virus infection, the dosage effective on the rat system was reported to be about 10–20 mg/kg (158). From these data we could infer a recommended human daily intake of about 500 mg, considering an average body weight of 65 kg. Several dishes rich in quercetin could fully satisfy this recommended daily intake, with a possible positive effect on human health (**Table 2**).

CONCLUSIONS AND FUTURE PERSPECTIVES

This survey of the properties of several phytochemicals present in edible organs of many cultivated plants appears to support the concept that people hit all over the world by the COVID-19 pandemic can rely on a very easily usable tool that may contribute to prevent the disease and/or decrease its severe effects which are causing so much lethality. This tool is simply the integration into our diet of the natural foods which selectively implement the daily intake of a few bioactive phytochemicals proven to possess properties which provide some degree of protection against COVID-19. Such natural compounds have in fact been shown to be able to put in place mechanisms of prevention and/or even inhibition of viral infection/replication. The plant derived molecules of anti-Covid interest belong mostly but not exclusively to the chemical class of the flavonoids. In particular, the flavonol quercetin and the flavanones naringenin and hesperidin appear the best candidates to play the role of anti-Covid shelters, particularly because of their ubiquitous spread in many edible fruit and vegetables of large consumption in which they can be found at high levels. Curcumin, a phenolic compound present in *Curcuma longa* roots is another phytochemical of interest because it is largely extracted and used as a food dye, so it can be easily integrated into the diet. Among other phenolics displaying antiviral activity, phloretin is also to be taken into account as an anti-Covid shelter because it is rather ubiquitous in vegetables and fruits (among them, apples and pears) and epigallocatechin gallate (present mostly in green tea, onion, plum, apple skin) because, besides being endowed with antiviral properties, it displays potential for the mitigation of diseases characterized by a chronic inflammatory component. Finally, the sulfur compounds sulforaphanes, diffused in cruciferous plants such as broccoli, may be antiviral shelters of particular interest because their action relies on the activation of transcription factors which in turn switches on cell mechanisms responsible for antiviral effects. The major future perspectives for enhancing and diffusing the above cited, already known and highly desirable plant-derived biochemical weapons to fight COVID-19, can be summarized in three different strategies and some examples of each of them are reported in the preceding paragraphs. The first one consists in the rather easily doable rediscovery of ancient varieties naturally rich in these molecules; as concerns this approach, it is known that traditional varieties/ecotypes are often richer in phytonutrients than the newly synthesized varieties where the improvement was mainly focused on yield (116, 125, 161). The second strategy is the use of classic genetic improvement techniques to enhance specific accumulation of a given antiviral phytochemical. The third is the use of biotechnological approaches, nowadays available and quite effective, such as CRISPR/Cas9, which are able to activate or, conversely, to inactivate genes involved in the synthesis of specific antiviral phytochemicals leading to the accumulation of specific compounds.

Moreover, in order to modulate and optimize the "functional diet," it will be necessary to further increase information concerning the actual levels each phytochemical reaches in the blood following intake of food or of nutraceutical preparations endowed with anti-Covid potential. In this regard, in cases in which fruits or vegetables containing the anti-Covid phytochemical must be cooked to be consumed, it will be also necessary to investigate more accurately and extensively the fate of these molecules during the cooking process and determine their absorption rate and extent.

It is probable that in the next decades many other phytochemicals capable of fighting human viral diseases will be found in the edible parts of plants and thoroughly characterized, since much research is at present under way to achieve this goal. Indeed, it seems that nowadays there is an increasing tendency to prefer or juxtapose to the pharmaceutical therapies, preventive or (more rarely) curative treatments based on bioactive nutraceuticals extracted from plants. So, it does not seem impossible that in the future, whenever possible, many diseases will be fought more "naturally" through a more focused and specific education of people's diet.

AUTHOR CONTRIBUTIONS

RP, EN, and ML contributed to conception and design of the study. MG, FC, SS, and ML wrote the first draft of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2021.661331/full#supplementary-material

REFERENCES

1. Dai W, Zhang B, Su H, Li J, Zhao Y, Xie X, et al. Structure-based design of antiviral drug candidates targeting the SARS-CoV-2 main protease. *Science.* (2020) 368:1331–5. doi: 10.1126/science.abb4489
2. Zhou P, Yang XL, Wang XG, Hu B, Zhang L, Zhang W, et al. A pneumonia outbreak associated with a new coronavirus of probable bat origin. *Nature.* (2020) 579:270–3. doi: 10.1038/s41586-020-2012-7
3. Wu F, Zhao S, Yu B, Chen YM, Wang W, Song ZG, et al. A new coronavirus associated with human respiratory disease in China. *Nature.* (2020) 579:265–9. doi: 10.1038/s41586-020-2008-3
4. Lu R, Zhao X, Li J, Niu P, Yang B, Wu H, et al. Genomic characterisation and epidemiology of 2019 novel coronavirus: implications for virus origins and receptor binding. *Lancet.* (2020) 395:565–74. doi: 10.1016/S0140-6736(20)30251-8
5. World *Health* Organization. *Coronavirus Disease (COVID-19) Pandemic.* (2020). Available online at: https://www.who.int/emergencies/diseases/novel-coronavirus-2019 (accessed *March* 25, 2020)
6. Fehr AR, Perlman S. Coronaviruses: an overview of their replication and pathogenesis. *Methods Mol Biol.* (2015) 1282:1–23. doi: 10.1007/978-1-4939-2438-7_1
7. Schoeman D, Fielding BC. Coronavirus envelope protein: current knowledge. *Virol J.* (2019) 16:1–22. doi: 10.1186/s12985-019-1182-0
8. Zhong NS, Zheng BJ, Li YM, Poon LLM, Xie ZH, Chan KH, et al. Epidemiology and cause of severe acute respiratory syndrome (SARS) in Guangdong, People's Republic of China, in February, 2003. *Lancet.* (2003) 362:1353–8. doi: 10.1016/S0140-6736(03)14630-2
9. Puelles VG, Lutgehetmann M, Lindenmeyer MT, Sperhake JP, Wong MN, Allweiss L, et al. Multiorgan and renal tropism of SARSCoV-2. *N Engl J Med.* (2020) 383:590–2. doi: 10.1056/NEJMc2011400
10. Varga Z, Flammer AJ, Steiger P, Haberecker M, Andermatt R, Zinkernagel AS, et al. Endothelial cell infection and endotheliitis in COVID-19. *Lancet.* (2020) 395:1417–8. doi: 10.1016/S0140-6736(20)30937-5
11. The Lancet. Redefining vulnerability in the era of COVID-19. *Lancet.* (2020) 395:1089. doi: 10.1016/S0140-6736(20)30757-1
12. Gurwitz D. Angiotensin receptor blockers as tentative SARS-CoV-2 therapeutics. *Drug Dev Res.* (2020) 81:537–40. doi: 10.1002/ddr.21656
13. Letko M, Marzi A, Munster V. Functional assessment of cell entry and receptor usage for SARS-CoV-2 and other lineage B betacoronaviruses. *Nat Microbiol.* (2020) 5:562–9. doi: 10.1038/s41564-020-0688-y
14. Rabi FA, Al Zoubi MS, Kasasbeh GA, Salameh DM, Al-Nasser AD. SARS-CoV-2 and coronavirus disease 2019: what we know so far. *Pathogens.* (2020) 9:231. doi: 10.3390/pathogens9030231
15. Wrapp D, Wang N, Corbett KS, Goldsmith JA, Hsieh CL, Abiona O, et al. Cryo-EM structure of the 2019-nCoV spike in the prefusion conformation. *Science.* (2020) 367:1260–3. doi: 10.1126/science.abb2507
16. Xu X, Chen P, Wang J, Feng J, Zhou H, Li X, et al. Evolution of the novel coronavirus from the ongoing Wuhan outbreak and modeling of its spike protein for risk of human transmission. *Sci China Life Sci.* (2020) 63:457–60. doi: 10.1007/s11427-020-1637-5
17. Adedeji AO, Marchand B, Te Velthuis AJW, Snijder EJ, Weiss S, Eoff RL, et al. Mechanism of nucleic acid unwinding by SARS-CoV helicase. *PLoS ONE.* (2012) 7:e36521. doi: 10.1371/journal.pone.0036521
18. Russo M, Moccia S, Spagnuolo C, Tedesco I, Russo GL. Roles of flavonoids against coronavirus infection. *Chem Biol Interact.* (2020) 328:109211. doi: 10.1016/j.cbi.2020.109211
19. Solnier J, Fladerer JP. Flavonoids: a complementary approach to conventional therapy of COVID-19? *Phytochem Rev.* (2020) 1–23. doi: 10.1007/s11101-020-09720-6
20. Derosa G, Maffioli P, D'Angelo A, Di Pierro. F. A role for quercetin in coronavirus disease 2019 (COVID-19). *Phytother. Res.* (2020) 2020:1–7. doi: 10.1002/ptr.6887
21. Wojdyło A, Nowicka P, Grimalt M, Legua P, Almansa MS, Amorós A, et al. Polyphenol compounds and biological activity of caper (*Capparis spinosa* L.) flowers buds. *Plants.* (2019) 8:539. doi: 10.3390/plants8120539
22. Holasova M, Fiedlerova V, Smrcinova H, Orsak M, Lachman J, Vavreinova S. Buckwheat—the source of antioxidant activity in functional foods. *Int Food Res J.* (2002) 35:207–11. doi: 10.1016/S0963-9969(01)00185-5
23. Inocencio C, Rivera D, Alcaraz F, Tomás-Barberán FA. Flavonoid content of commercial capers (*Capparis spinosa*, sicula C. and *C. orientalis)* produced in Mediterranean countries. *Eur Food Res Technol.* (2000) 212:70–4. doi: 10.1007/s002170000220
24. Calderón-Montaño JM, Burgos-Morón E, Pérez-Guerrero C, López-Lázaro M. A review on the dietary flavonoid kaempferol. *Mini-Rev Med Chem.* (2011) 11:298–344. doi: 10.2174/138955711795305335
25. Ahmadian R, Rahimi R, Bahramsoltani R. Kaempferol: an encouraging flavonoid for COVID-19. *Bol latinoam Caribe Plantas Med Aromát.* (2020) 19:492–5. doi: 10.37360/blacpma.20.19.5.33
26. Tutunchi H, Naeini F, Ostadrahimi A, Hosseinzadeh-Attar MJ. Naringenin, a flavanone with antiviral and anti-inflammatory effects: a promising treatment strategy against COVID-19. *Phytother Res.* (2020) 34:3137–47. doi: 10.1002/ptr.6781
27. Ranka S, Gee JM, Biro L, Brett G, Saha S, Kroon P, et al. Development of a food frequency questionnaire for the assessment of quercetin and naringenin intake. *Eur J Clin Nutr.* (2008) 62:1131–8. doi: 10.1038/sj.ejcn.1602827
28. Wilcox LJ, Borradaile NM, Huff MW. Antiatherogenic properties of naringenin, a citrus flavonoid. *Cardiovasc Drug Rev.* (1999) 17:160–78. doi: 10.1111/j.1527-3466.1999.tb00011.x
29. Bellavite P, Donzelli A. Hesperidin and SARS-CoV-2: new light on the healthy function of citrus fruits. *Antioxidants.* (2020) 9:742. doi: 10.3390/antiox9080742
30. Haslberger A, Jacob U, Hippe B, Karlic H. Mechanisms of selected functional foods against viral infections with a view on COVID-19: mini review. *Funct Food Health Dis.* (2020) 10:195–209. doi: 10.31989/ffhd.v10i5.707
31. Liu Z, Ying Y. The inhibitory effect of curcumin on virus-induced cytokine storm and its potential use in the associated severe pneumonia. *Front Cell Dev Biol.* (2020) 8:479. doi: 10.3389/fcell.2020.00479
32. Behzad S, Sureda A, Barreca D, Nabavi SF, Rastrelli L, Nabavi SM. Health effects of phloretin: from chemistry to medicine. *Phytochem Rev.* (2017) 16:527–33. doi: 10.1007/s11101-017-9500-x
33. Zielinska D, Laparra-Llopis JM, Zielinski H, Szawara-Nowak D, Giménez-Bastida JA. Role of apple phytochemicals, phloretin and phloridzin, in modulating processes related to intestinal inflammation. *Nutrients.* (2019) 11:1173. doi: 10.3390/nu11051173
34. Menegazzi M, Campagnari R, Bertoldi M, Crupi R, Di Paola R, Cuzzocrea S. Protective effect of epigallocatechin-3-gallate (EGCG) in diseases with uncontrolled immune activation: could such a scenario be helpful to counteract COVID-19? *Int J Mol Sci.* (2020) 21:5171. doi: 10.3390/ijms21145171
35. Hung WL, Wang S, Sang S, Wan X, Wang Y, Ho CT. Quantification of ascorbyl adducts of epigallocatechin gallate and gallocatechin gallate in bottled tea beverages. *Food Chem.* (2018) 261:246–52. doi: 10.1016/j.foodchem.2018.04.050
36. Bousquet J, Anto J, Czarlewski W, Haahtela T, Fonseca S, Iaccarino G, et al. Sulforaphane: from death rate heterogeneity in countries to candidate for prevention of severe COVID-19. *Authorea.* (2020) 14:100498. doi: 10.22541/au.159493397.79345039

37. Thaler R, Maurizi A, Roschger P, Sturmlechner I, Khani F, Spitzer S, et al. Anabolic and antiresorptive modulation of bone homeostasis by the epigenetic modulator sulforaphane, a naturally occurring isothiocyanate. *J Biol Chem.* (2016) 291:6754–71. doi: 10.1074/jbc.M115.678235
38. Tapas DA, Sakarkar DM, Kakde R. Flavonoids as nutraceuticals: a review. *Trop J Pharm Res.* (2008) 7:1090–9. doi: 10.4314/tjpr.v7i3.14693
39. Monteleone G, Ardizzone S. Are patients with inflammatory bowel disease at increased risk for Covid-19 infection? *J. Crohns Colitis.* (2020) 14:1334–6. doi: 10.1093/ecco-jcc/jjaa061
40. Stebbing J, Phelan A, Griffin I, Tucker C, Oechsle O, Smith D, et al. COVID-19: Combining antiviral and antiinflammatory treatments. *Lancet Infect Dis.* (2020) 20:400–2. doi: 10.1016/S1473-3099(20)30132-8
41. Sharma M, Chai C, Morohashi K, Grotewold E, Snook ME, Chopra S. Expression of flavonoid 30-hydroxylase is controlled by P1, the regulator of 3-deoxyflavonoid biosynthesis in maize. *BMC Plant Biol.* (2012) 12:196. doi: 10.1186/1471-2229-12-196
42. Petroni K, Pilu R, Tonelli C. Anthocyanins in corn: a wealth of genes for human health. *Planta.* (2014) 240:901–911. doi: 10.1007/s00425-014-2131-1
43. Pilu R, Piazza P, Petroni K, Ronchi A, Martin C, Tonelli C. pl-bol3, a complex allele of the anthocyanin regulatory pl1 locus that arose in a naturally occurring maize population. *Plant J.* (2003) 36:510–21. doi: 10.1046/j.1365-313X.2003.01898.x
44. Pilu R, Bucci A, Casella L, Lago C, Badone FC, Cassani E, et al. A quantitative trait locus involved in maize yield is tightly associated to the r1 gene on the long arm of chromosome 10. *Mol Breed.* (2012) 30:799–807. doi: 10.1007/s11032-011-9664-9
45. Dooner HK, Robbins TP, Jorgensen RA. Genetic and developmental control of anthocyanin biosynthesis. *Annu Rev Genet.* (1991) 25:173–99. doi: 10.1146/annurev.ge.25.120191.001133
46. Wang HK, Xia Y, Yang ZY, Natschke SL, Lee KH. Recent advances in the discovery and development of flavonoids and their analogues as antitumor and anti-HIV agents. *Adv Exp Med Biol.* (1998) 439:191–225. doi: 10.1007/978-1-4615-5335-9_15
47. D'Amelia V, Aversano R, Chiaiese P, Carputo D. The antioxidant properties of plant flavonoids: their exploitation by molecular plant breeding. *Phytochem Rev.* (2018) 17:611–25. doi: 10.1007/s11101-018-9568-y
48. LeJeune TM, Tsui HY, Parsons LB, Miller GE, Whitted C, Lynch, et al. Mechanism of action of two flavone isomers targeting cancer cells with varying cell differentiation status. *PLoS ONE.* (2015) 10:e0142928. doi: 10.1371/journal.pone.0142928
49. Abreu AC, Coqueiro A, Sultan AR, Lemmens N, Kim HK, Verpoorte R, et al. Looking to nature for a new concept in antimicrobial treatments: isoflavonoids from Cytisus striatus as antibiotic adjuvants against MRSA. *Sci Rep.* (2017) 7:3777. doi: 10.1038/s41598-017-03716-7
50. Catarino MD, Talhi O, Rabahi A, Silva AMS, Cardoso SM. The antiinflammatory potential of flavonoids. *Stud Nat Prod Chem.* (2016) 48:65–99. doi: 10.1016/B978-0-444-63602-7.00003-5
51. Yang Y, Islam MS, Wang J, Li Y, Chen X. Traditional chinese medicine in the treatment of patients infected with 2019-new coronavirus (SARS-CoV-2): a review and perspective. *Int J Biol Sci.* (2020) 16:1708–17. doi: 10.7150/ijbs.45538
52. Nileeka Balasuriya BW, Vasantha Rupasinghe HP. Plant flavonoids as angiotensin converting enzyme inhibitors in regulation of hypertension. *Funct Food Health Dis.* (2011) 1:172–88. doi: 10.31989/ffhd.v1i5.132
53. Guerrero L, Castillo J, Quinones M, Garcia-Vallve,' S, Arola L, Pujadas G, et al. Inhibition of angiotensinconverting enzyme activity by flavonoids: structure-activity relationship studies. *PLoS ONE.* (2012) 7:e49493. doi: 10.1371/journal.pone.0049493
54. Actis-Goretta L, Ottaviani JI, Fraga CG. Inhibition of angiotensin converting enzyme activity by flavanol-rich foods. *J Agric Food Chem.* (2006) 54:229–34. doi: 10.1021/jf052263o
55. Chen L, Li J, Luo C, Liu H, Xu W, Chen G, et al. Binding interaction of quercetin-3-beta-galactoside and its synthetic derivatives with SARS-CoV 3CL(pro): structure-activity relationship studies reveal salient pharmacophore features. *Bioorg Med Chem.* (2006) 14:8295–306. doi: 10.1016/j.bmc.2006.09.014
56. Jo S, Kim H, Kim S, Shin DH, Kim M.-S. Characteristics of flavonoids as potent MERS-CoV 3C-like protease inhibitors. *Chem Biol Drug Des.* (2019) 94:2023–30. doi: 10.1111/cbdd.13604
57. Wang X, Yang Z, Su F, Li J, Boadi EO, Chang YX, et al. Study on structure activity relationship of natural flavonoids against thrombin by molecular docking virtual screening combined with activity evaluation in vitro. *Molecules.* (2020) 25:422. doi: 10.3390/molecules25020422
58. McKee DL, Sternberg A, Stange U, Laufer S, Naujokat C. Candidate drugs against SARS-CoV-2 and COVID-19. *Pharmacol Res.* (2020) 157:104859. doi: 10.1016/j.phrs.2020.104859
59. Srinivas NR. Structurally modified 'dietary flavonoids': are these viable drug candidates for chemoprevention? *Curr Clin Pharmacol.* (2009) 4:67–70. doi: 10.2174/157488409787236065
60. Ajazuddin SS. Applications of novel drug delivery system for herbal formulations. *Fitoterapia.* (2010) 81:680–9. doi: 10.1016/j.fitote.2010.05.001
61. Zhao J, Yang J, Xie Y. Improvement strategies for the oral bioavailability of poorly water-soluble flavonoids: an overview. *Int J Pharm.* (2019) 570:118642. doi: 10.1016/j.ijpharm.2019.118642
62. Mehany T, Khalifa I, Barakat H, Althwab SA, Alharbi YM, El-Sohaimy S. Polyphenols as promising biologically active substances for preventing SARS-CoV-2: A review with research evidence and underlying mechanisms. *Food Biosci.* (2021) 40:100891. doi: 10.1016/j.fbio.2021.100891
63. Pandey KB, Rizvi SI. Plant polyphenols as dietary antioxidants in human health and disease. *Oxid Med Cell Longev.* (2009) 2:270–8. doi: 10.4161/oxim.2.5.9498
64. Anand David AV, Arulmoli R, Parasuraman S. Overviews of biological importance of quercetin: a bioactive flavonoid. *Pharmacogn Rev.* (2016) 10:84–9. doi: 10.4103/0973-7847.194044
65. Lakhanpal P, Rai DK. Quercetin: A versatile flavonoid. *Internet J Med Update.* (2007) 2:22-37. doi: 10.4314/ijmu.v2i2.39851
66. Al Shukor N, van Camp J, Gonzales GB, Staljanssens D, Struijs K, Zotti MJ, et al. Angiotensinconverting enzyme inhibitory effects by plant phenolic compounds: a study of structure activity relationships. *J Agric Food Chem.* (2013) 61:11832–9. doi: 10.1021/jf404641v
67. Abian O, Ortega-Alarcon D, Jimenez-Alesanco A, Ceballos-Laita L, Vega S, Hugh T, et al. Structural stability of SARS-CoV-2 3CLpro and identification of quercetin as an inhibitor by experimental screening. *Int J Biol Macromol.* (2020) 164:1693–703. doi: 10.1016/j.ijbiomac.2020.07.235
68. Riaz A, Rasul A, Hussain G, Zahoor MK, Jabeen F, Subhani Z, et al. Astragalin: a bioactive phytochemical with potential therapeutic activities. *Adv Pharmacol Sci.* (2018) 2018:9794625. doi: 10.1155/2018/9794625
69. Kotani M, Matsumoto M, Fujita A, Higa S, Wang W, Suemura M, et al. Persimmon leaf extract and astragalin inhibit development of dermatitis and IgE elevation in NC/Nga mice. *J Allergy Clin Immunol.* (2000) 106:159–66. doi: 10.1067/mai.2000.107194
70. Bitis L, Kultur S, Melikoglu G, Ozsoy N, Can A. Flavonoids and antioxidant activity of Rosa agrestis leaves. *Nat Prod Res.* (2010) 24:580–9. doi: 10.1080/14786410903075507
71. Kim YH, Choi YJ, Kang MK, Park SH, Antika LD, Lee EJ, et al. Astragalin inhibits allergic inflammation and airway thickening in ovalbumin-challenged mice. *J Agric Food Chem.* (2017) 65:836–45. doi: 10.1021/acs.jafc.6b05160
72. Burmistrova O, Quintana J, Díaz JG, Estévez F. Astragalin heptaacetate-induced cell death in human leukemia cells is dependent on caspases and activates the MAPK pathway. *Cancer Lett.* (2011) 309:71–7. doi: 10.1016/j.canlet.2011.05.018
73. Bainey KR, Armstrong PW. Clinical perspectives on reperfusion injury in acute myocardial infarction. *Am Heart J.* (2014) 167:637–45. doi: 10.1016/j.ahj.2014.01.015
74. Felgines C, Texier O, Morand C, Manach C, Scalbert A, Régerat F, et al. Bioavailability of the flavanone naringenin and its glycosides in rats. *Am J Physiol Gastrointest Liver Physiol.* (2000) 279:1148–54. doi: 10.1152/ajpgi.2000.279.6.G1148
75. Manchope MF, Casagrande R, Verri WA Jr. Naringenin: an analgesic and anti-inflammatory citrus flavanone. *Oncotarget.* (2017) 8:3766–7. doi: 10.18632/oncotarget.14084
76. Choudhury R, Chowrimootoo G, Srai K, Debnam E, Rice-Evans CA. Interactions of the flavonoid naringenin in the gastrointestinal tract and the

influence of glycosylation. *Biochem Biophys Res Commun.* (1999) 265:410–5. doi: 10.1006/bbrc.1999.1695
77. Zobeiri M, Belwal T, Parvizi F, Naseri R, Farzaei MH, Nabavi S, et al. Naringenin and its nano-formulations for fatty liver: cellular modes of action and clinical perspective. *Curr Pharm.* (2018) 19:196–205. doi: 10.2174/1389201019666180514170122
78. Kanaze FI, Bounartzi MI, Georgarakis M, Niopas I. Pharmacokinetics of the citrus flavanone aglycones hesperetin and naringenin after single oral administration in human subjects. *Eur J Clin Nutr.* (2007) 61:472–7. doi: 10.1038/sj.ejcn.1602543
79. Erlund I, Meririnne E, Alfthan G, Aro A. Plasma kinetics and urinary excretion of the flavanones naringenin and hesperetin in humans after ingestion of orange juice and grapefruit juice. *J Nutr.* (2001) 131:235–41. doi: 10.1093/jn/131.2.235
80. Jung UJ, Kim HJ, Lee JS, Lee MK, Kim HO, Park EJ, et al. Naringin supplementation lowers plasma lipids and enhances erythrocyte antioxidant enzyme activities in hypercholesterolemic subjects. *Clin Nutr.* (2003) 22:561–8. doi: 10.1016/S0261-5614(03)00059-1
81. Renugadevi J, Prabu SM. Naringenin protects against cadmium-induced oxidative renal dysfunction in rats. *Toxicology.* (2009) 256:128–34. doi: 10.1016/j.tox.2008.11.012
82. Den Hartogh DJ, Tsiani E. Antidiabetic properties of naringenin: a citrus fruit polyphenol. *Biomolecules.* (2019) 9:1–21. doi: 10.3390/biom9030099
83. Cavia-Saiz M, Busto MD, Pilar-Izquierdo MC, Ortega N, Perez-Mateos M, Muñiz P. Antioxidant properties, radical scavenging activity and biomolecule protection capacity of flavonoid naringenin and its glycoside naringin: a comparative study. *J Sci Food Agric.* (2010) 90:1238–44. doi: 10.1002/jsfa.3959
84. Da Pozzo E, Costa B, Cavallini C, Testai L, Martelli A, Calderone V, et al. The citrus flavanone naringenin protects myocardial cells against age-associated damage. *Oxid Med Cell Longev.* (2017) 2017:1–12. doi: 10.1155/2017/9536148
85. Rashmi R, Magesh SB, Ramkumar KM, Suryanarayanan S, SubbaRao MV. Antioxidant potential of naringenin helps to protect liver tissue from streptozotocin-induced damage. *Rep Biochem Mol Biol.* (2018) 7:76–84.
86. Jayaraman J, Jesudoss VAS, Menon VP, Namasivayam N. Anti-inflammatory role of naringenin in rats with ethanol induced liver injury. *Toxicol Mech Methods.* (2012) 22:568–76. doi: 10.3109/15376516.2012.707255
87. Hernandez-Aquino E, Muriel P. Beneficial effects of naringenin in liver diseases: molecular mechanisms. *World J Gastroenterol.* (2018) 24:1679–707. doi: 10.3748/wjg.v24.i16.1679
88. Nogata Y, Sakamoto K, Shiratsuchi H, Ishii T, Yano M, Ohta H. Flavonoid composition of fruit tissues of citrus species. *Biosci Biotechnol Biochem.* (2006) 70:178–92. doi: 10.1271/bbb.70.178
89. Gattuso G, Barreca D, Gargiulli C, Leuzzi U, Caristi C. Flavonoid composition of citrus juices. *Molecules.* (2007) 12:1641–73. doi: 10.3390/12081641
90. Meneguzzo F, Ciriminna R, Zabini F, Pagliaro M. Review of evidence available on hesperidin-rich products as potential tools against COVID-19 and hydrodynamic cavitation-based extraction as a method of increasing their production. *Processes.* (2020) 8:549. doi: 10.3390/pr8050549
91. Praditya D, Kirchhoff L, Brüning J, Rachmawati H, Steinmann J, Steinmann E. Anti-infective properties of the golden spice curcumin. *Front Microbiol.* (2019) 10:912. doi: 10.3389/fmicb.2019.00912
92. Sindhu K, Rajaram A, Sreeram K, Rajaram R. Curcumin conjugated gold nanoparticle synthesis and its biocompatibility. *RSC Adv.* (2014) 4:1808–18. doi: 10.1039/C3RA45345F
93. Pietra, R. C. C. D. S., Cruz RC, Melo CN, Rodrigues LB, Santos PC, et al. Evaluation of polymeric PLGA nanoparticles conjugated to curcumin for use in aPDT. *Braz J Pharm Sci.* (2017) 53. doi: 10.1590/s2175-97902017000216043
94. Trigo Gutierrez JK, Zanatta GC, Ortega ALM, Balastegui MIC, Sanit,á PV, Pavarina AC, et al. Encapsulation of curcumin in polymeric nanoparticles for antimicrobial photodynamic therapy. *PLoS ONE.* (2017) 12:e0187418. doi: 10.1371/journal.pone.0187418
95. Shoba G, Joy D, Joseph T, Majeed M, Rajendran R, Srinivas PS. Influence of piperine on the pharmacokinetics of curcumin in animals and human volunteers. *Planta Med*. (1998) 64:353–6. doi: 10.1055/s-2006-957450
96. Gosch C, Halbwirth H, Kuhn J, Miosic S, Stich K. Biosynthesis of phloridzin in apple (Malus domestica Borkh.). *Plant Sci.* (2009) 176:223–31. doi: 10.1016/j.plantsci.2008.10.011
97. Barreca D, Bellocco E, Caristi C, Leuzzi U, Gattuso G. Kumquat (Fortunella japonica Swingle) juice: flavonoid distribution and antioxidant properties. *Food Res Int.* (2011) 44:2190–7. doi: 10.1016/j.foodres.2010.11.031
98. Rezk BM, Haenen GR, van der Vijgh WJ, Bast A. The antioxidant activity of phloretin: the disclosure of a new antioxidant pharmacophore in flavonoids. *Biochem Biophys Res Commun.* (2002) 295:9–13. doi: 10.1016/S0006-291X(02)00618-6
99. Nakamura Y, Watanabe S, Miyake N, Kohno H, Osawa T. Dihydrochalcones: evaluation as novel radical scavenging antioxidants. *J Agric Food Chem.* (2003) 51:3309–12. doi: 10.1021/jf0341060
100. Cabrera C, Artacho R, Giménez R. Beneficial effects of green tea: a review. *J Am Coll Nutr.* (2006) 25:79–99. doi: 10.1080/07315724.2006.10719518
101. Higdon JV, Frei B. Tea catechins and polyphenols: health effects, metabolism, antioxidant functions. *Crit Rev Food Sci Nutr.* (2003) 43:89–143. doi: 10.1080/10408690390826464
102. Khan N, Afaq F, Saleem M, Ahmad N, Mukhtar H. Targeting multiple signaling pathways by green tea polyphenol (-)-epigallocatechin-3-gallate. *Cancer Res.* (2006) 66:2500–5. doi: 10.1158/0008-5472.CAN-05-3636
103. Shankar S, Ganapathy S, Hingorani SR, Srivastava RK. EGCG inhibits growth, invasion, angiogenesis and metastasis of pancreatic cancer. *Front Biosci.* (2008) 13:440–52. doi: 10.2741/2691
104. Kuzuhara T, Iwai Y, Takahashi H, Hatakeyama D, Echigo N. Green tea catechins inhibit the endonuclease activity of influenza A virus RNA polymerase. *PLoS Curr.* (2009) 1:RRN1052. doi: 10.1371/currents.RRN1052
105. Nance CL, Siwak EB, Shearer WT. Preclinical development of the green tea catechin, epigallocatechin gallate, as an HIV-1 therapy. *J Allergy Clin Immunol.* (2009) 123:459–65. doi: 10.1016/j.jaci.2008.12.024
106. Ciesek S. The green tea polyphenol, epigallocatechin-3-gallate, inhibits hepatitis C virus entry. *Hepatology.* (2011) 54:1947–55. doi: 10.1002/hep.24610
107. Hartjen P, Frerk S, Hauber I, Matzat V, Thomssen A, Holstermann B, et al. Assessment of the range of the HIV-1 infectivity enhancing effect of individual human semen specimen and the range of inhibition by EGCG. *AIDS Res Ther.* (2012) 9:1–9. doi: 10.1186/1742-6405-9-2
108. Vázquez-Calvo A, de Oya NJ, Martín-Acebes MA, Garcia-Moruno E, Saiz JC. Antiviral properties of the natural polyphenols delphinidin and epigallocatechin gallate against the flaviviruses West Nile Virus, Zika Virus, Dengue Virus. *Front Microbiol.* (2017) 8:1314. doi: 10.3389/fmicb.2017.01314
109. Quirante-Moya S, Garcia-Ibanez P, Quirante-Moya F, Villano D, Moreno DA. The role of Brassica bioactives on human health: are we studying it the right way? *Molecules.* (2020) 25:1591. doi: 10.3390/molecules25071591
110. Houghton CA. Sulforaphane: Its "Coming of Age" as a clinically relevant nutraceutical in the prevention and treatment of chronic disease. *Oxid Med Cell Longev.* (2019) 2019:2716870. doi: 10.1155/2019/2716870
111. Jimenez-Osorio AS, Gonzalez-Reyes S, Pedraza-Chaverri J. Natural Nrf2 activators in diabetes. *Clin Chim Acta.* (2015) 448:182–92. doi: 10.1016/j.cca.2015.07.009
112. Tonelli C, Chio IIC, Tuveson DA. Transcriptional regulation by Nrf2. *Antioxid Redox Signal.* (2018) 29:1727–45. doi: 10.1089/ars.2017.7342
113. Ghafar MFA, Prasad KN, Weng KK, Ismail A. Flavonoid, hesperidine, total phenolic contents and antioxidant activities from Citrus species. *Afr J Biotechnol.* (2010) 9:326–30.
114. Gull T, Sultana B, Bhatti IA, Jamil A. Antibacterial potential of *Capparis spinosa* and *Capparis decidua* extracts. *Int J Agric Biol.* (2015) 17:727–33. doi: 10.17957/IJAB/14.0007
115. Gupta N, Sharma SK, Rana JC, Chauhan RS. Expression of flavonoid biosynthesis genes vis-à-vis rutin content variation in different growth stages of Fagopyrum species. *J Plant Physiol.* (2011) 168:2117–23. doi: 10.1016/j.jplph.2011.06.018
116. Giupponi L, Borgonovo G, Panseri S, Giorgi A. Multidisciplinary study of a little known landrace of Fagopyrum tataricum Gaertn. *of Valtellina (Italian Alps). Genet Resour Crop Evol.* (2019) 66:783–96. doi: 10.1007/s10722-019-00755-z

117. Winkel-Shirley B. Flavonoid biosynthesis. A colorful model for genetics, biochemistry, cell biology, and biotechnology. *Plant Physiol*. (2001) 126:485–93. doi: 10.1104/pp.126.2.485
118. Koja E, Ohata S, Maruyama Y, Suzuki H, Shimosaka M, Taguchi G. Identification and characterization of a rhamnosyltransferase involved in rutin biosynthesis in Fagopyrum esculentum (common buckwheat). *Biosci Biotechnol Biochem*. (2018) 82:1790–802. doi: 10.1080/09168451.2018.1491286
119. Reddy AR, Reddy GM. Genetic control of quercetin formation in the aleurone tissue of maize. *Genetics.* (1975) 81:287–92. doi: 10.1093/genetics/81.2.287
120. Vives-Vallés JA, Collonnier C. The judgment of the CJEU of 25 July 2018 on mutagenesis: interpretation and interim legislative proposal. *Front Plant Sci*. (2020) 10:1813. doi: 10.3389/fpls.2019.01813
121. Lago C, Landoni M, Cassani E, Doria E, Nielsen E, Pilu R. Study and characterization of a novel functional food: purple popcorn. *Mol Breed.* (2013) 31:575–85. doi: 10.1007/s11032-012-9816-6
122. Lago C, Cassani E, Zanzi C, Landoni M, Trovato R, Pilu R. Development and study of a maize cultivar rich in anthocyanins: coloured polenta, a new functional food. *Plant Breed.* (2014) 133:210–7. doi: 10.1111/pbr.12153
123. Lago C, Landoni M, Cassani E, Atanassiu S, Canta-Luppi E, Pilu R. Development and characterization of a coloured sweet corn line as a new functional food. *Maydica.* (2014) 59:191–200.
124. Lago C, Landoni M, Cassani E, Cantaluppi E, Doria E, Nielsen E, et al. Study and characterization of an ancient European flint white maize rich in anthocyanins: Millo Corvo from Galicia. *PloS ONE.* (2015) 10:e0126521. doi: 10.1371/journal.pone.0126521
125. Cassani E, Puglisi D, Cantaluppi E, Landoni M, Giupponi L, Giorgi A, et al. Genetic studies regarding the control of seed pigmentation of an ancient European pointed maize (Zea mays L.) rich in phlobaphenes: the "Nero Spinoso" from the Camonica valley. *Genet Resour Crop Evol.* (2017) 64:761–73. doi: 10.1007/s10722-016-0399-7
126. Landoni M, Puglisi D, Cassani E, Borlini G, Brunoldi G, Comaschi C, et al. Phlobaphenes modify pericarp thickness in maize and accumulation of the fumonisin mycotoxins. *Sci Rep.* (2020) 10:1417. doi: 10.1038/s41598-020-58341-8
127. Guarrera PM, Savo V. Perceived health properties of wild and cultivated food plants in local and popular traditions of Italy: A review. *J Ethnopharmacol.* (2013) 146:659–80. doi: 10.1016/j.jep.2013.01.036
128. Slimestad R, Fossen T, Vågen IM. Onions: a source of unique dietary flavonoids. *J Agric Food Chem.* (2007) 55:10067–80. doi: 10.1021/jf0712503
129. Justesen U, Knuthsen P. Composition of flavonoids in fresh herbs and calculation of flavonoid intake by use of herbs in traditional Danish dishes. *Food Chem.* (2001) 73:245–50. doi: 10.1016/S0308-8146(01)00114-5
130. Tomaino A, Martorana M, Arcoraci T, Monteleone D, Giovinazzo C, Saija A. Antioxidant activity and phenolic profile of pistachio (Pistacia vera L., variety Bronte) seeds and skins. *Biochimie.* (2010) 92:1115–22. doi: 10.1016/j.biochi.2010.03.027
131. Tardugno R, Pozzebon M, Beggio M, Del Turco P, Pojana G. Polyphenolic profile of *Cichorium intybus L.* endemic varieties from the Veneto region of Italy. *Food Chem*. (2018) 266: 175–82. doi: 10.1016/j.foodchem.2018.05.085
132. Kulczyński B, Kobus-Cisowska J, Kmiecik D, Gramza-Michałowska A, Golczak D, Korczak J. Antiradical capacity and polyphenol composition of asparagus spears varieties cultivated under different sunlight conditions. *Acta Sci Pol Technol Aliment*. (2016) 15:267–79. doi: 10.17306/J.AFS.2016.3.26
133. Carmona M, Sánchez AM, Ferreres F, Zalacain A, Tomás-Barberán F, Alonso GL. Identification of the flavonoid fraction in saffron spice by LC/DAD/MS/MS: comparative study of samples from different geographical origins. *Food Chem.* (2007) 100:445–50. doi: 10.1016/j.foodchem.2005.09.065
134. Giuffrida D, Salvo F, Ziino M, Toscano G, Dugo G. Initial investigation on some chemical constituents of capers (*Capparis spinosa* L.) from the island of Salina. *Ital. J Food Sci.* (2002) 14:25–33.
135. Alam MA, Subhan N, Rahman MM, Uddin SJ, Reza HM, Sarker SD. Effect of citrus flavonoids, naringin and naringenin, on metabolic syndrome and their mechanisms of action. *Adv Nutr.* (2014) 5:404–417. doi: 10.3945/an.113.005603
136. Martínez I, Periago MJ, Provan G, Chesson A. Phenolic compounds, lycopene and antioxidant activity in commercial varieties of tomato (Lycopersicon esculentum). *J Sci Food Agric*. (2002) 82:323–30. doi: 10.1002/jsfa.1035
137. Rein MJ, Renouf M, Cruz-Hernandez C, Actis-Goretta L, Thakkar SK, da Silva Pinto M. Bioavailability of bioactive food compounds: a challenging journey to bioefficacy. *Br J Clin Pharm.* (2013) 75:588–602. doi: 10.1111/j.1365-2125.2012.04425.x
138. Benito P, Miller D. Iron absorption and bioavailability: an updated review. *Nutr Res.* (1998) 18:581–603. doi: 10.1016/S0271-5317(98)00044-X
139. Fernàndez-Garcìa E, Carvajal-Lérida I, Pérez-Gàlvez A. In vitro bioaccessibility assessment as a prediction tool of nutritional efficiency. *Nutr Res.* (2009) 29:751–60. doi: 10.1016/j.nutres.2009.09.016
140. Cassidy A, Minihane AM. The role of metabolism (and the microbiome) in defining the clinical efficacy of dietary flavonoids. *Am J Clin Nutr.* (2017) 105:10–22. doi: 10.3945/ajcn.116.136051
141. De Vries JH, Hollman PC, Meyboom S, Buysman MN, Zock PL, van Staveren WA, et al. Plasma concentrations and urinary excretion of the antioxidant flavonols quercetin and kaempferol as biomarkers for dietary intake. *Am J Clin Nutr.* (1998) 68:60–5. doi: 10.1093/ajcn/68.1.60
142. Ioannou I, Ghoul M. Biological activities and effects of food processing on flavonoids as phenolic antioxidants. *Adv Appl Microbiol.* (2012) 101–24. doi: 10.5772/30690
143. Ewald C, Fjelkner-Moding S, Johansson K, Sjoholm I, Akesson B. Effect of processing on major flavonoids in processed onions, green beans, and peas. *Food Chem.* (1999) 64:231–5. doi: 10.1016/S0308-8146(98)00136-8
144. Makris DP, Rossiter JT. Domestic processing of onion bulbs (Allium cepa) and asparagus spears (Asparagus officinalis): effect on flavonol content and antioxidant status. *J Agric Food Chem.* (2001) 49:3216–22. doi: 10.1021/jf001497z
145. Valverdú-Queralt A, Medina-Remón A, Andres-Lacueva C, Lamuela-Raventos RM. Changes in phenolic profile and antioxidant activity during production of diced tomatoes. *Food Chem.* (2011) 126:1700–7. doi: 10.1016/j.foodchem.2010.12.061
146. Makris DP, Rossiter JT. Heat-induced, metal-catalyzed oxidative degradation of quercetin and rutin (Quercetin 3-O-Rhamnosylglucoside) in aqueous model. *J Agric Food Chem.* (2000) 48:3830–8. doi: 10.1021/jf0001280
147. Buchner N, Krumbein A, Rhon S, Kroh LW. Effect of thermal processing on the flavonols rutin and quercetin. *Rapid Commun Mass Spectrom.* (2006) 20:3229–35. doi: 10.1002/rcm.2720
148. Price KR, Bacon JR, Rhodes MJC. Effect of storage and domestic processing on the content and composition of flavonol glucosides in onion (Allium cepa). *J Agric Food Chem.* (1997) 45:938–42. doi: 10.1021/jf9605916
149. Lee SU, Lee JH, Choi SH, Lee JS, Ohnisi-Kameyama M, Kozukue N, et al. Flavonoid content in fresh, home-processed, and light-exposed onions and in dehydrated commercial onion products. *J Agric Food Chem.* (2008) 56:8541–8. doi: 10.1021/jf801009p
150. Lombard K, Peffley E, Geoffriau E, Thompson L, Herring A. Quercetin in onion (Allium cepa L.) after heat-treatment simulating home preparation. *J Food Compos Anal.* (2005) 18:571–81. doi: 10.1016/j.jfca.2004.03.027
151. Ioannou I, M'hiri N, Chaaban H, Boudhrioua NM, Ghoul M. Effect of the process, temperature, light and oxygen on naringin extraction and the evolution of its antioxidant activity. *J Food Sci Technol.* (2018) 53:2754–60. doi: 10.1111/ijfs.13887
152. Storniolo CE, Sacanella I, Mitjavila MT, Lamuela-Raventos RM, Moreno JJ. Bioactive compounds of cooked tomato sauce modulate oxidative stress and arachidonic acid cascade induced by oxidized LDL in macrophage cultures. *Nutrients.* (2019) 11:1880. doi: 10.3390/nu11081880
153. Valverdú-Queralt A, Rinaldi de Alvarenga JF, Estruch R, Lamuela-Raventos RM. Bioactive compounds present in the *Mediterranean sofrito*. *Food Chem.* (2013) 141:3365–72. doi: 10.1016/j.foodchem.2013.06.032

154. Yoshimura M, *Sano* A, *Kamei* JI, *Obata*, A. Identification and quantification of metabolites of orally administered naringenin chalcone in rats. *J Agric Food Chem*. (2009) 57:6432–7. doi: 10.1021/jf901137x
155. Martínez-Huelamo M, Tulipani S, Estruch R, Escribano E, Ilan M, Corella D, et al. The tomato sauce making process affects the bioaccessibility and bioavailability of tomato phenolics: a pharmacokinetic study. *Food Chem.* (2015) 173:864–72. doi: 10.1016/j.foodchem.2014.09.156
156. Formica JV, Regelson W. Review of the biology of quercetin and related bioflavonoids. *Food Chem Toxicol.* (1995) 33:1061–80. doi: 10.1016/0278-6915(95)00077-1
157. Li M, Zhu X, Tian J, Liu M, Wang G. Dietary flavonoids from Allium mongolicum Regel promotes growth, improves immune, antioxidant status, immune-related signaling molecules and disease resistance in juvenile northern snakehead fish (Channa argus). *Aquac Res.* (2019) 501:473–81. doi: 10.1016/j.aquaculture.2018.12.011
158. Milenković M, Arsenović-Ranin N, Stojić-Vukanić Z, Bufan B, Vučićević D, Jančić I. Quercetin ameliorates experimental autoimmune myocarditis in rats. *Int J Pharm Pharm Sci.* (2010) 13:311–9. doi: 10.18433/J3VS3S
159. Bugianesi R, Catasta G, Spigno P, D'Uva A, Maiani G. Naringenin from cooked tomato paste is bioavailable in men. *J Nutr.* (2002) 132:3349–52. doi: 10.1093/jn/132.11.3349
160. Germ M, Árvay J, Vollmannová A, Tóth T, Golob A, Luthar Z, et al. The temperature threshold for the transformation of rutin to quercetin in Tartary buckwheat dough. *Food Chem*. (2019) 283:28–31. doi: 10.1016/j.foodchem.2019.01.038
161. Giupponi L, Pilu R, Scarafoni A, Giorgi A. Plant agro-biodiversity needs protection, study and promotion: results of research conducted in Lombardy region (Northern Italy). *Biodivers Conserv*. (2020) 29:409–30. doi: 10.1007/s10531-019-01889-3
162. Sun T, Xu Z, Wu CT, Janes M, Prinyawiwatkul W, No HK. Antioxidant activities of different colored sweet bell peppers (*Capsicum annuum* L.). *J Food Sci.* (2007) 72:98–102. doi: 10.1111/j.1750-3841.2006.00245.x

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Impact of Crop Diversity on Dietary Diversity Among Farmers in India During the COVID-19 Pandemic

Kaela Connors[1], Lindsay M. Jaacks[1,2], Poornima Prabhakaran[3], Divya Veluguri[1,2], G. V. Ramanjaneyulu[4] and Aditi Roy[3]*

[1] Department of Global Health and Population, Harvard T.H. Chan School of Public Health, Harvard University, Boston, MA, United States, [2] Global Academy of Agriculture and Food Security, The University of Edinburgh, Edinburgh, United Kingdom, [3] Public Health Foundation of India, New Delhi, India, [4] Centre for Sustainable Agriculture, Hyderabad, India

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***Correspondence:**
Lindsay M. Jaacks
lindsay.jaacks@ed.ac.uk

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Crop diversity is thought to have small, positive impacts on dietary diversity among farming households, particularly when market access is restricted. Policy responses to the COVID-19 pandemic severely restricted market access. To date, no study has explored the relationship between crop and dietary diversity in this context. To address this gap, we used longitudinal data collected from 833 farmers across 12 states in India at three time points between May and August 2020. Dietary diversity was measured using a modified version of the FAO Minimum Dietary Diversity score for women, which has been used in representative samples of the Indian population in both men and women. Eight food groups were included: (1) starchy staples (rice, wheat, and potatoes), (2) pulses, (3) nuts, (4) vegetables, (5) fruits, (6) dairy, (7) eggs, and (8) fleshy foods (meat, poultry, and fish). Multivariate polynomial logistic regression was used to estimate the association between crop and dietary diversity. Models were adjusted for educational attainment, caste, farm size, having a kitchen garden, and livestock ownership. Participants were, on average, 42.2 years old and 94.2% were male. Dietary diversity decreased over the study period, especially between baseline and follow-up 1, when lockdown measures were the most restrictive (34.2% of participants experienced a decline compared to 16.1% from follow-up 1 to follow-up 2). Compared to farmers who cultivated 1 crop (monocroppers), farmers who cultivated 2 crops or 3 or more crops were significantly less likely to experience a decline in dietary diversity from baseline to follow-up 1: adjusted relative risk (RR) (95% confidence interval [CI]), 0.52 (0.35, 0.78) and 0.48 (0.31, 0.75), respectively. There was no significant association between crop diversity and change in dietary diversity from follow-up 1 to follow-up 2, when phased re-opening had begun. These findings suggest that farmers with greater crop diversity in India were more resilient to market disruptions from the COVID-19 pandemic. Thus, while the links between crop and dietary diversity may be small under normal circumstances, diversifying production systems may play an increasingly important role, as there is greater uncertainty due to global events such as pandemics and climate change.

Keywords: agriculture, biodiversity, crop diversity, nutrition, nutrition-sensitive agriculture, minimum dietary diversity, South Asia

INTRODUCTION

At the onset of the COVID-19 pandemic, India imposed the world's largest national lockdown. In addition to physical disruptions in the transport of agricultural products and restrictions on the movement of labor, the loss of livelihoods in urban centers resulted in a drop in demand, particularly for high-value products such as fruit, vegetables, and animal-source foods. Before the pandemic, farmers in India were already experiencing economic distress (NABARD, 2018) and carried the greatest malnutrition burden (Ministry of Health and Family Welfare, 2016). Understanding the impact of COVID-19 on agricultural production and diet quality among farmers is critical to informing targeted government action in the context of this pandemic and future shocks.

There are multiple pathways from agriculture to nutrition (Dizon et al., 2021); among them, the link between crop diversity and dietary diversity has been a major focus of research in the past 10 years. However, a recent meta-analysis of 45 studies from 26 countries found little evidence that diversifying production has a meaningful impact on dietary diversity—and if it does, the impact is very small (Sibhatu and Qaim, 2018). In India, two studies have found small, positive associations between crop diversity and dietary diversity (Bhagowalia et al., 2012; Singh et al., 2020), but three have found no association (Chinnadurai et al., 2016; Kavitha et al., 2016; Gupta et al., 2020a). All of these studies were cross-sectional. Nonetheless, the Government of India has prioritized nutrition-sensitive agriculture and especially the diversification of crops by bolstering "traditional" crops such as millets (Irani, 2019). Therefore, continuing to elucidate the relationship between crop diversity and dietary diversity is important in this context.

There are two pathways by which crop diversification can influence dietary diversity: (1) through own-consumption and (2) through household income and the purchasing of food from markets (Dizon et al., 2021). The first of these pathways is important when access to markets is limited, such was the case during the COVID-19 lockdown. Since consumption of food produced on-farm is generally low in India and markets play an influential role in improving dietary diversity (Nandi et al., 2021), studying the impact of the lockdown on dietary diversity among farmers provides unique insights into the role of crop diversity on farmer nutrition when market access is restricted. To date, no study has evaluated the association of crop diversity and dietary diversity in the context of the COVID-19 pandemic and prior to the pandemic, very few studies evaluated this association longitudinally. Given the need for immediate action to mitigate the impact of the COVID-19 lockdown on food and nutrition security, and widespread interest in crop diversification as a means to improve diets and nutritional outcomes, including from the Government of India, such evidence is timely and has immediate policy and programmatic impacts. Our aim was to quantify the association between crop diversity (number of crops cultivated in Kharif [monsoon] 2020) and change in dietary diversity over the course of the pandemic (May to August 2020). We hypothesized that farming households cultivating a greater diversity of crops would be less likely to experience a decline in dietary diversity as the pandemic progressed.

METHODS

Survey Sample

Details of the study design have been published elsewhere (Jaacks et al., 2021). Briefly, participant recruitment was initiated through a list of contacts generated by a civil society organization network. Snowball sampling was used to contact additional farmers beyond those on this initial list. We recruited participants from the top 12 agricultural producing states in India: Andhra Pradesh, Bihar, Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Punjab, Rajasthan, Telangana, Uttar Pradesh, and West Bengal. To participate, respondents had to be 18 years or older and belong to an agricultural household, which could be any combination of the following: own land, harvest a crop in the past month irrespective of land ownership, earn a daily wage or contract-based wage from agricultural labor, or earn an income from livestock or fishing.

The baseline survey was conducted from 3 to 15 May 2020. The first follow-up survey was conducted from 3 to 19 June 2020 and the second follow-up survey from 20 July to 12 August 2020. Thus, the baseline survey coincided with the Rabi (winter) season harvest and both follow-up surveys coincided with the Kharif (monsoon) season sowing. With regards to how these dates aligned with the COVID-19 pandemic and government response, the baseline survey coincided with the nation-wide complete lockdown that started on 25 March 2020. Both follow-up surveys were conducted at a time when phased re-opening was occurring, starting on 8 June 2020. Also at that time, many states began distributing take-home rations through the Public Distribution System (PDS) beyond normal coverage.

Ethics

The study protocol was reviewed and approved by the Harvard T.H. Chan School of Public Health Institutional Review Board (Protocol #: IRB20-0689) and the Public Health Foundation of India Institutional Ethics Committee (Protocol #: TRC-IEC 438/20). Verbal informed consent was obtained from all participants.

Data Collection

Survey interviews were carried out over the phone and responses were recorded by trained enumerators using Qualtrics (Qualtrics, Provo, Utah, USA). The baseline survey took ∼15–30 min to complete, and the follow-up 1 and 2 surveys took ∼20 and 10 min to complete, respectively. The survey instrument was translated into eight languages and enumerators assigned to each state were native speakers of the language spoken there.

This analysis focused on survey questions relating to cropping patterns and diet. Questions on cropping patterns were adapted from Government of India surveys (Ministry of Statistics and Programme Implementation, 2013; Agriculture Census, 2016) with input from agricultural experts. Respondents reported cultivated land area in local units, and these were converted to hectares. At baseline (Rabi), we only asked about the primary crop harvested (defined as the crop for which the participant made the most money) and the total land harvested for that crop. During follow-up, we asked about all different types of crops sown and the land sown for each of these crops in Kharif 2020 and

2019. Given the distribution of the number of crops cultivated in Kharif (**Supplementary Figure 1**), we categorized participants as cultivators of 1 crop, 2 crops, or 3 or more crops. The primary exposure variable was crop diversity category in Kharif 2020.

We used dietary diversity in our assessment because it is an important predictor of adequate nutrient intake and a proxy for diet quality (Miller et al., 2020). Questions on diet were derived from the FAO's Minimum Dietary Diversity for Women (MDD) (FAO, 2016). Eight food groups were included: (1) starchy staples (rice, wheat, and potatoes), (2) pulses, (3) nuts, (4) vegetables, (5) fruits, (6) dairy, (7) eggs, and (8) fleshy foods (meat, poultry, and fish). Vegetables and fruits were not divided further into dark green leafy vegetables and vitamin A-rich fruits and vegetables vs. other vegetables and fruits because we were conducting telephone interviews and had to simplify the survey as much as possible to maximize participant engagement and data quality. Those who consumed a food group every day in the past week were assigned a value of "1" and those who did not were assigned a value of "0" and the values across these eight food groups were summed. Thus, the dietary diversity score ranged from 0 to 8 with 8 representing maximum dietary diversity. Low dietary diversity was defined as MDD$<$4 and high dietary diversity was defined as MDD $>=$ 4. The two primary outcomes were changes in dietary diversity from (1) baseline to follow-up 1 and (2) follow-up 1 to follow-up 2, categorized as no change, decrease, or increase.

Covariates included respondent age, educational attainment, household size, having children under 5 years of age in the household, caste, farm size, livestock ownership, and having a kitchen garden. These covariates were determined through a literature review of the association between crop diversity and dietary diversity (Adjimoti and Kwadzo, 2018; Deb and Bayes, 2018; Gupta et al., 2020a). The minimum adjustment set was determined using a Directed Acyclic Graph (**Supplementary Figure 2**) and DAGitty software (Textor et al., 2016). Respondent age, educational attainment, household size, livestock ownership, and farm size were recorded at baseline. Livestock ownership included owning any number of the following: cows/buffalo/oxen/bulls, poultry, or goats/sheep. Farm size was categorized according to land ownership as: landless (0 ha), small/marginal farms (0.01–2.00 ha), medium farms (2.01–4.00 ha), and large farms ($>$4.00 ha) (Agriculture Census, 2016). Information on respondent's caste, having children under 5 years of age in the household, and having a kitchen garden were recorded at follow-up 1.

Statistical Analysis

Data management and statistical analyses were carried out using STATA version 16 (StataCorp, College Station, Texas, USA). A $p < 0.05$ was considered statistically significant. We conducted a complete-case analysis. Baseline demographic characteristics were compared between those included in the complete-case analysis and those lost to follow-up using chi-square tests for categorical variables and t-tests for continuous variables. Descriptive statistics were used to summarize demographic characteristics of participants (age, educational attainment, household size, children under 5 years of age in the household, and caste), livestock ownership, having a kitchen garden, and farm size, for the total sample and according to (1) change in dietary diversity from baseline to follow-up 1 and (2) crop diversity in Kharif 2020. We described changes over time in both crop and dietary diversity and tested for differences over time using chi-square tests for categorical variables and one-way ANOVA for continuous variables.

The association between crop diversity in Kharif 2020 and change in dietary diversity between (1) baseline and follow-up 1 and (2) follow-up 1 and follow-up 2 was estimated using multivariate polynomial logistic regression. Models were adjusted for educational attainment, caste, farm size, kitchen garden, and livestock ownership as per the minimal adjustment set of covariates from the DAG.

In sensitivity analyses, we constructed the Simpson's Index as an alternate measure of crop diversity that considers both the land area used for cultivation and number of crops cultivated (Adjimoti and Kwadzo, 2018). The Simpson's Index has been previously found to be associated with increased dietary diversity and food security status (Kavitha et al., 2016; Adjimoti and Kwadzo, 2018; Deb and Bayes, 2018; Chegere and Stage, 2020). The total score ranges between 0 and 1 where 0 corresponds to monocropping and 1 to highest achievable crop diversity. It was calculated for landowning farmers using the following equation:

$$\text{Simpson's Index} = 1 - \sum_{1}^{n} P_i^2 \tag{1}$$

where P_i is the area proportion of the i-th crop in the gross cropped area and n is the total number of crops cultivated per farm. We used multivariate polynomial logistic regression adjusting for the same covariates as in our main analysis to assess the association between the Simpson's Index in Kharif 2020 and change in individual dietary diversity.

In an additional sensitivity analysis, because there could potentially be some differences in cropping patterns from 2019 to 2020, we used the same multivariate polynomial logistic regression as for our main analysis but used crop diversity in Kharif 2019 as the exposure in lieu of crop diversity in Kharif 2020.

RESULTS

Participants were, on average, 42.2 years old (range: 18–78 years) and 94.2% were male (**Table 1**). Almost half of participants (46.3%) belonged to 6 or more person households. There were no statistically significant differences between those with complete data ($n = 833$) and those lost to follow-up ($n = 604$) (**Supplementary Table 1**).

Demographic characteristics according to change in dietary diversity from baseline to follow-up 1 are shown in **Table 1**. Those with no change in dietary diversity tended be older, have lower educational attainment, belong to a scheduled caste/tribe, have cultivated 2 crops in Kharif 2020, and have income from wages (all $p < 0.05$; **Table 1**). They also were less likely to have children $<$5 years in the household and a kitchen garden (both $p < 0.05$; **Table 1**). Those with an increase in dietary diversity

TABLE 1 | Demographic characteristics of participants from agricultural households across 12 states in India during the COVID-19 pandemic, according to change in dietary diversity from baseline (May 2020) to follow-up 1 (June 2020) ($n = 833$).

	Total ($n = 833$)	No change in dietary diversity* ($n = 421$)	Decrease in dietary diversity* ($n = 285$)	Increase in dietary diversity* ($n = 127$)	*P*-value†
Gender					
Male	94.2 (785)	93.3 (393)	94.4 (269)	96.9 (123)	0.33
Female	5.8 (48)	6.7 (28)	5.6 (16)	3.1 (4)	
Age, years	42.2 (12.5)	43.4 (12.6)	41.1 (12.5)	40.7 (11.6)	0.02
Household size					
1–3	9.8 (82)	10.2 (43)	8.8 (25)	11.0 (14)	0.15
4	23.3 (194)	27.1 (114)	21.1 (60)	15.7 (20)	
5	20.5 (171)	19.5 (82)	21.8 (62)	21.3 (27)	
6 or more	46.3 (386)	43.2 (182)	48.4 (138)	52.0 (66)	
Educational attainment					
No formal schooling/primary school	33.3 (277)	38.5 (162)	24.6 (70)	35.7 (45)	0.01
Secondary school	38.2 (318)	36.1 (152)	43.2 (123)	34.1 (43)	
Grad/post grad/professional	28.5 (237)	25.4 (107)	32.3 (92)	30.2 (38)	
Caste					
Scheduled caste/tribe	23.6 (195)	29.3 (123)	16.0 (45)	21.3 (27)	0.01
Backward caste	37.2 (308)	33.8 (142)	41.6 (117)	38.6 (49)	
Other/no answer	39.3 (325)	36.9 (155)	42.3 (119)	40.2 (51)	
Children <5 years, % yes	34.5 (287)	28.7 (121)	38.9 (111)	43.3 (55)	0.01
Farm size					
Landless (0 ha)	6.4 (53)	6.9 (29)	6.8 (19)	4.0 (5)	0.21
Small/marginal (0.01–2.00 ha)	51.2 (423)	48.7 (205)	54.3 (152)	52.8 (66)	
Medium (2.01–4.00 ha)	18.9 (156)	21.4 (90)	13.9 (39)	21.6 (27)	
Large (>4.00 ha)	23.5 (194)	23.0 (97)	25.0 (70)	21.6 (27)	
Crop diversity (Kharif 2020)					
1 crop	45.4 (352)	38.0 (149)	61.8 (162)	33.9 (41)	<0.01
2 crops	28.0 (217)	31.9 (125)	22.1 (58)	28.1 (34)	
3 or more crops	26.6 (206)	30.1 (118)	16.0 (42)	38.0 (46)	
Simpson's index‡	0.24 (0.26)	0.29 (0.27)	0.15 (0.23)	0.29 (0.26)	<0.01
Livestock ownership, % yes	76.8 (640)	78.1 (329)	74.4 (212)	78.0 (99)	0.48
Income from livestock, % yes	26.7 (171)	28.6 (94)	24.1 (51)	26.3 (26)	0.51
Income from wages, % yes	32.0 (259)	35.7 (147)	25.2 (70)	35.0 (42)	0.01
Received food rations, % yes	47.5 (394)	47.1 (198)	51.2 (146)	40.0 (50)	0.11
Kitchen garden, % yes	55.0 (458)	47.7 (201)	65.3 (186)	55.9 (71)	<0.01

Values are percent (n) or mean (SD).

**Dietary diversity score calculated based on consumption of eight food groups over the past 7 days including: (1) starchy staples (rice, wheat, and potatoes), (2) pulses, (3) nuts, (4) vegetables, (5) fruits, (6) dairy, (7) eggs, and (8) fleshy foods (meat, poultry, and fish). Those who consumed a food group every day in the past week were assigned a value of "1" and those who did not were assigned a value of "0" and the values across these eight food groups were summed. Thus, the dietary diversity score ranged from 0 to 8 with 8 representing maximum dietary diversity.*

†P-value from chi-square test for categorical variables and one-way ANOVA for continuous variables.

‡Simpson's Index calculated using the equation: Simpson's Index = $1 - \sum_1^n P_i^2$ where P_i is the area proportion of the i-th crop in the gross cropped area and n is the total number of crops cultivated per farm. Values range from 0 to 1 where 0 corresponds to monocropping and 1 to the highest achievable crop diversity.

tended to be younger, have children <5 years in the household, and to have cultivated 3 or more crops in Kharif 2020 (all $p < 0.05$; **Table 1**). Those who experienced a decrease in dietary diversity had higher levels of education, were least likely to belong to a scheduled caste/tribe, and were most likely to have cultivated 1 crop in Kharif 2020 and have a kitchen garden (all $p < 0.05$; **Table 1**).

Demographic characteristics according to crop diversity in Kharif 2020 are shown in **Table 2**. Those who cultivated 1 crop in Kharif 2020 had higher educational attainment, were more likely to belong to other/no answer caste category, and to have a kitchen garden, and less likely to have income from wages and own livestock (all $p < 0.05$; **Table 2**). Those who cultivated 2 crops were most likely to own a large farm ($p = 0.03$; **Table 2**). Those who cultivated 3 or more crops tended to have lower educational attainment and were most likely to belong to a scheduled caste/tribe, own livestock, and earn an income from wages,

TABLE 2 | Demographic characteristics of participants from agricultural households across 12 states in India during the COVID-19 pandemic, according to number of crops cultivated in Kharif 2020 (n = 775).

	Total (n = 775)	Cultivated 1 crop (n = 352)*	Cultivated 2 crops (n = 217)*	Cultivated 3 or more crops (n = 206)*	P-value†
Gender					
Male	95.2 (738)	93.5 (329)	96.8 (210)	96.6 (199)	0.111
Female	4.8 (37)	6.5 (23)	3.2 (7)	3.0 (7)	
Age, years	42.41 (12.57)	42.45 (13.15)	41.62 (12.95)	43.15 (11.05)	0.458
Household size					
1–3	9.5 (74)	11.1 (39)	10.1 (22)	6.3 (13)	0.501
4	22.7 (176)	21.6 (76)	23.5 (51)	23.8 (49)	
5	20.4 (158)	21.9 (77)	17.5 (38)	20.9 (43)	
6 or more	47.4 (367)	45.5 (160)	48.8 (106)	49.0 (101)	
Educational attainment					
No formal schooling/primary school	31.1 (241)	23.6 (83)	34.1 (74)	41.0 (84)	<0.001
Secondary school	39.1 (303)	41.8 (147)	36.9 (80)	37.1 (76)	
Grad/post grad/professional	29.7 (230)	34.7 (122)	29.0 (63)	22.0 (45)	
Caste					
Scheduled caste/tribe	21.7 (167)	11.2 (39)	26.4 (57)	34.5 (71)	<0.001
Backward caste	39.1 (301)	40.2 (140)	37.5 (81)	38.8 (80)	
Other/no answer	39.2 (302)	48.6 (122)	36.1 (78)	26.7 (55)	
Children <5 years, % yes	34.8 (270)	33.8 (119)	34.1 (74)	37.4 (77)	0.669
Farm size					
Landless (0 ha)	2.8 (22)	1.7 (6)	2.3 (5)	5.3 (11)	0.032
Small/marginal (0.01–2.00 ha)	52.3 (405)	54.5 (192)	53.2 (115)	47.6 (98)	
Medium (2.01–4.00 ha)	20.2 (156)	19.6 (69)	16.2 (35)	25.2 (52)	
Large (>4.00 ha)	24.7 (191)	24.1 (85)	28.2 (61)	21.8 (45)	
Crop diversity (Kharif 2019)					
1 crop	47.6 (362)	96.0 (332)	10.8 (23)	3.5 (7)	<0.001
2 crops	26.5 (217)	3.5 (12)	81.7 (174)	7.9 (16)	
3 or more crops	25.9 (197)	0.6 (2)	7.5 (16)	88.6 (179)	
Simpson's index‡	0.54 (0.17)	0 (0)	0.36 (0.18)	0.17 (0.54)	<0.001
Livestock ownership, % yes	79.4 (615)	75.6 (266)	78.3 (170)	86.9 (179)	0.006
Income from livestock, % yes	26.3 (162)	28.9 (77)	22.4 (38)	26.3 (47)	0.313
Income from wages, % yes	28.6 (216)	23.4 (78)	30.6 (66)	35.1 (72)	0.010
Received food rations, % yes	45.2 (349)	45.6 (160)	46.5 (100)	43.2 (89)	0.778
Kitchen garden, % yes	55.0 (458)	68.8 (242)	49.3 (107)	46.6 (96)	<0.001

Values are percent (n) or mean (SD).

Crop diversity was calculated based on the number of crops cultivated by a farmer in Kharif 2020.

†P-value from chi-square test for categorical variables and one-way ANOVA for continuous variables.

‡Simpson's Index calculated using the equation: Simpson's Index = $1 - \sum_1^n P_i^2$ where P_i is the area proportion of the i-th crop in the gross cropped area and n is the total number of crops cultivated per farm. Values range from 0 to 1 where 0 corresponds to monocropping and 1 to the highest achievable crop diversity.

and least likely to have a kitchen garden (all $p < 0.05$; **Table 2**).

With regards to changes in cropping patterns over time, 96.0% of farmers who cultivated 1 crop in 2020 had cultivated 1 crop in 2019 ($p < 0.001$; **Table 2**). Very few farmers had increased the number of crops cultivated from 2019 to 2020 (6.0%; data not shown) and even fewer had decreased the number of crops cultivated over that period (3.9%; data not shown). Comparing crop type, those cultivating only 1 crop in Kharif 2020 were mostly cultivating paddy (**Figure 1**). However, among those cultivating 3 or more crops, the most popular crop was pulses. In Kharif 2019, cropping patterns were slightly different. While farmers who cultivated 1 crop were disproportionately growing paddy in 2019, a larger proportion of farmers were also cultivating vegetables, soybeans, and pulses than in 2020. Among farmers growing 3 or more crops in 2019, the most popular crops were pulses and paddy.

Low dietary diversity (MDD<4) had a prevalence of 78.9% at baseline, 88.6% at follow-up 1, and 88.0% at follow-up 2 (data not shown). With regards to changes in dietary diversity over time, MDD decreased from baseline to follow-up 1 and slightly increased from follow-up 1 to follow-up 2: MDD (mean ± SD)

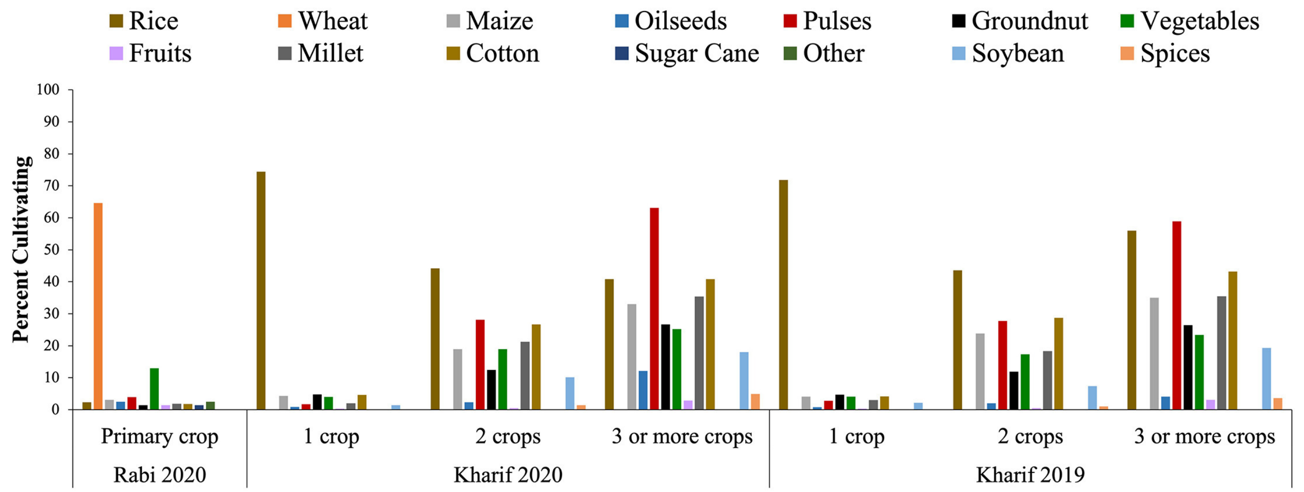

FIGURE 1 | Crops contributing to crop diversity over time in participants from agricultural households across 12 states in India during the COVID-19 pandemic (n = 775 for Kharif 2020; n = 761 for Kharif 2019; n = 515 for Rabi 2020).

2.33 ± 1.24 at baseline compared to 2.05 ± 1.03 at follow-up 1 and 2.11 ± 1.00 at follow-up 2 (data not shown). From baseline to follow-up 1, dietary diversity decreased for 34.2%, and from follow-up 1 to follow-up 2, it decreased for 16.1% (data not shown). Among participants with low dietary diversity, starches, dairy, and vegetables were the food groups consumed most frequently, and there was a slight decline in consumption of vegetables over time (**Figure 2**). Among participants with high dietary diversity, grains, dairy, vegetables, and pulses were the food groups consumed most frequently, and there was a slight decline in consumption of fruits and slight increase in consumption of meat/poultry/fish and eggs over time (**Figure 2**).

Compared to farmers who cultivated 1 crop, farmers who cultivated 2 crops or 3 or more crops were significantly less likely to experience a decline in dietary diversity from baseline to follow-up 1: adjusted relative risk (RR) (95% confidence interval [CI]), 0.52 (0.35, 0.78) and 0.48 (0.31, 0.75), respectively (**Table 3**). Farmers who cultivated 3 or more crops were significantly more likely to experience an increase in dietary diversity from baseline to follow-up 1 compared to farmers who cultivated 1 crop: RR (95% CI), 1.71 (1.01, 2.88). There was no significant association between crop diversity and change in dietary diversity from follow-up 1 to follow-up 2, when phased re-opening had begun (**Table 3**).

With regards to the association of food-security related covariates (kitchen garden and livestock) with change in dietary diversity, those with a kitchen garden were significantly less likely to experience a decline in dietary diversity from baseline to follow-up 1 and from follow-up 1 to follow-up 2, compared to those without a kitchen garden: RR (95% CI), 0.43 (0.30, 0.61) and 0.52 (0.34, 0.81), respectively (**Table 3**). However, those with a kitchen garden were less likely to experience an increase in dietary diversity from follow-up 1 to follow-up 2 (phased re-opening period) than those without a kitchen garden: RR (95% CI), 0.53 (0.35, 0.79). Livestock ownership was not significantly associated with dietary diversity in this sample.

Results were consistent with the Simpson's Index as a measure of crop diversity: those with a higher Simpson's Index (indicating greater crop diversity) were less likely to experience a decrease in dietary diversity from baseline to follow-up 1 but no significant effect was observed from follow-up 1 to follow-up 2 (**Supplementary Table 2**). Similarly, results were consistent when crop diversity in Kharif 2019 was evaluated in place of Kharif 2020 in sensitivity analyses (**Supplementary Table 3**).

DISCUSSION

This paper is the first longitudinal analysis to examine the association of crop diversity with dietary diversity in the context of the COVID-19 pandemic. We found that in the initial lockdown period, when measures were most restrictive, crop diversity was protective against declines in dietary diversity. Having a kitchen garden was also protective against a decline in dietary diversity. While crop diversity was no longer significantly associated with dietary diversity during later stages of the lockdown when restrictions were lifted, having a kitchen garden remained protective during this stage. Livestock ownership was not associated with dietary diversity at any time point. In sum, these findings suggest that farmers with greater crop diversity in India were more resilient to market disruptions from the COVID-19 pandemic. Thus, while the links between crop diversity and dietary diversity may be small under normal circumstances, diversifying production systems may play an important role in resiliency when major market disruptions occur.

Five previous studies, including one systematic review focused on South Asia, have quantified the association between crop diversity and dietary diversity in India (Bhagowalia et al., 2012; Chinnadurai et al., 2016; Kavitha et al., 2016; Gupta et al., 2020a;

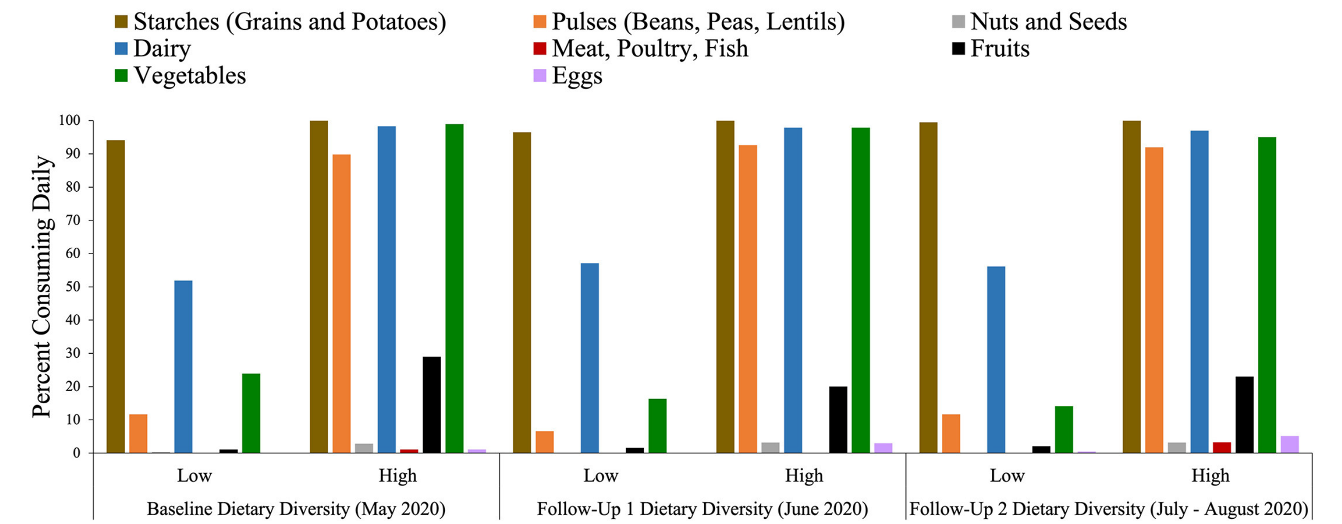

FIGURE 2 | Food groups contributing to low vs. high dietary diversity over time in participants from agricultural households across 12 states in India during the COVID-19 pandemic (n = 833). Low dietary diversity defined as <4 dietary diversity score and high dietary diversity defined as ≥4 dietary diversity score out of a total of 8.

Singh et al., 2020; Dizon et al., 2021). Cross-sectional, nationally representative data from 2004/2005 indicated that crop diversity was positively associated with dietary diversity (beta coefficient from OLS regression was 0.32, $p < 0.01$), especially intake of pulses, and the effect was slightly larger among marginal/small farmers as compared to large farmers (Bhagowalia et al., 2012). In contrast, a panel study of two representative cross-sections of Tamil Nadu (2004/2005 and 2012/2013) found no consistent association between crop diversity and dietary diversity (Chinnadurai et al., 2016). Similarly, after adjustment for confounding factors, an analysis of six villages in Telangana and Maharashtra participating in the Indian Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Village Level Studies found no association between crop diversity and dietary diversity (Kavitha et al., 2016). The lack of or inconsistent evidence for the association between crop and dietary diversity motivated the exploration of this association longitudinally in the context of COVID-19. We build on these previous efforts by demonstrating that this association may be most prominent in the wake of a shock to the food supply chain, and that the strength of this association may vary over time.

Previous studies have found that access to food markets influences dietary diversity, potentially to a greater extent than crop diversity (Nandi et al., 2021). Rural communities may not be able to access markets offering diverse food options due to factors such as distance, transportation, and purchasing power, and this may in turn increase their vulnerability to poor nutritional outcomes (Nandi et al., 2021). In India, where farmers often purchase food that is not grown on their own farm to complement their meals, market access plays an important role in increasing dietary diversity (Galab and Vijaya Kumar, 2011; Ludwig, 2018). During the initial COVID-19 lockdown in India, restrictions resulted in a complete disruption to food market access as farmers and markets alike were required to suspend all activities (Sinha, 2021). The shock to the food supply chain resulting from the lockdown presented an unprecedented opportunity to study the longitudinal association between crop and dietary diversity in the near absence of market access. Our results suggest that farmers growing 2 or more crops in the wake of the abrupt government shutdown were protected from a decrease in dietary diversity, suggesting resilience to market access disruptions.

We also observed that participants with a kitchen garden were less likely to experience a decline in dietary diversity for the entire study period. Prior to the COVID-19 pandemic, several intervention studies had found that kitchen gardens were associated with increased dietary diversity in India (Pradhan et al., 2018; Suri, 2020; Vijayalakshmi and Swamy, 2020). In this respect, kitchen gardens may have complemented on-farm production, acting as a dietary buffer to limited market access during the lockdown or reduced income in later stages. An intervention study comparing baseline dietary intake data from 2013/14 to post-intervention in 2016/17 found a significant increase in fruit and vegetable consumption following the introduction of nutrition garden in the state of Odisha in India (Pradhan et al., 2018). Notably, weekly consumption of green leafy vegetables almost tripled when comparing pre- and post- intervention (Pradhan et al., 2018). Similar results were observed after the introduction of a "nutri garden" intervention in Andhra Pradesh (Vijayalakshmi and Swamy, 2020). However, not all studies of kitchen gardens in India have found significant effects (Gupta et al., 2020a). Our study findings with regards to kitchen gardens being protective is particularly timely as kitchen gardens (a.k.a. "nutri gardens") are now being promoted by the Ministry of Women and Child Development and several state governments including, for example, Andhra Pradesh.

TABLE 3 | Association between crop diversity and dietary diversity in participants from agricultural households across 12 states in India during the COVID-19 pandemic ($n = 833$).

	Baseline to follow-up 1 (May to June 2020)		Follow-up 1 to follow-up 2 (June to August 2020)	
	Increase in dietary diversity*	**Decrease in dietary diversity***	**Increase in dietary diversity***	**Decrease in dietary diversity***
Crop diversity (Kharif 2020)				
1 crop	Ref	Ref	Ref	Ref
2 crops	1.10 (0.64, 1.86)	**0.52 (0.35, 0.78)**	0.90 (0.56, 1.44)	1.07 (0.65, 1.76)
3 or more crops	**1.71 (1.01, 2.88)**	**0.48 (0.31, 0.75)**	0.80 (0.48, 1.33)	1.11 (0.66, 1.87)
Covariates				
Education				
No formal schooling/primary school	Ref	Ref	Ref	Ref
Secondary school	0.99 (0.60, 1.64)	**1.81 (1.19, 2.75)**	1.29 (0.80, 2.10)	**1.80 (1.08, 3.01)**
Grad/post grad/Professional	1.29 (0.76, 2.19)	**1.81 (1.15, 2.84)**	**2.15 (1.30, 3.58)**	**1.97 (1.13, 3.43)**
Caste				
Scheduled caste/tribe	0.68 (0.37, 1.24)	0.60 (0.36, 1.01)	1.34 (0.74, 2.41)	0.81 (0.44, 1.48)
Backward caste	1.05 (0.64, 1.72)	1.14 (0.77, 1.69)	1.59 (0.99, 2.55)	0.79 (0.49, 1.27)
Other/no answer	Ref	Ref	Ref	Ref
Farm size				
Landless (0 ha)	0.65 (0.17, 2.47)	0.82 (0.27, 2.23)	2.27 (0.84, 6.16)	0.97 (0.25, 3.79)
Small/marginal (0.01–2.00 ha)	Ref	Ref	Ref	Ref
Medium (2.01–4.00 ha)	0.81 (0.47, 1.39)	**0.55 (0.35, 0.88)**	**0.37 (0.21, 0.67)**	0.74 (0.43, 1.27)
Large (>4.00 ha)	0.76 (0.44, 1.31)	0.82 (0.53, 1.25)	**0.30 (0.17, 0.52)**	0.63 (0.38, 1.06)
Livestock ownership				
No	Ref	Ref	Ref	Ref
Yes	1.08 (0.83, 1.40)	1.11 (0.90, 1.37)	0.88 (0.69, 1.13)	0.85 (0.65, 1.11)
Kitchen garden				
No	Ref	Ref	Ref	Ref
Yes	0.71 (0.46, 1.10)	**0.43 (0.30, 0.61)**	**0.53 (0.35, 0.79)**	**0.52 (0.34, 0.81)**

Values are adjusted relative risk (95% confidence interval) from multivariate polynomial logistic regression. Bold values indicate statistical significance at the $p < 0.05$ level.
**Dietary diversity score calculated based on consumption of eight food groups over the past 7 days including: (1) starchy staples (rice, wheat, and potatoes), (2) pulses, (3) nuts, (4) vegetables, (5) fruits, (6) dairy, (7) eggs, and (8) fleshy foods (meat, poultry, and fish). Those who consumed a food group every day in the past week were assigned a value of "1" and those who did not were assigned a value of "0" and the values across these eight food groups were summed. Thus, the dietary diversity score ranged from 0 to 8 with 8 representing maximum dietary diversity.*

Interestingly, we did not find a significant association between livestock ownership and dietary diversity in this sample. Livestock ownership may impact dietary diversity through acting as a source of animal-source foods but also through the generation of income (Dizon et al., 2021). Similar to kitchen gardens, livestock ownership is typically viewed as a complement to crop diversity in enhancing dietary diversity. One study in India found that livestock ownership was positively associated with dietary diversity only in women but not the household (Gupta et al., 2020a). Livestock ownership has also been found to be associated with dietary diversity outside of India, especially in women (Ambikapathi et al., 2019; Zanello et al., 2019). Given our null finding, we hypothesize that the high prevalence of livestock ownership (>75%) and dairy consumption (>50%) in this sample did not allow for much room for improvement. Therefore, our null result may be due to lack of variation in exposure rather than a true lack of impact.

In addition to the COVID-19 pandemic, farmers in India simultaneously faced climate-related disruptions that resulted in crop loss (Sarkar, 2020). Heat waves, a "super cyclone," and erratic rainfall impeded transportation and placed an additional obstacle to accessing markets and the sale of agricultural products during this period (Meyers, 2020; The New Indian Express, 2020). The effects of climate change are projected to place a substantial burden on farmers in India and already do, as they struggle to adapt to erratic weather patterns (Srivastava et al., 2010; Sinha and Bhogal, 2021). Moving forward, adaptation strategies to enhance resilience to natural disasters will be critical to ensuring nutritional security among farming households in India. Promoting the production of diverse crops represents a potential course of action that may mitigate the impact of unexpected shocks to production and market access on farmer diets.

These results should be interpreted while considering several limitations. First, this is an observational study, and while we adjusted for all measured confounders, the possibility of residual confounding remains. For example, we did not explicitly measure market access (i.e., distance to nearest market or availability of transport). However, as described above, market access was substantially disrupted due to the lockdown and therefore may have been less of a confounder in this context. In addition, the small sample size of women and pregnant women prevented us from exploring gender as an effect modifier or adjusting for it as a potential confounder. Women's nutritional knowledge has been found to be an important determinant of individual and household dietary diversity (Gupta et al., 2020a). We are also unable to comment on on gender disparities in dietary diversity within farming households. It is plausible that the lockdown impacted women's dietary diversity more severely because of prevailing gender norms around distribution of food among household members (Gupta et al., 2020b). Despite these limitations, this study was strengthened by its longitudinal design and novelty–being one of the first studies to evaluate this association in the context of the COVID-19 pandemic, and in a country where a large proportion of the world's malnourished live.

This is an especially timely analysis given the recent agricultural policy environment in India. Three new agriculture bills have been passed which led to widespread protests across the country, but especially in the northern states of Punjab and Haryana (India's so-called "breadbasket") (Sharma, 2020). The protests are at least in part due to speculation that procurement at Minimum Support Price (MSP) will decrease as a result of these bills. The Government of India hopes that these bills will lead to increased investment in infrastructure support for perishable commodities while also ensuring price stabilization. This could help farmers become less dependent on MSP-supported crops (e.g., rice and wheat) and increase diversification toward high-value crops, with potentially positive impacts on dietary diversity of farming households (Aujla, 2020). The Ministry of Women and Child Development has also emphasized the need to diversify crop production as part of POSHAN Abhiyaan (the Prime Minister's Overarching Scheme for Holistic Nutrition) with the development of Bhartiya Poshan Krishi Kosh, a web portal mapping district-level crop diversity (Press Information Bureau, 2020).

In conclusion, we found that increased crop diversity was associated with improved dietary diversity among farmers in the first stage of the COVID-19 lockdown in India, when measures were most restrictive. However, this association was not significant for the latter half of the study period, when restrictions were eased. Our findings suggest that crop diversity most likely blunted the initial impact of the lockdown on dietary diversity among farmers. Kitchen gardens may play an important role in supporting diverse diets when on-farm production is low, or market access is limited. This has immediate policy implications for government response to COVID-19 and other abrupt shocks to the food supply and market access. Such market access restrictions are predicted to become more frequent and severe in the wake of climate-related disasters and future pandemics. Crop diversity may be an effective strategy to building resilience to and mitigating the effects of disasters on diets and nutrition. In understanding the parallels between the COVID-19 pandemic with other calamities of large scale, we can inform policies that work to safeguard food security, nutrition, and health through promotion of diverse crop production systems.

DATA AVAILABILITY STATEMENT

De-identified participant data are available in the Harvard Dataverse: https://doi.org/10.7910/DVN/JZ511O.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Harvard T. H. Chan School of Public Health Institutional Review Board (Protocol #: IRB20-0689) and Public Health Foundation of India Institutional Ethics Committee (Protocol #: TRC-IEC 438/20). Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

LJ, GR, AR, DV, and PP conceived of the study. LJ and KC secured funding. KC conducted the data analysis under the supervision of LJ. KC wrote the initial draft of the manuscript with guidance from LJ. AR, GR, PP, and DV provided feedback on the manuscript. All authors read and approved the final version of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2021.695347/full#supplementary-material

REFERENCES

Adjimoti, G. O., and Kwadzo, G. T. M. (2018). Crop diversification and household food security status: evidence from Rural Benin. *Agri. Food Security* 7:82. doi: 10.1186/s40066-018-0233-x

Agriculture Census (2016). *Agriculture Census 2016*. Available online at: https://agricoop.nic.in/en/divisiontype/agriculture-census (accessed April 20, 2021).

Ambikapathi, R., Gunaratna, N. S., Madzorera, I., Passarelli, S., Canavan, C. R., Noor, R. A., et al. (2019). Market food diversity mitigates the effect of environment on women's dietary diversity in the agriculture to nutrition (ATONU) study, Ethiopia. *Publ. Health Nutr.* 22, 2110–2119. doi: 10.1017/S136898001900051X

Aujla, I. S. (2020). *Does MSP Stall Crop Diversification? - Times of India. The Times of India*. Available online at: https://timesofindia.indiatimes.com/india/does-msp-stall-crop-diversification/articleshow/78399992.cms (accessed April 20, 2021).

Bhagowalia, P., Headey, D., and Kadiyala, S. (2012). *Agriculture, Income, and Nutrition Linkages in India: Insights From a Nationally Representative Survey*. Washington, DC: International Food Policy Research Institute.

Chegere, M. J., and Stage, J. (2020). Agricultural production diversity, dietary diversity and nutritional status: panel data evidence from Tanzania. *World Dev.* 129:104856. doi: 10.1016/j.worlddev.2019.104856

Chinnadurai, M., Karunakaran, K. R., Chandrasekaran, M., Balasubramanian, R., and Umanath, M. (2016). Examining linkage between dietary pattern and crop diversification: An evidence from Tamil Nadu. *Agri. Econ. Res. Rev.* 29:149. doi: 10.5958/0974-0279.2016.00042.2

Deb, U., and Bayes, A. (2018). *Crop Diversity, Dietary Diversity and Nutritional Outcome in Rural Bangladesh: Evidences from VDSA Panel Household Surveys*, Vol. 2018. LANSA Working Paper Series. Brighton, UK: Institute of Development Studies.

Dizon, F., Josephson, A., and Raju, D. (2021). Pathways to better nutrition in South Asia: Evidence on the effects of food and agricultural interventions. *Global Food Security* 28:100467. doi: 10.1016/j.gfs.2020.100467

FAO (2016). *Minimum Dietary Diversity for Women- A Guide to Measurement*. Rome: FAO.

Galab, S., and Vijaya Kumar, S. (2011). *The Impact of Growth on Childhood Poverty in Andhra Pradesh: Initial Findings from India: Round 3 Survey Report*. Oxford: Young Lives, Department of International Development, University of Oxford.

Gupta, S., Sunder, N., and Pingali, P. (2020a). Market access, production diversity, and diet diversity: Evidence from India. *Food Nutr. Bull.* 41, 167–185. doi: 10.1177/0379572120920061

Gupta, S., Sunder, N., and Pingali, P. L. (2020b). Are women in rural India really consuming a less diverse diet? *Food Nutr. Bull.* 41, 318–331. doi: 10.1177/0379572120943780

Irani, S. (2019). *The Indian Express*. Available online at: https://indianexpress.com/article/opinion/columns/a-jan-aandolan-for-nutrition-6124546/ (accessed April 20, 2021).

Jaacks, L. M., Veluguri, D., Serupally, R., Roy, A., Prabhakaran, P., and Ramanjaneyulu, G. V. (2021). Impact of the COVID-19 pandemic on agricultural production, livelihoods, and food security in India: Baseline results of a phone survey. *Food Secur*. 13, 1–17. doi: 10.1007/s12571-021-01164-w

Kavitha, K., Soumitra, P., and Padmaja, R. (2016). Understanding the linkages between crop diversity and household dietary diversity in the semi-arid regions of India. *Agri. Econ. Res. Rev.* 29, 129–137. doi: 10.5958/0974-0279.2016.00040.9

Ludwig, T. (2018). *An Egg for an Egg and a Bean for a Bean? How Production Diversity Determines Dietary Diversity of Smallholder Farmers in Rural India*. Rochester, NY: Social Science Research Network.

Meyers, T. (2020). One *Pandemic, Two Cyclones: In India, Aid Groups Respond Amid the Damage*. Available online at: https://www.directrelief.org/2020/06/one-pandemic-two-cyclones-in-india-aid-groups-respond-amid-the-damage/ (accessed June 17, 2020).

Miller, V., Webb, P., Micha, R., and Mozaffarian, D. (2020). *Defining Diet Quality: A Synthesis of Dietary Quality Metrics and Their Validity for the Double Burden of Malnutrition*. Available online at: https://www.thelancet.com/journals/lanplh/article/PIIS2542-5196(20)30162-5/fulltext (accessed April 20, 2021).

Ministry of Health and Family Welfare (2016). *National Family Health Survey-4 (NFHS-4): India Fact Sheet*. New Delhi: Government of India.

Ministry of Statistics and Programme Implementation (2013). *National Sample Survey (NSS), 70th Round*. New Delhi: Government of India.

NABARD (2018). *NABARD*. Available online at: https://www.nabard.org/PressReleases-article.aspx?id=25&cid=554&NID=43 (accessed April 20, 2021).

Nandi, R., Nedumaran, S., and Ravula, P. (2021). The interplay between food market access and farm household dietary diversity in low and middle income countries: a systematic review of literature. *Global Food Security* 28:100484. doi: 10.1016/j.gfs.2020.100484

Pradhan, A., Sathanandhan, R., Panda, A. K., and Wagh, R. (2018). *Improving Household Diet Diversity Through Promotion of Nutrition Gardens in India*. Available online at: https://opendocs.ids.ac.uk/opendocs/handle/20.500.12413/13816 (accessed April 20, 2021).

Press Information Bureau (2020). *Ministry of Women and Child Development. Bhartiya Poshan Krishi Kosh*. Delhi: PIB, Government of India.

Sarkar, S. (2020). *Farmers Hammered by Unseasonal Rain, Covid-19 Lockdown. India Climate Dialogue*. Available online at: https://www.eco-business.com/news/farmers-hammered-by-unseasonal-rain-covid-19-lockdown/ (accessed April 10, 2020).

Sharma, M. G. (2020). *Explained: What Punjab's Three New Farm Bills Say, and What They Seek to Achieve. The Indian Express*. Available online at: https://indianexpress.com/article/explained/explained-what-punjabs-three-new-farm-bills-say-what-they-seek-to-achieve-6813386/ (accessed December 3, 2020).

Sibhatu, K. T., and Qaim, M. (2018). Farm production diversity and dietary quality: linkages and measurement issues. *Food Sec.* 10, 47–59. doi: 10.1007/s12571-017-0762-3

Singh, S., Jones, A. D., and Jain, M. (2020). Regional differences in agricultural and socioeconomic factors associated with farmer household dietary diversity in India. *PLoS ONE* 15: e0231107. doi: 10.1371/journal.pone.0231107

Sinha, D. (2021). Hunger and food security in the times of Covid-19. *J. Soc. Econ. Dev*. 45, 1–4. doi: 10.1007/s40847-020-00124-y

Sinha, S., and Bhogal, S. (2021). *India Protests: Farmers Could Switch to More Climate-Resilient Crops – but They Have Been given No Incentive*. Available online at: http://theconversation.com/india-protests-farmers-could-switch-to-more-climate-resilient-crops-but-they-have-been-given-no-incentive-154700 (accessed April 20, 2021).

Srivastava, A., Naresh Kumar, S., and Aggarwal, P. K. (2010). Assessment on vulnerability of sorghum to climate change in India. *Agri. Ecosyst. Environ.* 138, 160–169. doi: 10.1016/j.agee.2010.04.012

Suri, S. (2020). *Nutrition Gardens: A Sustainable Model for Food Security and Diversity*. Available online at: https://www.orfonline.org/research/nutrition-gardens-a-sustainable-model-for-food-security-and-diversity-67933/ (accessed April 20, 2021).

Textor, J. B., van der Zander, M. S., Gilthorpe, Liskiewicz, M., and Ellison, G. T. (2016). Robust causal inference using directed acyclic graphs: the R package 'dagitty.' *Int. J. Epidemiol.* 45, 1887–1894. doi: 10.1093/ije/dyw341

The New Indian Express (2020). *Farmers Demand Relief for Crops Damaged by Cyclone. The New Indian Express*. Available online at: https://www.newindianexpress.com/states/tamil-nadu/2020/may/21/farmers-demand-relief-for-crops-damaged-by-cyclone-2146193.html (accessed April 20, 2021).

Vijayalakshmi, K., and Swamy, G. (2020). A study on nutritional security and economic empowerment of women through homestead nutrigardens in Nellore District of Andhra Pradesh. *Pharma Innov. J.* 9, 207–212.

Zanello, G., Shankar, B., and Poole, N. (2019). Buy or make? Agricultural production diversity, markets and dietary diversity in Afghanistan. *Food Policy* 87:101731. doi: 10.1016/j.foodpol.2019.101731

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frontiers in Sustainable Food Systems

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COVID-19 Impact on Poultry Production and Distribution Networks in Bangladesh

*Abdullah Al Sattar[1], Rashed Mahmud[1], Md. Abu Shoieb Mohsin[1], Nurun Nahar Chisty[1], Md. Helal Uddin[1], Nusrat Irin[1], Tony Barnett[2,3], Guillaume Fournie[2], Eve Houghton[2] and Md. Ahasanul Hoque[1]**

[1] Department of Medicine and Surgery, Faculty of Veterinary Medicine, ChattogramVeterinary and Animal Sciences University, Chattogram, Bangladesh, [2] Veterinary Epidemiology, Economics and Public Health Group, Department of Pathobiology and Population Sciences, The Royal Veterinary College, University of London, London, United Kingdom, [3] Firoz Lalji Institute for Africa, London School of Economics and Political Science, London, United Kingdom

The COVID-19 pandemic has severely affected numerous economic sectors across the world, including livestock production. This study investigates how the pandemic has impacted the poultry production and distribution network (PDN), analyses stakeholders' changing circumstances, and provides recommendations for rapid and long-term resilience. This is based on a literature review, social media monitoring, and key informant interviews ($n = 36$) from across the poultry sector in Bangladesh. These included key informants from breeder farms and hatcheries, pharmaceutical suppliers, feed companies, dealers, farmers, middlemen, and vendors. We show that the poultry sector was damaged by the COVID-19 pandemic, partly as a result of the lockdown and also by rumors that poultry and their products could transmit the disease. This research shows that hardly any stakeholder escaped hardship. Disrupted production and transportation, declining consumer demand and volatile markets brought huge financial difficulties, even leading to the permanent closure of many farms. We show that the extent of the damage experienced during the first months of COVID-19 was a consequence of how interconnected stakeholders and businesses are across the poultry sector. For example, a shift in consumer demand in live bird markets has ripple effects that impact the price of goods and puts pressure on traders, middlemen, farmers, and input suppliers alike. We show how this interconnectedness across all levels of the poultry industry in Bangladesh makes it fragile and that this fragility is not a consequence of COVID-19 but has been revealed by it. This warrants long-term consideration beyond the immediate concerns surrounding the COVID-19 pandemic.

Keywords: poultry sector, Bangladesh, COVID-19, impact, rumor, transaction chains

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Patrick Meyfroidt, Catholic University of Louvain, Belgium

Reviewed by:
Mangala De Zoysa, University of Ruhuna, Sri Lanka
Mohammad Giasuddin, Bangladesh Livestock Research Institute, Bangladesh

***Correspondence:**
Md. Ahasanul Hoque
md.hoque@my.jcu.edu.au

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INTRODUCTION

In addition to its impact on public health, COVID-19 has affected social and economic life in many ways. Areas impacted include the livestock production sector, at global, regional and national levels (Marchant-Forde and Boyle, 2020). Governmental actions, taken in attempts to control the pandemic, have included national lockdowns, travel restrictions, border closures and controls. These have resulted in some inevitable negative consequences. With regard to the livestock sector, these have included: (i) local and international movements of live animals and animal products; (ii) supplies of raw materials for feed and medicine; (iii) provision of other production inputs and equipment; (iv) access to labor and professional services (Food Agriculture Organization, 2020a).

In many countries, the closure of schools, restaurants, shops and markets, limitations on public gatherings and travel have reduced demand for animal products (InEuropa, 2020; Marchant-Forde and Boyle, 2020). Infections among workers and subsequent closure of slaughterhouses and food processing plant has reduced slaughtering and processing throughput (Good, 2020). These factors resulted in the overstocking or culling of animals and animal products (Huffstutter, 2020), with farmers depopulating their farms to reduce the costs of maintaining animal populations which they could neither feed nor trade (Barrett, 2020). Inevitably, this affected poultry production and trade (Mulder, 2020).

The impact on the Bangladesh poultry sector was devastating. Poultry production is the main livestock sector in Bangladesh, providing an important component of food security and contributing to the country's economic development more generally. Over 8.5 million people are employed in this sector, which is the second-most important source of employment after the garments industry (Hossain, 2020). Poultry accounts for 37% of the country's total meat production and 22–27% of the animal protein supply and forms a substantial fraction of the livestock sector's 1.4 % contribution to the country's GDP (DLS: Department of Livestock Services, 2020). Of course, COVID-19 is by no means the first or only challenge this growing sector faces. The avian influenza outbreak of 2007 had catastrophic repercussions for the sector, shutting down more than half of the country's poultry farms and hatcheries, and the emergence of this disease continues to afflict poultry farmers (Gupta et al., 2021). Recurring outbreaks of other diseases in flocks have hampered overall production, leaving some farmers in precarious financial positions (Hamid et al., 2017). There are also structural challenges shaping the sector. Risks associated with the market, such as value chain fragmentation, high intermediation costs, and no or lack of traceability, all impede the distribution of poultry and poultry products (MoFood-Ministry of Food, 2020). The unregulated and fluctuating cost of certain critical farm inputs, including day-old chick (DOC) and feed, and uncertain market price of finished live poultry have also become a major worry for stakeholders. The strategies of feed manufacturing, promotion, and distribution differ amongst companies and hence they set prices unilaterally and are not subject to government regulation often (Hamid et al., 2017). Hatcheries raise the price of DOC for certain events and festivals, putting farmers at a disadvantage (Høg et al., 2019). Fluctuating prices are also a concern. Changes in supply and demand cause chicken and egg prices to change regularly, sometimes beyond the reach of many consumers, and sometimes so severely that farmers suffer financially. Moreover, the insufficient coordination between the country's public-private and research institutions and inadequate government oversight of the poultry sector is hampering the development of this sector (Hamid et al., 2017). Despite these challenges, COVID-19 still presented a new and extreme challenge to the sector both introducing new problems and exacerbating some of these existing ones.

The first case of COVID-19 was reported in Bangladesh on 8 March 2020 (World Health Organization, 2020a). The government took measures to prevent the spread of the virus, including the implementation of a nationwide lockdown (referred to as "General Holiday") between 26 March and 30 May. During this period, the government ordered closure of all businesses and institutions other than hospitals, kitchen markets (*kachar bazar*)[1], pharmacies, and other emergency and health-related services (World Health Organization, 2020b). This study assesses the impacts of the first four months of the COVID-19 pandemic, and in particular the national lockdown, on the production, trade and marketing of chickens and eggs in Bangladesh.

This research focuses on four of the most important components of the chicken sector: (i) improved cross-bred chickens called S*onali murgi*; (ii) exotic broiler chickens; (iii) eggs from exotic layer birds; (iv) *Deshi murgi* ("backyard"/local/indigenous chickens). Here we first compare variations in the prices of different chicken commodities across the study period. We then explore the way in which the pandemic has affected the activities of different poultry production stakeholders.

MATERIALS AND METHODS

Literature Review

At an early stage of the COVID-19 epidemic in Bangladesh, we conducted a review of news articles published in mainstream print and electronic media. We compiled an analytical account of the diverse impacts of COVID-19 on the poultry sector in the country. The following resources were screened daily from 26 March to 31 May 2020: news channel (Somoy News), 12 Bangladeshi daily national newspapers (Prothom Alo, Financial express, Kalerkantha, Jugantor, Samakal, Ittefaq, Nayadiganta, Inqilab, Daily Star, The Independent, Bangladesh Pratidin, and The Azadi) and nine online news websites (Agrinews24, Adhunik Krishi Khamar, Poultry Doctors BD, Jagonews24, Banglanews24, BDnews24, UNB, Banglatribune and Bangla.24 Live Newspaper).

Interviews

Based on a list of poultry stakeholders compiled through the previous field studies (Høg et al., 2019; Gupta et al., 2021; Moyen et al., 2021) and a policy consultation (Chattopadhyay et al., 2018) which took place within the context of the associated research project "Behavioral adaptations in live poultry trading and farming systems and zoonoses control in Bangladesh" (BALZAC) (Grant No. BB/L018993/1), 36 key informant stakeholders were purposively selected with the aim to capture a range of actors involved in poultry production and distribution. They were contacted through email and telephone in the last week of March 2020. Informed consent was requested prior to interviews; none of those approached refused to participate.

[1] Kitchen markets (*kachar bazar)* are markets selling a wide range of foods and goods seen as essential to daily life including fruit, vegetables and meat.

Three groups of informants were identified. **Group-1** consisted of managers or senior employees of six poultry breeder and hatchery companies, four feed companies, and four pharmaceutical companies. **Group-2** included farmers from three small-scale (<500 birds/farm), three medium-scale (501–5,000 birds/farm), one large-scale (>5,000 birds/farm) exotic broiler chicken farm, and one small-scale (1,500 birds/farm), one medium-scale (5,000 birds/farm) and one large-scale (8,000 birds/farm) layer farm. **Group-3** included three middlemen, three feed dealers, three wholesalers and three retailers operating in markets. Although most recruited stakeholders were from Chattogram district, the companies in **Group-1** were selected from across the entire country.

Participants were asked open-ended questions about the impact of COVID-19 on their business, their coping strategies, current livelihood and financial situation, assessment of the future of the poultry business in the coming months, the support they have received and their expectations of the government. The questions were adapted to the different types of stakeholders, and further probing questions were asked as appropriate. Most stakeholders were interviewed individually by cell phone, but the managers or senior employees of the breeder and hatchery companies, pharmaceutical and feed companies were emailed the questions, to which they replied by email within 2–3 days. Face-to-face interviews were not possible during this period of research due to government sanctioned restrictions to address the spread of COVID-19. Using remote methods, however, allowed us to gather real information on stakeholder experiences in the midst of the pandemic. Oral interviews were recorded with the consent of the participants and lasted an average of 30 min. They were conducted in Bengali by one researcher (RM) between 4 April and 2 May 2021, transcribed and translated into English. The respondents were contacted again if clarification was required.

Price Monitoring

The average daily farm gate wholesale prices of exotic broiler and Sonali chickens and eggs as reported by the Poultry Professionals Bangladesh (https://www.facebook.com/Poultry-Professionals-Bangladesh-PPB-1597613347020175/) were recorded for 10 districts (Barisal, Bogura, Chattogram, Comilla, Cox's Bazar, Gazipur, Jashore, Mymensingh, Rajshahi, and Tangail) from January to June 2020. Nationwide price data could not be consistently recorded and the frequency of price data reporting differed between districts. Therefore, analysis of price data was limited to 10 districts where prices were most consistently reported. These cover different geographical areas of the country. Data on poultry prices prior to 2020 were not available from this source. To assess whether observed poultry price patterns could have been explained by seasonal variations, prices for the first half of 2020 were compared with poultry prices for 2016. These data were collected through a previous study (Moyen et al., 2021). Briefly, 43 vendors operating in six markets in Dhaka and Chattogram were interviewed monthly about the price of their chickens, to assess price changes over a year. In addition, 2020's retail prices of exotic broiler and Sonali chickens and eggs in two live bird markets within Chattogram City Corporation area (Jhautola and Pahartoli urban markets) were recorded. For the period January to March 2020, these prices were supplied retrospectively by the poultry vendors operating in these markets. Prices were then monitored prospectively and daily from April to June 2020.

Data Analysis

This study was approved by the ethical committee of the Chattogram Veterinary and Animal Sciences University (Memo No: CVASU/Dir (R & E) EC/2020/165 (10); Date: 21/07/2020).

Thematic analysis was conducted to identify and interpret the manifest and latent content of the qualitative responses following (Pope et al., 2000). For this purpose, two researchers (AAS, ASM) familiarized themselves with the transcripts of the stakeholder interviews. One of them (AAS) systematically coded the data. The coding was reviewed and iteratively amended with inputs from other researchers in the team (MAH, RM, ASM, MHU, NNC). Initial themes were then generated and discussed. They were refined and a final set of themes agreed. The temporal evolution of chicken and egg prices was visualized using Microsoft Excel 2020.

RESULTS AND DISCUSSION

Changes in the Price of Live Chickens and Eggs Over Time

A distinct impact of COVID-19 on the poultry sector was a fluctuation in live chicken and egg prices prior to, during and following lockdown (January–June 2020). For each commodity, namely exotic broiler chickens, Sonali chickens and layer eggs, wholesale farm gate prices followed similar patterns across the 10 selected districts (gray lines in **Figure 1**). In the following, we focus on the prices averaged over the 10 districts (black lines in **Figure 1**).

Prices of exotic broiler chickens, Sonali chickens and eggs decreased in the period immediately following the announcement of the General Holiday on 22 March 2020, with the greatest impact on exotic broilers. By 25 March their price had dropped by 28% compared with their price on 1 January 2020. As Ramadan started, on 24 April, the price of chickens and eggs rose(**Figures 1**, **2**). As a result, the price of chicken also rises. This upward trend continued until the Eid-ul-Fitr, in late May. The price of exotic broiler was then almost twice as high as at the start of the lockdown. This may indicate some recovery in consumer demand brought about by activities associated with these holidays (New Age, 2020). Indeed, in Bangladesh and throughout the Muslim world, the demand for animal protein has been reported to increase during Ramadan (Poultry World, 2012). After the Eid-ul-Fitr, the price of exotic broilers saw another downturn. As the lockdown was lifted (30 May 2020), prices continued to fluctuate while remaining higher than during the pre-lockdown period. Sonali chicken prices showed smaller fluctuations. Prices increased steadily during Ramadan, and, by the end of the lockdown period, they had reached slightly higher levels than at the start of the year. Sonali chickens make up a smaller proportion of the chicken products sold as compared to broilers, and they sell for a higher price to (mostly) wealthier customers. Furthermore, while broiler chickens reach maturity in

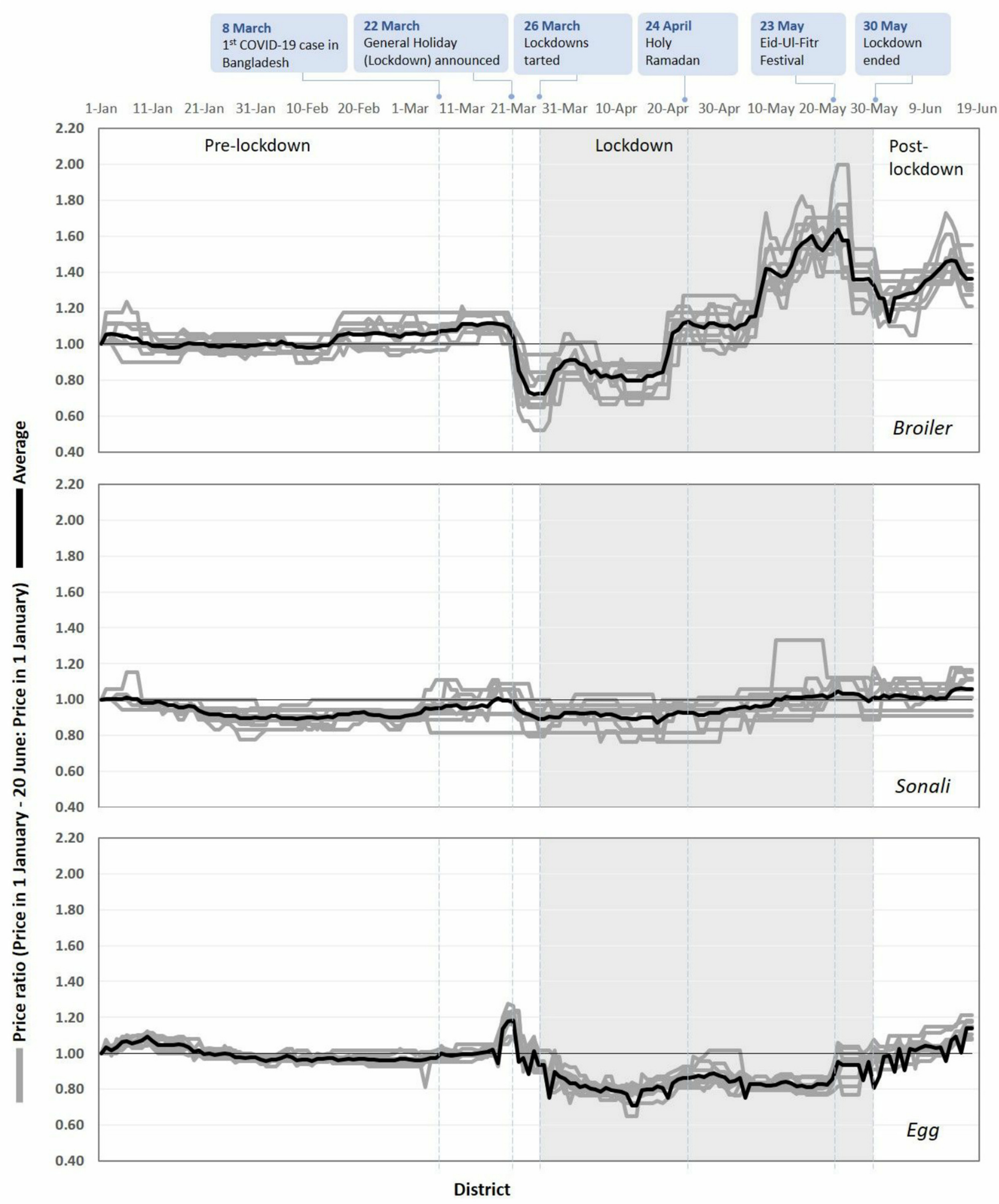

FIGURE 1 | Variations of farm gate price for the period 1/1/2020 to 20/6/2020 in 10 administrative districts of Bangladesh (Barisal, Bogura, Chattogram, Comilla, Cox's Bazar, Gazipur, Jashore, Mymensingh, Rajshahi, and Tangail).

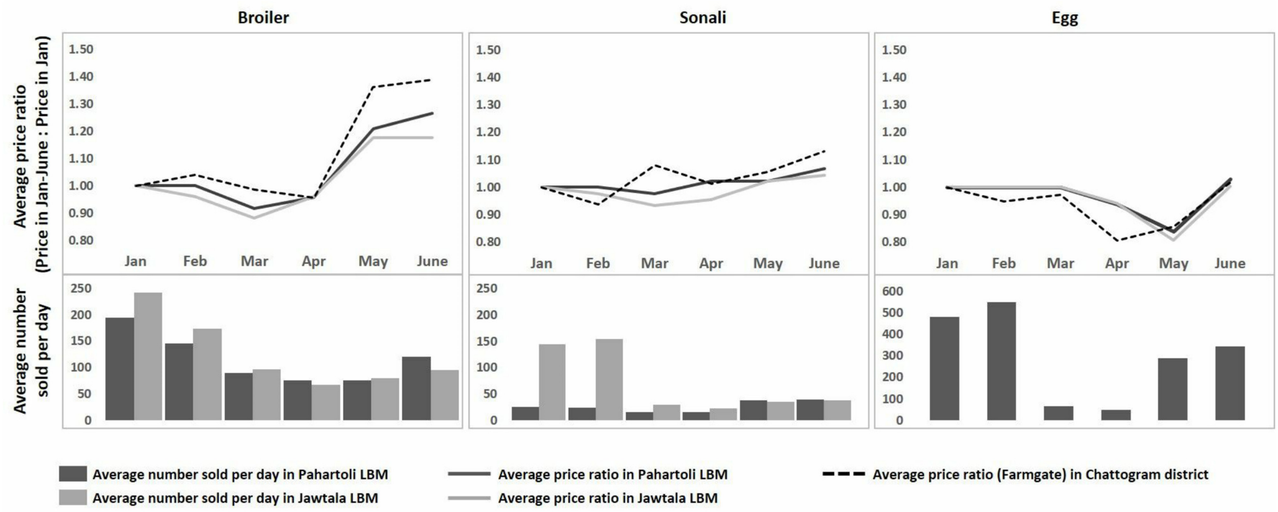

FIGURE 2 | Sales per day by volume, and retail and farm gate chicken and egg prices compared as reported in two live bird markets in Chattogram in January to June 2020.

30–35 days committing producers to a relatively fast sale of flocks and hesitancy to keep them longer, Sonali chickens only reach maturity after 70–90 days so can be held back from sale for longer if the price is not satisfactory. This may be one of the reasons for Sonali chicken prices to fluctuate less than the prices of other types of chickens. Whether this is the case cannot be explored from the data reported in this study but may be answered from further research. As for eggs, prices were consistently 20% lower during lockdown than in the immediately preceding period. They attained their pre-lockdown level in the week preceding the end of the lockdown.

A comparison of chicken price ratios from January to June in 2016 (Dhaka and Chattogram markets) and 2020 (all 10 districts) suggests that this pattern is unlikely explained by seasonal variations but instead strongly influenced by the COVID-19 pandemic and associated interventions (**Figure 3**). While broiler chicken prices were relatively steady in the first half of 2016, they became more volatile in 2020, including an 11% drop in early April and a 40% short-term surge in late May. Monitored Sonali prices showed no major fluctuations in both years. Compared to exotic broilers the price fluctuations for Sonali were markedly less dramatic, with fluctuations during the lockdown periods no greater than during the pre-lockdown period.

We also monitored retail prices in two poultry shops in two markets of Chattogram City retrospectively (January to April) and prospectively (May and June). Similar patterns were observed in retail prices of broiler and Sonali chicken as in farm gate prices, but fluctuations of retail prices were smaller (**Figure 2**). For eggs, the trough in retail prices was similar, but delayed, compared to wholesale prices.

The number of exotic broiler chickens, Sonali chickens and eggs sold by our vendor informants dropped from February to March by an average of 41%, 74% and 88%, respectively. Sales increased in May and June but remained lower than in January and February.

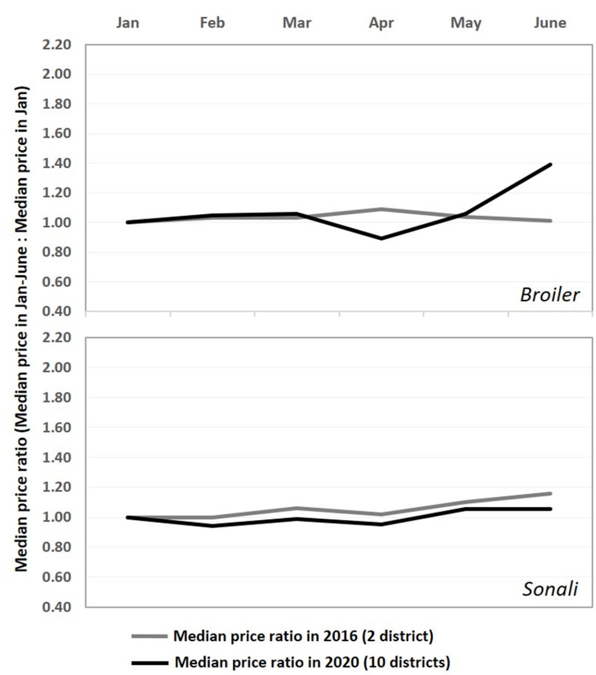

FIGURE 3 | Comparison of chicken prices (median prices in January–June: median price in January) in 2016 (two districts) and 2020 (10 districts).

Impact of COVID-19 on the Poultry Sector

This section discusses key themes relating to the impact of COVID-19 on the poultry sector. These themes emerged from data extracted from the literature review and from interviews with stakeholders where they described the impact of the pandemic and associated lockdown, as well as their expectations of interventions that could help the industry in the future.

Movement Restrictions and Supply Chain Disruptions

Disruption to supply chains at a global level and local limitations on movement both had implications for Bangladesh's poultry sector. Suppliers reported that disruption in global trade meant they could not import component raw materials to produce feed and medicine. This is supported by reports of prolonged border closures preventing the import of essential feed items like maize. Production in pharmaceutical industries was also severely disrupted as the import of Active Pharmaceutical Ingredients (API) was blocked (IDLC, 2020). In addition, due to an absence of necessary equipment, regular testing of imported feed ingredients at the country's sole diagnostic laboratory was suspended (Khan, 2021). This meant that raw materials were delayed at the port, resulting in severe reductions in overall production. The shortage of laborers in the lockdown situation also slowed operations in the feed industries (Food Agriculture Organization, 2020b). Overall, feed production decreased by near 40% between April and June 2020 (Saeque, 2020).

Delays processing goods at ports of entry meant demurrage had to be paid, advanced income tax and non-withdrawal of corporate tax further increased costs for the industry (The Independent, 2020). One of the interviewees, the general manager of a multipurpose agro-based industry, expressed concern over the surplus charges for such delayed imports:

> *"The government may take steps to reduce import tariffs, VAT, and other taxes for agro-based companies as compensation for the unforeseen circumstances during the pandemic."*

In addition, as a result of the lockdown imposed in the last week of March 2020, the movement of all types of vehicles was extremely limited (World Health Organization, 2020b).

Feed dealers and middlemen, who act as important intermediaries in the poultry distribution network in Bangladesh, faced huge challenges as a result of all of the factors reported above. Although the authorities announced that the transport of food items would not be subject to delay, administrative confusion meant that law enforcement agencies frequently obstructed the movement of livestock and poultry feed vehicles (Food Agriculture Organization, 2020b).This along with drivers' fears of being affected by the virus, resulted in general shortages of transport. According to a rapid assessment report released by the FAO, only 15% of trucks were active in April and May in comparison to March, and more than 40% of drivers refrained from driving, leading to a vehicle crisis that forced stakeholders to pay extra for moving their goods (Food Agriculture Organization, 2020b). According to one feed dealer:

> *"In the current situation, renting vehicles to transport poultry feed costs almost 1.5 times as much as usual."*

The impact of these disruptions for input suppliers also had consequences for farmers, some reporting that difficulty accessing feed and essential medicines were negatively affecting their ability to continue their farming operations. These difficulties further affected farmers when it came to trying to distribute their goods, with movement restrictions and higher transport costs disrupting their standard business practices. For example, a large portion of the country's total Deshi chickens come from the backyard poultry farmers in the north, who rely on a variety of transport links to supply different parts of the country. These routes were completely shut down due to movement restrictions. This caused financial loss to the backyard farmers and traders. A wholesaler who would usually have traded Deshi chickens from these regions, described his difficulties as follows:

> *"The demand for Deshi chicken has decreased by about 50%. In my stall, most of the Deshi chicken and duck come from other districts mainly from the northern part by using rooftops of public transport. Now, the transportation fares are higher, and the supply has decreased by 80%."*

A Drop in Demand

In 2018–19, the total production of eggs in Bangladesh was 17.11 billion. This met 98.8% of the country's demand. Overall meat production was 7.6 million metric tons (MOFL-Ministry of Fisheries Livestock, 2020a). In 2019, poultry meat made up 37% of production (FAOSTAT, 2019). After March 2020, these production levels fell by at least half (Berkhout, 2020): disruption to supply and transport was a major reason for this. Another is that COVID-19 caused the demand for chickens and eggs to fall. Input suppliers noticed the demand for poultry and poultry products dropped dramatically with the onset of the COVID-19 crisis. The Assistant General Manager of one of the country's leading day-old chicks and poultry feed producing companies said:

> *"People avoided consumption of chicken and egg as the COVID-19 outbreak had started. Besides, consumers were unable to go to the markets due to the lockdown, which significantly reduced demand for meat, egg, and other processed food."*

This had a significant adverse effect on all stakeholders along the transaction chain, from producers to sellers, resulting in a sharp fall in chicken prices and sales over a very short period. Informants suggested two key reasons for these changes: (i) lockdown restrictions limited both business opportunities and customer incomes, and (ii) rumors circulated which suggested that poultry products spread COVID-19. We shall consider each of these in turn.

The Effect of Lockdown Restrictions on Demand

A key part of the disruption occurred when retailers reported that they could not continue normal trading practices in markets and shops. This resulted from government restrictions on all businesses in an effort to prevent public gatherings (World Health Organization, 2020b). Exceptions were made for "emergency services" which included food stalls and kitchen markets. Even those emergency services permitted to remain open had to close by 7 p.m. (TBSNEWS, 2020). In addition, various social, religious and political events such as weddings, parties, religious gatherings, election campaigns, where chicken and eggs were necessary food items, were banned (Ali, 2020).

In the case of markets, some had to close or adapt their business practices. Thus, to ensure social distancing among shoppers, markets were later relocated from their permanent places to more open spaces (Mahmud, 2020) and the use of masks by workers was made mandatory. With limited business hours, new locations, and rising infection rates, the presence of customers in the poultry market during lockdown declined by over a third (Rosen, 2020). In their interview responses, traders reported that the emphasis placed on social distancing by health experts and politicians meant consumers became less willing to visit markets and other crowded places. One retail poultry vendor observed that:

> *"Due to the imposed restricted movements and instructions of maintaining social distance by the authorities, the number of chicken buyers, especially the middle-class consumers, in the market has decreased even though the price is very low now (in April). Moreover, many middlemen have temporarily suspended the supply of chickens to the market due to the risk of being infected."*

A wholesaler who bought chickens from different parts of the country and sold them in an LBM in Chattogram commented:

> *"The upper and upper-middle-class people did not come to LBM at the time of the lockdown regularly like before, but basically, they are the main buyers of Deshi chickens."*

The closure of hotels, restaurants, bakeries and other industries also contributed to the drop in demand. A middleman who used to regularly supply broiler and Sonali chickens to wholesalers, retailers, and other establishments, said:

> *"Hotels, restaurants, and individual stalls which were our key customers are now closed. Besides, we also used to sell a huge number of chickens in Export Processing Zone (EPZ), to garments factories, and residential hostels of universities and colleges which are temporarily closed. In typical times where I was able to trade at least three truckloads of chickens per day, now I can sell only one truckload every other day."*

Poultry traders also reported that the gradual increase in the severity of lockdown measures (World Health Organization, 2020b), including the temporary closure of businesses and workplaces, had reduced consumer incomes. They speculated that many people could no longer afford to buy chickens even if they were able to adapt to new market systems. These responses are in keeping with the findings of recent reports in which job losses or disruptions in the ability to do certain jobs during lockdown diminished many people's income (Islam and Babu, 2020; Rahman and Ruszczyk, 2020). In one report exploring COVID's impact on the labor market in Dhaka and Chittagong City Corporations, 22–25% of people reported losing their jobs either permanently or temporarily as a result of disruptions linked to COVID-19 (Genoni et al., 2020). According to one study, about 95% of households experienced income loss in the first two months of the pandemic, and 62% of earners reported lost jobs (Miah et al., 2020).

The Impact of Rumors

Unfounded reports and rumors circulated quickly and widely in the early months of the pandemic. Propelled into popular discourse via social and some mainstream media, one rumor that gained public attention was that consumption of poultry and poultry products could cause COVID-19 (Islam and Babu, 2020; Mahmud, 2020). Informants we interviewed identified these rumors as a reason for reduced chicken consumption. A farmer who had a flock of 4,500 broiler chickens and who had lost nearly BDT 0.1 million in April 2020 alone commented:

> *"At this time of uncertainty, people are afraid to eat chicken, a large part of the public, especially the villagers, believe that eating chicken meat is likely to cause COVID-19."*

Another informant, a wholesaler and retailer of both broiler and Sonali chickens, said:

> *"A large portion of regular chicken buyers are currently absent from the market; many also believe that COVID-19 may be transmitted to humans from poultry and poultry products. The declining sales volume has already caused me a huge loss."*

Several news articles also presented the rumors as a major cause of the drop in consumer demand (Ali, 2020; Sharma, 2020). These describe how misconceptions about the potential transmission of COVID-19 by chickens and other meat products led consumers to cut back on chicken consumption, contributing to a sharp drop in market demand with the result that prices fell by as much as 75% (Mahmud, 2020).

Despite the temporary positive turn in price during Ramadan and Eid, feed dealers, whose role in the transaction chain is to provide credit to farmers, claimed that demand for chicken and eggs did not match that of previous years and that this prevented the input suppliers, farmers and traders from making the profits they expected. One article reporting on sales during this period noted that limited demand may not have been the only issue. It states that due to the closure of many farms, interrupted production, and transportation problems, the supply and sales volume of chickens in the market were low and it did not return to normal until June 2020 (The Observer, 2020). Thus, although prices may have increased in response to increasing demand during this period, that does not necessarily indicate a substantial enough recovery throughout the production and distribution network for stakeholders working across the industry to bounce back and function as they had prior to COVID-19.

Economic Consequences

Disruption to business across the production and distribution network resulted in price fluctuations and financial losses for stakeholders across the sector. In an overview of the impact the pandemic had, the Bangladesh Poultry Industries Central Council (BPICC) reported an approximate loss of above BDT 300 billion in the country's poultry industry between 26 March and 30 April 2020 (Ali, 2020).

It is normal for the prices of chickens and eggs to varying over the year and so some stakeholders anticipated market volatility as soon as the pandemic began. However, despite varying levels of anticipation, most were unable to respond rapidly. Initially, prices of chickens and eggs fell due to lower-than-normal demand, and then rose dramatically during Ramadan. The initial drop in price resulted in many stakeholders temporarily shutting down operations or focusing on alternative agricultural endeavors. The Bangladesh Poultry Industries Central Council (BPICC) reported that 50–60% of all poultry farms closed temporarily in response to COVID-19 (Ali, 2020). Although a portion of the broiler farmers restarted farming by June (IDLC, 2020), the permanence of most of these closures is still unclear, in February 2021, 30% of broiler farms and hatcheries that closed due to the pandemic in April 2020 had remained closed to date (Financial Express, 2021).

Informants from all groups reported a drop in the price of their commodities and described this as a direct consequence of a fall in demand. For farmers, this meant from the earlier retail price of BDT 130–150 per kg of broiler, the price fell below BDT 90 in March and April. This was challenging for farmers as the production costs for broilers per kg were between BDT 90–100. All farmers reported that traders were also reluctant to buy their chickens and eggs due to this low price. A medium scale broiler farmer mentioned that:

> *"Since the lockdown started, I have not been able to sell my chickens at the same price as before. Traders are not interested in buying chickens as before due to the risk of losses...Many poultry stalls are already closed in LBM. Mobile vendors and seasonal vendors (sell broiler chicken during the festival time) are not doing poultry business at this moment."*

This is confirmed by a report from the Food and Agricultural Organization of the United Nations, stating that about 70% of chickens were said to remain unsold (Food Agriculture Organization, 2020b). As a result, farmers were forced to sell birds and eggs at a very low price. A large-scale broiler farmer, who for decades had reared flocks of more than 5,000 birds, shared his experience saying:

> *"I never experienced this kind of critical situation in the last 10 years. I cannot sell mature broiler to middlemen even at BDT 80–90 per kg, whereas my production cost is near BDT 100 per kg."*

This discrepancy between production cost and wholesale price made the business unsustainable for many farmers. Consequently, around 70% of small to medium-sized broiler farms were closed by April (IDLC, 2020). Small-scale farms were hard-hit, while many large-scale farms reduced their flock size, the result of which was that chicken meat production rapidly declined from 90,000 to 25,000–27,000 tons/month (Ali, 2020).

For layer farmers, the cost of production per egg was around BDT 5.50, but the market price fell to BDT 4.00. Nevertheless, it was reported that nearly 50% of eggs remained unsold (Food Agriculture Organization, 2020b). From the onset of the pandemic until April, 32–35% of the layer farms were completely closed (Ali, 2020). During interviews, farmers reported selling their laying hens as spent hens before the end of their laying cycle to reduce financial losses.

Both broiler and layer farmers expressed concerns about the sustainability of their activity. This was due to the price fluctuations, particularly for broilers, where the impact was amplified because farmers depend on credit provided by feed dealers. The credits are usually reimbursed at the end of the batch production cycle, the sale was often managed, and prices negotiated by the feed dealers/lenders. However, due to the adverse situation brought on by COVID-19, farmers were unable to repay their creditors. Some marginal small-scale farmers stopped poultry farming temporarily or permanently and reported setting up new agricultural activities or non-agricultural small-scale businesses instead. Describing his plight, a small-scale broiler farmer (1,500 bird) stated:

> *"If this situation lasts, I will have to leave poultry farming forever. I have already lost BDT 100,000 with the last batch. The feed dealer is pressuring me to reimburse my credit. I am now doing other agricultural work on my land, and I had to sell my cow as I needed cash."*

If a farm closes, as described in the quote above, dealers cannot recover the arrears owed by farmers. In a word, the unanticipated incidents in the poultry sector disrupted the cash flow among all the stakeholders associated with the entire transaction chain.

Input suppliers also reported a loss of income. According to a senior official at one of the country's leading poultry hatcheries:

> *"Chicken prices are usually slightly higher in March and April, so this is a profitable season for poultry traders and producers. But with the onset of the pandemic in the country and the government's declaration of lockdown on March 26, the situation was completely reversed. Broiler and layer DOC prices had come down from BDT 30 and 40 to BDT 15 and 18, respectively."*

The prices of day-old layer chicks and broiler chicks reportedly declined by 75 and 90%, respectively. Besides, 40–50% of newly hatched DOCs were reported to be unsold (Food Agriculture Organization, 2020b). Several hatcheries reported that they had to cull unsold DOCs and sell hatchable eggs as table eggs at the very low price of BDT 3.9–5.5 (USD 0.046- 0.065). Noting the comparative difference between the DOC production cost and the selling price, the general manager of an agriculture-based company commented:

> *"The sale price of broiler DOC dropped below the production cost. Now, broiler DOC selling price is BDT 4–5, whereas it was around BDT 35 before COVID-19. Our production cost is around BDT 30–32. So, we had to reduce the weekly production of DOCs from 13 million to 7.5–8 million."*

Consequently, hatcheries, breeders and feed industries had to reduce the production of DOCs, feed and medicine in an attempt to mitigate their financial losses. Bangladesh Poultry Industries Central Council (BPICC) found near 50% of the hatcheries ceased DOC production (Ali, 2020), and overall poultry production nosedived to almost 50% in a matter of months (Berkhout, 2020). A report of 120 hatcheries that used to produce 1.4 million broiler chicks and 17 million layer chicks weekly, dropped to around 9 million as many commercial poultry farmers postponed farming (Ali, 2020).

While some participants described the adverse effects of falling demand on their business and the actions they took to mitigate financial losses, traders reported additional causes for the financial losses they experienced. These included higher transportation costs, restricted business hours, the management of an unusually high number of unsold birds, and the inability to reduce their daily expenditures despite the reduction of their business. Referring to the overall loss due to regular expenses regardless of deficient income, one wholesaler commented:

> *"Revenues have reduced with declined price and supply. But you know, my operational cost did not decrease, I have to pay the rent of the shop, the salary of the staff, utility bill, etc. In the last three months, I have lost around BDT 400,000–450,000 from my capital."*

Wholesalers and retailers also reported that due to low consumer demand and restricted business hours (10 a.m. to 4 p.m.), many more birds than usual were left unsold every day meaning that vendors had to bear the cost of keeping them alive (**Figure 4**).

Appeals for Intervention and Support

Despite government efforts to limit financial loss across the sector in the form of cash incentives (Amin, 2020; MOFL-Ministry of Fisheries Livestock, 2020b), subsidized feed, medicines and vaccines (AgriNews24, 2020), and health messaging to counteract rumors (UNB, 2020), informants from all stakeholder groups still described the need for financial support from the government and urged national and international NGOs and multilateral organizations to help. Notably, poultry traders did not expect to receive any financial support from the government themselves but supported the government for small-scale, marginal farmers.

Most respondents in the input suppliers group reported that they had already sought interest-free or low-interest loans from the government together with the cancellation of utility bills. For farmers, however, concerns were raised about access to the stimulation package offered by the government. Only one small-scale broiler farmer whom we interviewed reported having benefited from governmental and NGO financial support. Another, who had reduced his flock size by about two-thirds expressed fears that:

> *"I haven't got any government support yet. I am sure if the government provides financial support, it won't reach us at all. It will be for big poultry farms or companies."*

Respondents from all groups also recommended that the government should intervene to stabilize prices. Some specifically sought government intervention as some trading syndicates were reportedly seeking to control the poultry market by manipulating prices. Both farmers and traders highlighted the volatility of production input and output prices as an issue, with farmers' concerns focusing particularly on DOC, eggs and mature birds, and their consequences for the future of their activity.

Informants from the input suppliers group urged the government to reduce import taxes on agricultural products. They also asked that government raise public awareness to curb misinformation connecting chickens to the spread of COVID-19.

CONCLUSION AND RECOMMENDATIONS

Ultimately, this work has shown that the lockdown that was put in place in response to the COVID-19 pandemic has had a significant effect on the poultry sector in Bangladesh. Rumors that arose during the initial lockdown period linking the disease to chicken consumption had a small, but not inconsequential impact and one that reveals the importance of accurate health messaging in times of crisis.

Crucially, although many of the disruptions identified in this study can be linked to the impact that COVID-19 has had on the poultry industry, it is important to recognize that many of the most significant consequences of the pandemic—such as the volatility of input and production prices and credit-dependence—are structural factors. Rather than being created by the crisis, COVID-19 rather brought these endemic issues to the fore and previously hidden structural fragility to light (Hennessey et al., 2021). For example, price fluctuations and credit dependence were both existing concerns for farmers prior to the pandemic but became significantly damaging during the lockdown period in ways that individuals were unable to mitigate—leading to the loss of income and entire businesses closing in some cases. Therefore, while this work highlights the need for specific interventions to be implemented when facing a pandemic, it also acts as a reminder that some structural factors need to be examined in the long term, as, independently from the pandemic, they negatively impact food security, income generation for stakeholders and may well-generate other types of pandemic risk.

Based on these preliminary findings, this research indicates that the sector needs a program of effective short, medium and long-term interventions that can be implemented in response to disruptions that arise at different points of the poultry industry's extensive network. Further research would be required to understand the full extent of the impact that COVID-19 has on the sector in the longer term which is being undertaken by our research team. This study is able to suggest that any future research and development of interventions should consider the following:

- The government must be prepared to promptly disseminate public health information and develop a strategy to prevent and counter the spread of false news and misleading information in anticipation of any future pandemics. In the case of COVID-19, public information campaigns should continue to promote the dietary value of consuming eggs and chicken for overall health and immunity and provide additional resources to help consumers access poultry products safely and counter prominent rumors.

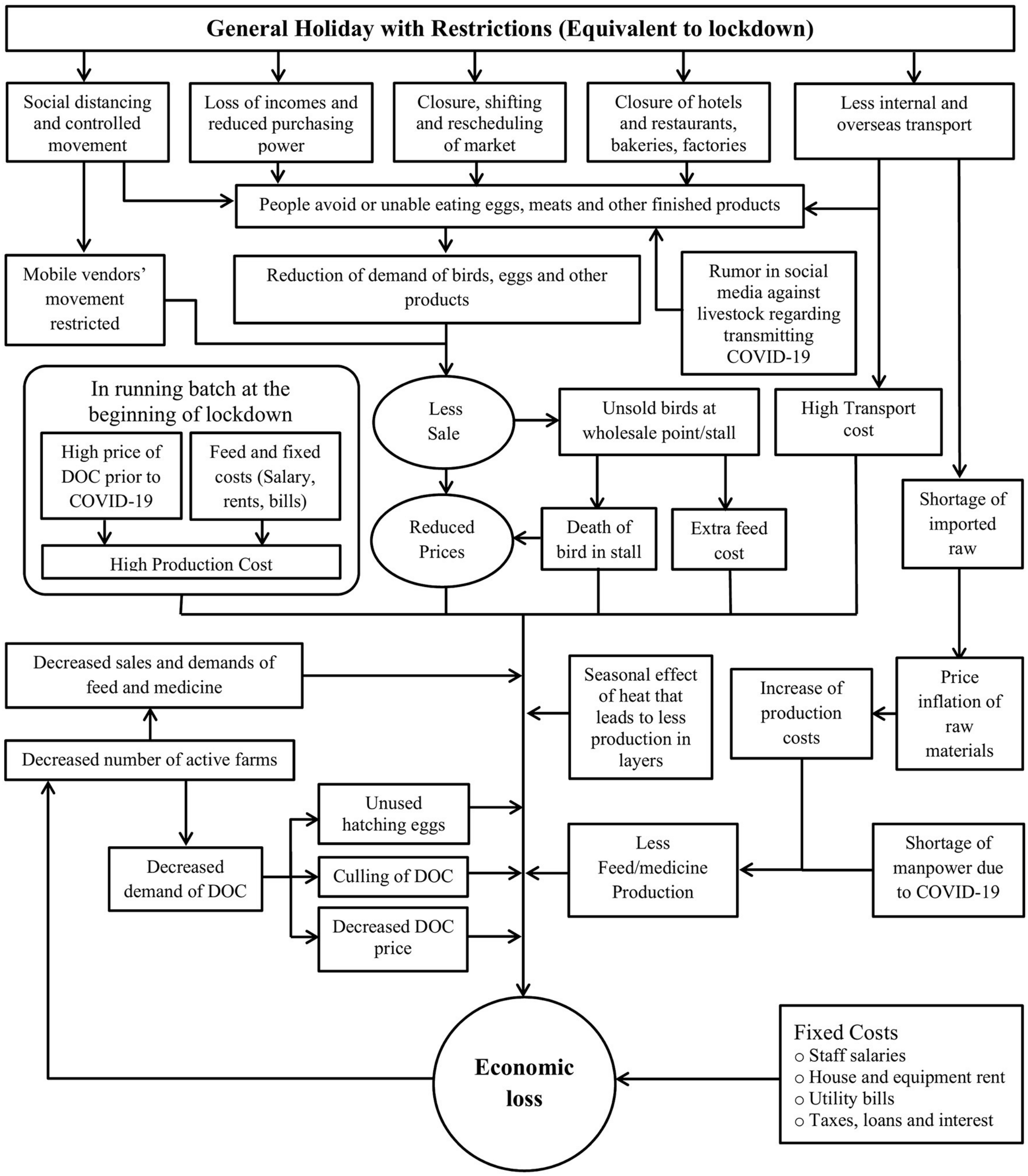

FIGURE 4 | Impact of COVID-19 on PDN in Bangladesh.

- The financial incentives announced by the government must reach vulnerable stakeholders, including marginal farmers. This will depend on better dissemination of information about what is available and consideration of how they will be accessed. Specifically, the procedures of getting and repaying bank loans need to be made more flexible for the agricultural and livestock sector, with government acknowledgment of the complex financial relationships businesses may be reliant on.
- The COVID-19 pandemic has highlighted limitations to continuing safe farming and distribution practices in times of national crisis. The livestock and agriculture sector should be declared as essential or strategic activities of public interest in order to continue smooth production during the COVID-19 pandemic. It is also essential to develop a medically responsible, unobstructed and fast transportation system to maintain the proper distribution of agricultural products around the country during any crisis.

- Gaining a better understanding of the underlying structural fragility of agricultural, fisheries and livestock sectors should be a priority. Doing so will enable the policy makers to develop a constructive and proactive pre-plan for rapid rehabilitation and provision of alternative income-generating activities for stakeholders involved in these sectors affected by a pandemic or other natural disasters in future.
- To connect producers, businesses and consumers in any circumstances, explore alternative sales and distribution platforms of poultry and poultry products through online resources and e-commerce to a greater degree.
- In order to ensure food security for every citizen of the country during and after the pandemic, the government must be prepared with the resources necessary to ensure optimal livestock and agricultural production, as well as equitable distribution and price regulation.

In addition to these recommendations, this research has revealed some areas warranting further investigation. Specifically, it is worth considering what the "fragility" discussed here means for how different stakeholders structure their business and strive to adapt to challenges as they arise. For those farmers suspending or closing poultry production in response to the pandemic, it may be that they were not solely dependent on this income source and were able to shift their attention to other income-generating activities. Evidence that marginal and small-scale production is more likely to have ceased operations than larger farms, should encourage us to consider whether COVID-19 marks a permanent shift in favor of larger-scale integrated production and what this would mean for the future of the poultry sector as a whole. Ultimately, although not to underestimate the challenges and losses affecting the many people who were hit hard as a result of COVID-19, we should problematize the evidence of "fragility" seen here and consider if the survival of the sector despite this actually presents us with as yet unresearched evidence of resilience.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

RM: stakeholder interview. MM, NC, MU, AS, and NI: literature review and market data collection. AS: data analysis and interpretation of results. AS and EH: draft manuscript preparation. TB, GF, and MH: critical review and feedback. MH: study conception and design. All authors contributed to the article and approved the submitted version.

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REFERENCES

AgriNews24 (2020). *The Ministry of Fisheries and Livestock Will Provide Feed to the Farmers at Subsidized Price (In Bengali)*. Available online at: https://tinyurl.com/y9wz73yz (accessed December 28, 2020).

Ali, S. (2020). *Poultry Production Falls Alarmingly*. Available online at: https://tbsnews.net/coronavirus-chronicle/covid-19-bangladesh/poultry-production-falls-alarmingly-80857 (accessed December 28, 2020).

Amin, M. A. (2020). *Tackling Coronavirus: PM Announces Tk5,000cr Package for Bangladesh's Agriculture Sector*. Available online at: https://www.dhakatribune.com/bangladesh/2020/04/12/coronavirus-pm-holds-videoconference-with-district-officials-of-khulna-barisal (accessed April 12, 2020).

Barrett, R. (2020). *Wisconsin Farmers Forced to Dump Milk as Coronavirus Slams a Fragile Dairy Economy*. Available online at: https://www.jsonline.com/story/money/2020/04/01/coronavirus-forces-dairy-farmers-dump-milk-wisconsin-covid-19/5108609002/ (accessed December 18, 2020).

Berkhout, N. (2020). *Bangladesh Poultry Production Plummets*. Available online at: https://www.poultryworld.net/Meat/Articles/2020/5/Bangladesh-poultry-production-plummets-585903E/ (accessed December 28, 2020).

Chattopadhyay, K., Fournié, G., Abul Kalam, M., Biswas, P. K., Hoque, A., Debnath, N. C., et al. (2018). A qualitative stakeholder analysis of avian influenza policy in Bangladesh. *Ecohealth* 15, 63–71. doi: 10.1007/s10393-017-1285-2

DLS: Department of Livestock Services (2020). *Livestock Economy at a Glance*. Available online at: http://dls.portal.gov.bd/sites/default/files/files/dls.portal.gov.bd/page/ee5f4621_fa3a_40ac_8bd9_898fb8ee4700/2020-07-22-19-34-e4cd5ed65f45419ee038e00b8939c1a0.pdf (accessed December 24, 2020).

FAOSTAT (2019). Available online at: http://www.fao.org/faostat/en/ (accessed December 28, 2020).

Financial Express (2021). *Poultry Meat Gets Dearer in Dhaka*. Available online at: https://www.thefinancialexpress.com.bd/trade/poultry-meat-gets-dearer-in-dhaka-1614316181 (accessed February 23, 2021).

Food and Agriculture Organization (2020a). *Mitigating the Impacts of COVID-19 on the Livestock Sector*. Available online at: http://www.fao.org/3/ca8799en/CA8799EN.pdf (accessed December 23, 2020).

Food and Agriculture Organization (2020b). *Rapid Assessment of Food and Nutrition Security in the Context of COVID-19 in Bangladesh*. Available online at: https://fscluster.org/sites/default/files/documents/fao_bangladesh_covid-19_rapid_assessment_report_09-05-2020_final13may2020.pdf (accessed December 28, 2020).

Genoni, M. E., Khan, A. I., Krishnan, N., Palaniswamy, N., and Raza, W. (2020). *Losing Livelihoods: The Labor Market Impacts of COVID-19 in Bangladesh*. Washington, DC: World Bank. doi: 10.1596/34449

Good, K. (2020). *As COVID-19 Slows Meat Processing, Meat Shortages a Growing Concern; Livestock Producers Face Tough Choices*. Available online at: https://farmpolicynews.illinois.edu/2020/04/as-covid-19-slows-meat-processing-livestock-producers-may-face-tough-choices/ (accessed December 16, 2020).

Gupta, S. D., Hoque, M. A., Fournié, G., and Henning, J. (2021). Patterns of Avian Influenza A (H5) and A (H9) virus infection in backyard, commercial broiler and layer chicken farms in Bangladesh. *Transbound Emerg. Dis.* 68, 137–151. doi: 10.1111/tbed.13657

Hamid, M., Rahman, M., Ahmed, S., and Hossain, K. J. A. J. o. P. S. (2017). Status of poultry industry in Bangladesh and the role of private sector for its development. *Asian J. Poult. Sci*. 11, 1–13. doi: 10.3923/ajpsaj.2017.1.13

Hennessey, M., Fourni,é, G., Hoque, M. A., Biswas, P. K., Alarcon, P., Ebata, A., et al. (2021). Intensification of fragility: poultry production and distribution in Bangladesh and its implications for disease risk. *Prev. Vet. Med.* 191:105367. doi: 10.1016/j.prevetmed.2021.105367

Høg, E., Fournié, G., Hoque, M. A., Mahmud, R., Pfeiffer, D. U., and Barnett, T. (2019). Competing biosecurity and risk rationalities in the Chittagong poultry commodity chain, Bangladesh. *BioSocieties* 14, 368–392. doi: 10.1057/s41292-018-0131-2

Hossain, T. M. (2020). *Bangladesh: Grain and Feed Annual. USDA*. Available online at: https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Grain%20and%20Feed%20Annual_Dhaka_Bangladesh_03-27-2020 (accessed December 22, 2020).

Huffstutter, P. J. (2020). *U.S. Dairy Farmers Dump Milk as Pandemic Upends Food Markets*. Available online at: https://www.weforum.org/agenda/2020/04/dairy-milk-pandemic-supply-chains-coronavirus-covid19-pandemic/ (accessed December 17, 2020).

IDLC (2020). "Feed industry of Bangladesh: sustaining COVID-19 and potentials in upcoming days," in *IDLC Monthly Business Review*. Available online at: https://idlc.com/mbr/images/public/xWV4Ylp7Dg1TyTKLENXGmW.pdf (accessed December, 2020).

InEuropa (2020). *FoodTalks: Coronavirus and Food Waste*. Available online at: https://www.progettareineuropa.com/en/2020/03/foodtalks-coronavirus-and-food-waste/ (accessed December, 2020).

Islam, J., and Babu, M. U. (2020). *Bangladesh Rural Economy Reels From Shutdown*. Available: https://www.tbsnews.net/economy/rural-economy-reels-shutdown-63994 (accessed December 28, 2020).

Khan, M. R. (2021). *Lockdown Deals Fresh Blow to Poultry Farmers*. Available online at: https://www.thedailystar.net/business/economy/news/lockdown-deals-fresh-blow-poultry-farmers-2079333 (accessed April 24, 2021).

Mahmud, N. (2020). *Coronavirus: Local Poultry Industry Facing a Massive Loss*. Available online at: https://www.dhakatribune.com/health/coronavirus/2020/04/03/coronavirus-local-poultry-industry-facing-a-massive-loss (accessed December 28, 2020).

Marchant-Forde, J. N., and Boyle, L. A. (2020). COVID-19 effects on livestock production: a one welfare issue. *Front. Vet. Sci.* 7:585787. doi: 10.3389/fvets.2020.585787

Miah, A. S. M. J., Islam, T., Anika, I. A., and Swarna, N. R. (2020). *Economic Impact of COVID-19 and Way forward for Bangladesh*. Available online at: https://www.brac.net/images/news/downloads/Economic-Impact_PPT_9%20June_final.pdf (accessed December 28, 2020).

MOFL-Ministry of Fisheries And Livestock (2020a). *Demand and Supply of Livestock in Last 10 Years*. Available online at: shorturl.at/hqwS2 (accessed January 1, 2021).

MOFL-Ministry of Fisheries And Livestock (2020b). *Due to the Outbreak of Nobel Coronavirus, the Formulation, and Management of Refinancing Schemes Worth BDT 5,000 Crore for the Provision of Working Capital in the Agricultural Sector (In Bengali)*. Available online at: https://mofl.gov.bd/sites/default/files/files/mofl.portal.gov.bd/divisional_noc/9646112a_e6ab_47cd_8361_03885933294d/Bangladesh%20bank.pdf (accessed November, 2020).

MoFood-Ministry of Food (2020). *Bangladesh Second Country Investment Plan Nutrition-Sensitive Food Systems (CIP2 2016-2020) Monitoring Report*. Available online at: https://mofood.portal.gov.bd/sites/default/files/files/mofood.portal.gov.bd/policies/9671c0af_d252_4042_8d86_b09ca74cc258/MonitoringReport2020.pdf (accessed December 28, 2020).

Moyen, N., Hoque, M. A., Mahmud, R., Hasan, M., Sarkar, S., Biswas, P. K., et al. (2021). Avian influenza transmission risk along live poultry trading networks, *Bangladesh. Nat. Sci. Rep*. (Under review).

Mulder, N. (2020). *Poultry Quarterly Q3 2020, Fragile Recovery After Covid-19 Storm*. Available online at: https://avicultura.info/en/poultry-quarterly-2020-fragile-recovery-after-covid19-storm/ (accessed December 18, 2020).

New Age (2020). *Prices of Ramadan Essentials Rise*. Available online at: https://www.newagebd.net/article/105050/prices-of-ramadan-essentials-rise.%20Accessed:%20September%202020 (accessed December 24, 2020).

Pope, C., Ziebland, S., and Mays, N. (2000). Qualitative research in health care. Analysing qualitative data. *BMJ* 320, 114–116. doi: 10.1136/bmj.320.7227.114

Poultry World (2012). *Bangladesh Allows Egg Imports to Meet Ramadan Demand*. Available online at: https://www.poultryworld.net/Broilers/Markets--Trade/2012/6/Bangladesh-allows-egg-imports-to-meet-Ramadan-demand-WP010484W/ (accessed December 24, 2020).

Rahman, M. F., and Ruszczyk, H. A. (2020). *Coronavirus: How Lockdown Exposed Food Insecurity in a Small Bangladeshi City*. Available online at: https://theconversation.com/coronavirus-how-lockdown-exposed-food-insecurity-in-a-small-bangladeshi-city-140684 (accessed December 28, 2020).

Rosen, L. (2020). *Field Notes: Bangladesh in Times of COVID-19 and Food Security Implications*. Available online at: https://fish.cgiar.org/news-and-updates/news/field-notes-bangladesh-times-covid-19-and-food-security-implications (accessed December 28, 2020).

Saeque, M. A. (2020). *Mitigating the Impact of COVID-19 on Poultry Sector*. Available online at: https://www.aci-bd.com/all-news/mitigating-the-impact-of-covid-19-on-poultry-sector.html (accessed December 26, 2020).

Sharma, S. (2020). *Poultry Sector Loses Hope as Sales Hit More by Rumours Than Lockdown; Govt Says, Eating Chicken Safe*. Available online at: https://www.financialexpress.com/economy/poultry-sector-looses-hope-as-sales-hit-more-by-rumours-than-lockdown-govt-says-eating-chicken-safe/1917922/ (accessed December 28 2020).

TBSNEWS (2020). *Close Shops, Supershops, Kitchen Markets by 7pm Daily: DMP*. Available online at: https://www.tbsnews.net/coronavirus-chronicle/covid-19-bangladesh/close-shops-supershops-kitchen-markets-6pm-daily-dmp-65857 (accessed December 28, 2020).

The Independent (2020). *Poultry Industry Hit Hard*. Available online at: https://www.theindependentbd.com/post/243190 (accessed November 28, 2020).

UNB (2020). *Crisis in poultry, Dairy Sector: Ministry to Open Control Room*. Available online at: https://unb.com.bd/category/Bangladesh/crisis-in-poultry-dairy-sector-ministry-to-open-control-room/48543 (accessed November 27, 2020).

World Health Organization (2020a). *Bangladesh COVID-19 Situation Report No. 10*. Available online at: https://www.who.int/docs/default-source/searo/bangladesh/covid-19-who-bangladesh-situation-reports/who-ban-covid-19-sitrep-10.pdf?sfvrsn=c0aac0b8_4 (accessed December 20, 2020).

World Health Organization (2020b). *Bangladesh COVID-19 Situation Report No. 4*. Available online at: https://cdn.who.int/media/docs/default-source/searo/bangladesh/covid-19-who-bangladesh-situation-reports/who-ban-covid-19-sitrep-04.pdf?sfvrsn=69b6d931_8 (accessed December 23, 2020).

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frontiers in Sustainable Food Systems

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From Farm to Fork: Early Impacts of COVID-19 on Food Supply Chain

Shalika Vyas*, Nitya Chanana, Madhur Chanana and Pramod K. Aggarwal

Consultative Group on International Agricultural Research (CGIAR) Research Program on Climate Change, Agriculture and Food Security (CCAFS), Borlaug Institute for South Asia (BISA), International Maize and Wheat Improvement Centre (CIMMYT), New Delhi, India

COVID-19 pandemic has resulted in widespread global disruptions. While much is being discussed about the health and economic impacts, there has been a limited focus on the immediate food sector shocks and their related social implications in developing countries, especially when the farmer surveys cannot be conducted due to mobility restrictions in many countries. To overcome these challenges, this study uses news mining and content analysis of media articles published from February to April 2020, to assess the early impacts of the COVID-19 pandemic on the food supply chain and farm distress in India. It also presents the media perception of the impact of the pandemic and resulting policy measures using sentiment analysis, in addition to the cross-tabulation of results that show differential impacts across food supply chain components among different commodity groups and regions. The results show wide-scale impacts across different components of the food supply chain ranging from crop harvesting and processing, distribution and logistics to disruptions across food markets, as represented by 22, 11 and 30% of total articles, respectively. The impacts are also differentiated by commodity groups, with animal products having more trade and demand-side issues, logistic bottlenecks in fruits and vegetables and crops showing problems in labor availability and harvesting. Sentiment analysis of news items shows a spike in the negative sentiment immediately post the national lockdown, with relatively less negativity in subsequent weeks due to large-scale policy and community action. Sentiment classification along different indicators shows the highest negative sentiment for animal products (85%) in commodity groups, western states of India (78%) among different regions, and food supply (85%) and markets (83%) among supply chain components. Further, extreme weather analysis (using excess rainfall events) shows that farmers faced compound risks from the COVID-19 pandemic and extreme weather events in many parts of the country. The results highlight the importance of building resilient food systems, especially when the biotic and abiotic shocks are projected to increase globally due to many drivers including biodiversity loss and climate change.

Keywords: food, supply chain, COVID-19, market, producer, India, news mining

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*Patrick Meyfroidt,
Catholic University of Louvain, Belgium*

Reviewed by:
*Hilary King,
Emory University, United States*
*Shilp Verma,
International Water Management Institute, Sri Lanka*

****Correspondence:***
*Shalika Vyas
S.vyas@cgiar.org*

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INTRODUCTION

COVID-19 declared as a pandemic by WHO is an ongoing global health emergency being faced by countries across the world. From its first emergence in China in December 2019, the disease has rapidly spread, infecting more than 157.36 million people globally and fatally affecting 3.27 million people as of 11th May 2021 (World Health Organization, 2021). The highly transmissive nature of the disease forced several countries to impose regulations related to social distancing, self-isolation and travel restrictions (Nicola et al., 2020). Implementation of a nationwide lockdown, including the closure of international borders and, in some cases, domestic borders was an instant and important measure adopted by most countries to control the spread of the virus. In countries with full lockdown, fears of a socio-economic and; humanitarian crisis were highlighted as different sectors were negatively impacted (Abhishek et al., 2020; McKibbin and Fernando, 2020; UNDP, 2020).

Among other macro-economic impacts like poverty (Buheji et al., 2020) and trade (Maliszewska et al., 2020), food supply chain disruption was also an increasingly highlighted area of concern, especially for countries such as India that are largely comprised of small agricultural producers (Workie et al., 2020). Restricted access to markets and labor, along with reduced food demand were some of the key challenges in such places (FAO, 2020a; United Nations, 2020). Other global crises in the past such as the 2014 Ebola virus disease (EVD) epidemic, as well as the food price crisis of 2006–2008, also suggest similar patterns of supply chain disruptions in many countries (FAO, 2016, 2020b). However, given the wide scale of the COVID-19 pandemic, its socio-economic implications are expected to be more severe. These may range from increased food insecurity and malnutrition to a rise in poverty and inequality (Headey and Ruel, 2020; Laborde et al., 2020; Sumner et al., 2020).

The first official COVID-19 case in India was reported on 30th January 2020. Since then the Indian government announced a slew of measures to contain the spread of the disease and to manage the resulting impact of the same. On 12th March the government declared international travel bans and on 25th March, a nationwide lockdown was declared with mobility restrictions across the country. The resulting lockdown had an extensive impact on Indian agriculture across different commodities—from aquaculture (Kumaran et al., 2021) and fisheries (Avtar et al., 2021), to cereals (Balwinder-Singh et al., 2020) and vegetables (Harris et al., 2020). The lockdown resulted in supply chain bottlenecks for various agricultural commodities and affected agricultural supply and production. Several studies highlighting these trends utilized qualitative and quantitative surveys, remote sensing methods, modeling techniques and analysis of publicly available data. However, these methods are limited in their scope (both spatial and temporal), and surveys require substantial time and logistical resources to generate data. Further, the available literature does not highlight compound shocks faced by the farmers. In this paper, therefore, we utilize news mining as an innovative data collection methodology to analyze the immediate impact of COVID-19 on the Indian food supply chain. News mining is an upcoming tool that can generate useful and actionable insights, especially for dynamic scenarios such as the ongoing pandemic (Buckingham et al., 2020; Jahanbin and Rahmanian, 2020; Sadman et al., 2021). In fact, recent studies have used media analysis to understand the impact of the COVID-19 pandemic on various sectors including public health and food (Bai et al., 2020; Thomas et al., 2020; Moriom Khatun et al., 2021; Suryadi, 2021). This study uses this tool for the following three objectives—(1) assessing early impacts of COVID-19 pandemic on different components and sectors of the food supply chain, (2) understanding the media perception of the impact of the pandemic and resulting policy measures using content and sentiment analysis and (3) analyzing compound risks (from the pandemic and extreme weather events) faced by supply chain players in the study period and identify the policy/community actions undertaken to overcome them.

DATA AND METHODS

Selection of Articles for Review

The selection and extraction of news articles involved multiple steps (**Figure 1**). Different keywords were used to search for the news articles in Google News. These keywords included a combination of words related to food supply and COVID-19 pandemic—COVID-19, pandemic, Corona, farmers, agriculture, agricultural producers, farm producers, consumers, food supply, agricultural supply chain, food supply chain, food demand. The "Selenium" package in Python was used to web scrap the articles from Google News. Only articles published in the English language were selected. The exclusion of regional language articles remains a limitation of this analysis. The initial search resulted in 6,568 news articles, for which the metadata was extracted including the Title, Date, Source, and a brief description of the article. These articles were screened for their relevance to the analysis, and duplicates were removed—resulting in a total of 2,361 articles, which were selected, and their full text was extracted. Out of this, all articles that referred to other countries (and not India) were excluded to get a list of 786 articles. This list was further refined to exclude articles that were not related to COVID-19 and food supply. A final subset of 335 articles was selected based on which the review was carried out. To focus on the immediate impact of COVID-19 (and resulting national lockdown in India on 25th March 2020), the entire analysis was conducted from 1st February to 6th April 2020, covering the first 2 weeks following the announcement of the national lockdown. There was no baseline data collected (number of articles published during non-COVID years), as the objective of the study was to assess impact of the COVID-19 pandemic on different components and sectors of food supply chain (and not a comparison of media analysis for baseline years and the COVID-19 pandemic). The duration of the temporal analysis and non-comparison with baseline data remains a limitation of the study.

Content Analysis

Framework

The framework described in **Figure 2** forms the basis of data collation and analysis of the selected articles. **Figure 2** shows how

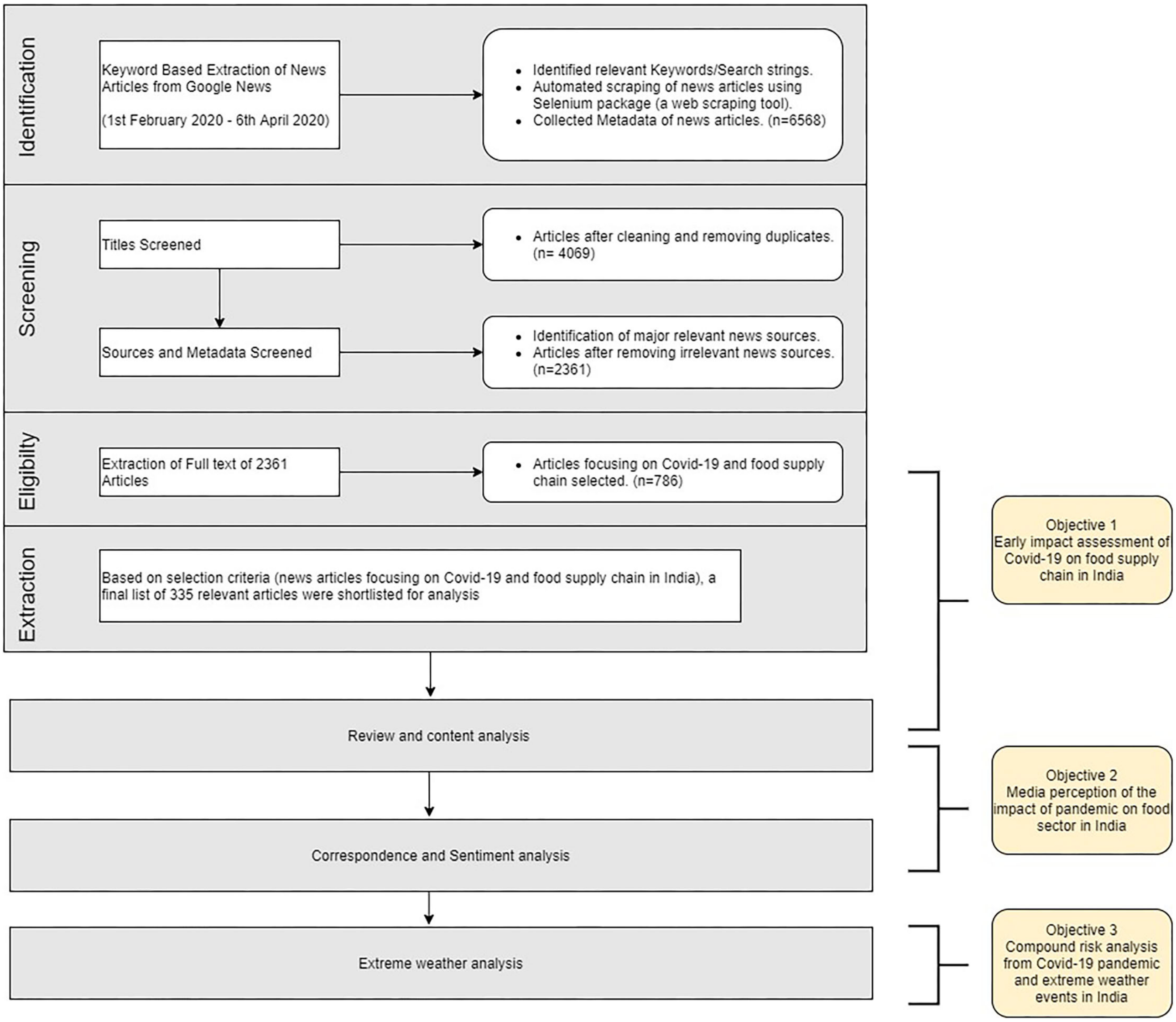

FIGURE 1 | Methodology for the selection and analysis of news articles.

food supply disruptions can be caused by both biotic and abiotic risks (in this case, the COVID-19 pandemic and extreme weather events, respectively). These risks affect different components of the supply chain including Labor (labor required for agricultural operations), Production inputs (seeds, fertilizers and pesticides), Harvesting and processing (harvesting operations and processing of different commodities, including post-harvest storage), Market and prices (farm, wholesale and retail markets, as well as price-related information for different commodities in these markets). These components affect different stakeholders of the supply chain—producers (farmers), market (market intermediaries) and consumers. To stabilize the food supply from the impact of different risks, public, private and trade-related actions are undertaken. The analysis presented in this paper is based on this framework—it assesses multiple risks that were faced by the food sector in the given timeframe, how these risks affected different stakeholders and components of the supply chain, and finally, how these impacts were managed through public and private initiatives.

While collating information from the articles selected from the news mining, the authors read through each article in detail and started categorizing the articles based on the type of risks focused upon in the articles, the components of supply chain impacted and different stakeholders affected, and the measures undertaken, if any, to resolve supply chain issues. In addition to the supply chain components described (**Figure 2**), there were a few articles that focused on the entire food sector, resulting in two additional categories—Food supply (articles focusing on food distribution and food security in general, including food supply for migrant workers stuck in

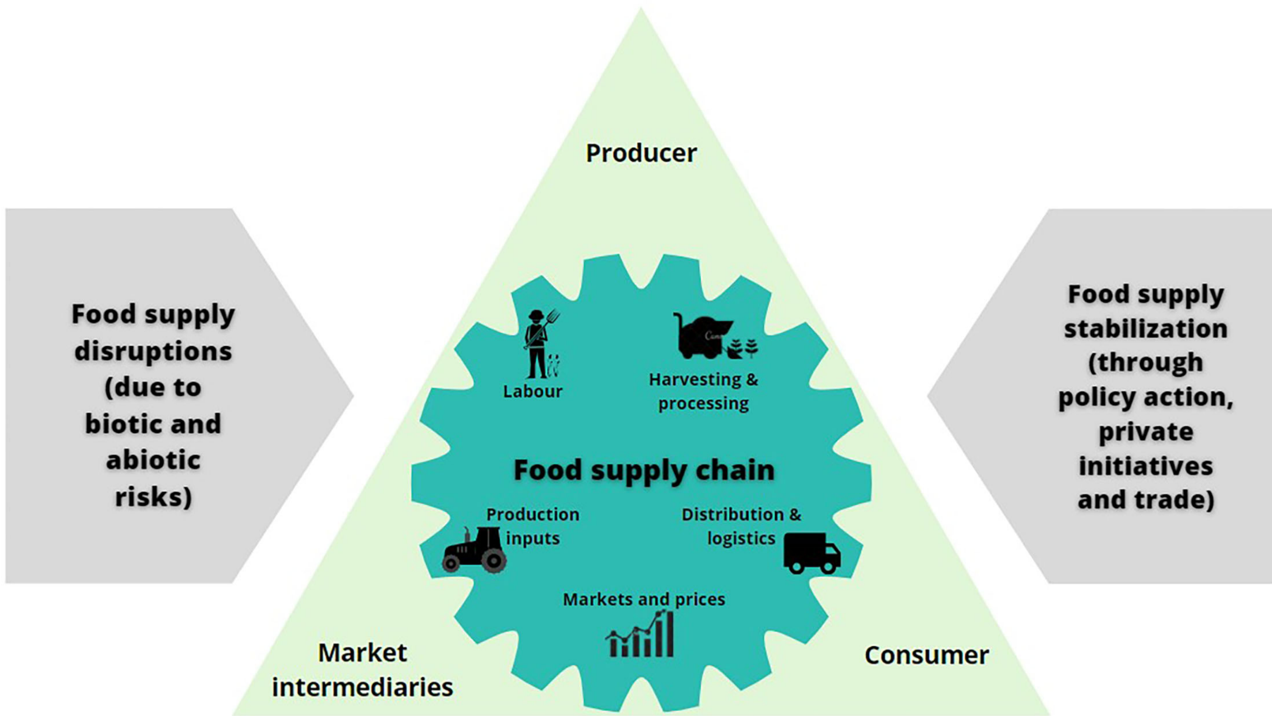

FIGURE 2 | Framework for assessing different risks affecting the food supply chain. Icon credit-this figure has been designed using visual icons from Flaticon.com.

many cities due to the lockdown) and Food demand (articles on food demand from different consumers). Information was also collected on different commodity groups, four exclusive categories for commodities included Food (articles where no specific commodity is mentioned or multiple commodities are mentioned), Crops (articles specifically related to arable crops like cereals, pulses, millets, oilseeds and other crops), Animal products (articles related to poultry, milk, fish and seafood) and Fruits and Vegetables. Additional information was also collected from the selected articles in the review, including the region/place focused upon in the news articles, the type of methods used and the date of publication.

Correspondence Analysis

A review of selected media articles, through the framework described above, helped in understanding the impacts of the COVID-19 pandemic on Indian agriculture. To further strengthen the qualitative insights, a correspondence analysis was also conducted on the full texts of the articles. Correspondence analysis is a quantitative exploratory technique, which helps in cross-tabulations and understanding the variation in the distribution of keywords across different commodities. This method is frequently used for qualitative analysis in social sciences (Brunette et al., 2018; Hjellbrekke, 2018) and has been recently used to understand the change in consumer perceptions and motivations toward food, after the COVID-19 pandemic (Laguna et al., 2020). For this study, the correspondence analysis was conducted using the WordStat software. The software first identified keywords from the full text of the selected articles and then calculated the contingency tables (crosstabulations) using the frequencies of these keywords across different categorical variables (in this case, different commodity groups).

Sentiment Analysis

For the second objective of the study, sentiment analysis was undertaken to assess the sentiment of news during the pandemic. Sentiment analysis categorizes data based on the "sentiment" of the words used. These "sentiments" are based on semantics, semantic theory, feelings around the words used (adjectives), and, etymology and phrasing; based on which the text can be classified into different sentiment groups, for example—negative, neutral and positive (Jacobs, 2019; Saura et al., 2019). For example, negative words like "panic," "frightened," and "devastated", which are mentioned across the article text are scored negatively, highlighting a negative sentiment. This analysis has been used by social science researchers to investigate research questions related to public opinion and perception (Soo et al., 2012), has also been used recently to analyze the public perception of quarantine guidelines as a result of the COVID-19 pandemic, in educational institutes (Pastor, 2020). For this study, a supervised learning model was trained with a 30% random sample using Monkey Learn, a widely used software for sentiment analysis[1]. The model was trained by assigning sentiment categories manually on 102 articles (∼30% of the total articles), which formed the

[1]MonkeyLearn API Reference. from https://monkeylearn.com/api/v3/.

training set. The five categories were Negative, Negative: Neutral, Neutral, Neutral: Positive, and Positive; with values −2, −1,0, 1, 2, respectively. These sentiment categories represent a scale, where the extreme end is "negative" where the incidence of words with negative sentiments are high, and with "positive" at the other end of the spectrum where words used in the article have positive connotations. For many news articles, a mix of both negative and positive words was observed, and these were classified in the middle of the scale—negative: neutral (presence of both positive and negative sentiments, but the proportion of negative sentiments is higher), neutral (both positive and negative sentiments equally present), and neutral: positive (presence of both negative and positive sentiments, but the proportion of positive sentiments is higher). Each article was assigned a tag and was fed to a feature extractor where the text vectorization was performed. The resultant list of features was then fed to a machine learning algorithm and passed to a classifier model. The model was strengthened and validated by achieving an efficiency score of 70%, which means that the model was repeatedly trained till 70% of the articles in the training set were correctly classified by the machine learning algorithm, across all five sentiment categories. The final model thus developed was used to classify the dataset of 335 articles. The results are presented using the frequency of the articles (under each sentiment category) based on their sentiment classification. As an example, an excerpt from the text of a news article which was classified as "negative" is presented—*"Rumors in India that birds could spread the coronavirus are taking a massive toll on sales of poultry in the world's second-most populous nation. The speculation is circulating on social media, according to B.S. Yadav, managing director of Godrej Agrovet Ltd., India's biggest compound animal feed company. Industry-wide weekly sales have plummeted at least 47% to 35 million to 40 million birds in the past 3–4 weeks, while prices have slumped almost 60%, he said. "The damage is so severe that whatever we have done in the past seven months will be wiped out if the decline in sales continues for next 1–2 months," Yadav said."*

Extreme Weather Analysis (Excess Rainfall)

To assess compound risks (both biotic and abiotic risks) faced by the food supply chain actors, analysis was also undertaken to assess the weather events which occurred during the study period (February to March 2020). We restrict the analysis to precipitation, as these were the main weather events reported by farmers in the media. Extreme rainfall, heat stress and hailstorms are the major climatic risks faced during the winter cropping season in India, which adversely affects crop production, especially during the maturity and harvest stage of crops like wheat (Zampieri et al., 2017). Excess rainfall is known to cause significant harvest[2] and post-harvest losses (Bjerge and Trifkovic, 2018; Li et al., 2019). Satellite-based daily precipitation data was downloaded from the Climate Prediction Centre of the National Oceanic and Atmospheric Administration (NOAA-CPC) at 0.1-degree resolution (Rainfall-NOAA-CPC-RFE V2.0). The daily precipitation data was analyzed to calculate three indices to assess rainfall volume and distribution in the study months—cumulative monthly rainfall, number of rainy days in a month (number of days when rainfall is >2.5 mm, as defined by the Indian Metrological Department) and maximum 1-day rainfall in a month. These indices are used by several crop monitoring systems to track weather events and monitor crop progress (Fritz et al., 2019; van der Velde and Nisini, 2019; Aggarwal et al., 2020). By assessing all the three indices together, areas with excessive rainfall risk were identified. Next, a cropland mask was used to highlight areas with significant crop acreage. A threshold of 50% was used to mask non-agricultural areas (only pixels where crop area was more than 50% were used).

RESULTS

Content Analysis

Overview of Key Trends

The news articles analyzed in this study were segregated into different groups to understand key trends (**Figure 3**). More than half of the news articles were nationally focused, followed by articles related to northern and southern parts of the country (state-wise distribution of news articles is given in **Supplementary Figure 2**). The news articles were also grouped based on the supply chain actors affected, with a third of the articles focusing on "Markets and price," while only 7.6% of the articles focusing on "Production inputs." Among different commodities, the highest share was of "Food." with minimal focus on "Fruits and vegetables." For different stakeholders, almost half of the articles focused on the market (intermediaries), followed by producers and consumers.

Out of the 335 articles reviewed, 66% of articles were published after the nationwide lockdown in the country. This is expected as media focus on food sector in the country increased after the national lockdown. However, a few exceptions in this trend were also observed for different sectors and components of the supply chain, for example, Animal Product (commodity) was the exception to this trend, with articles highlighting the commodity much before the lockdown (**Figure 4**). This was primarily driven by reduced export demand for poultry which began earlier in the year as the pandemic spread across countries, affecting international food trade. Post lockdown, the issues related to "Market and prices" increased, with the shutting down of wholesale and retail markets, increase in prices of different commodities across the country due to limited supply and panic-driven demand from consumers, and the closure of markets for mass sanitization. Logistics and Distribution challenges were also witnessed due to mobility restrictions from farms, warehouses and factories to wholesale and retail markets. Mobility restrictions, as well as labor shortage also affected labor intensive operations across the farms, storage and processing units, factories, transportation and markets.

Commodity and Theme-Wise Results

Figure 5 highlights the article frequency across the thematic areas and commodity group. About half of "Market and price" related disruptions were mentioned for the Food commodity.

[2] https://indianexpress.com/article/india/heavy-rain-damages-standing-crops-over-4-5-lakh-hectares-6745312/.

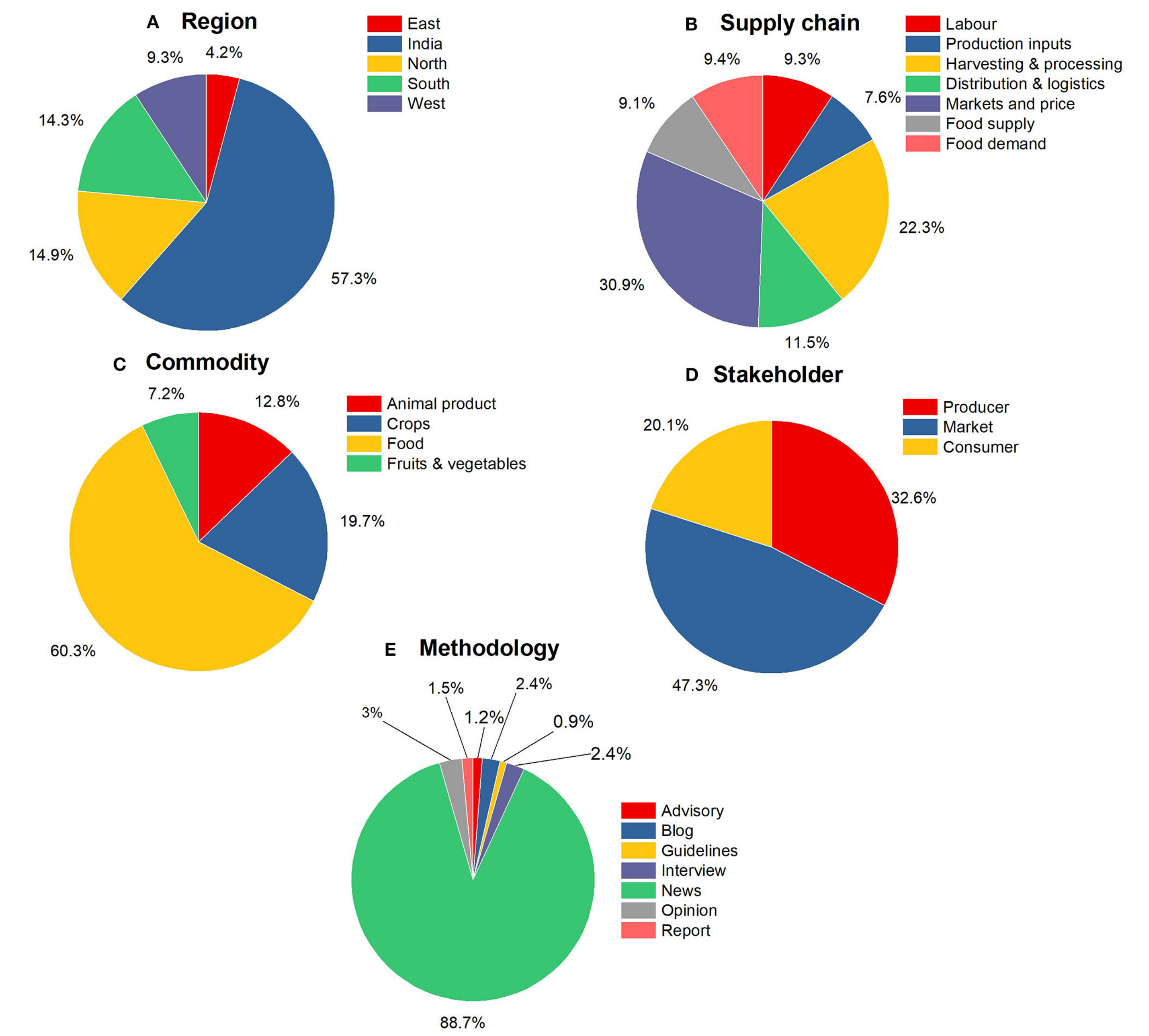

FIGURE 3 | Overview of news articles analyzed in the review by—**(A)** the region covered, **(B)** supply chain component affected, **(C)** commodity type, **(D)** type of stakeholder focused, and **(E)** methodology/type of news article.

For "Crops" commodity, harvesting and processing were the most affected operations, and many news articles reported labor shortage for harvesting of wheat crop in the northern parts of the country. This is also supported by literature—farmers in major wheat-producing states of Haryana and Punjab, contributing 60% to India's wheat procurement (Directorate of Economics Statistics, 2018), were unable to meet their requirement of about 1.6 million laborers for harvesting (Sethi, 2020). Additionally, the news articles also reported limited availability and access to harvesting machines, which further caused bottlenecks in harvest operations. To tackle this, the government assured procurement of wheat from farmers while requesting them to delay the harvesting by 2 weeks. In addition to this, storage of the harvested produce and limited accessibility to markets in rural areas for seeds and inputs for the next cropping season (summer crop) also emerged as an area of concern by farmers in the Northern and Southern regions of India, as reported by the news articles.

Impacts on "Animal Products" commodity were mainly related to poultry, with 80% of the total articles highlighting the decline in chicken prices as a result of reduced international and domestic demand (Kolluri et al., 2020; Rakshit and Basistha, 2020). The news articles highlighted that this market trend was driven by social media rumors about the spread of COVID-19 through birds which began earlier in 2020. Consequently,

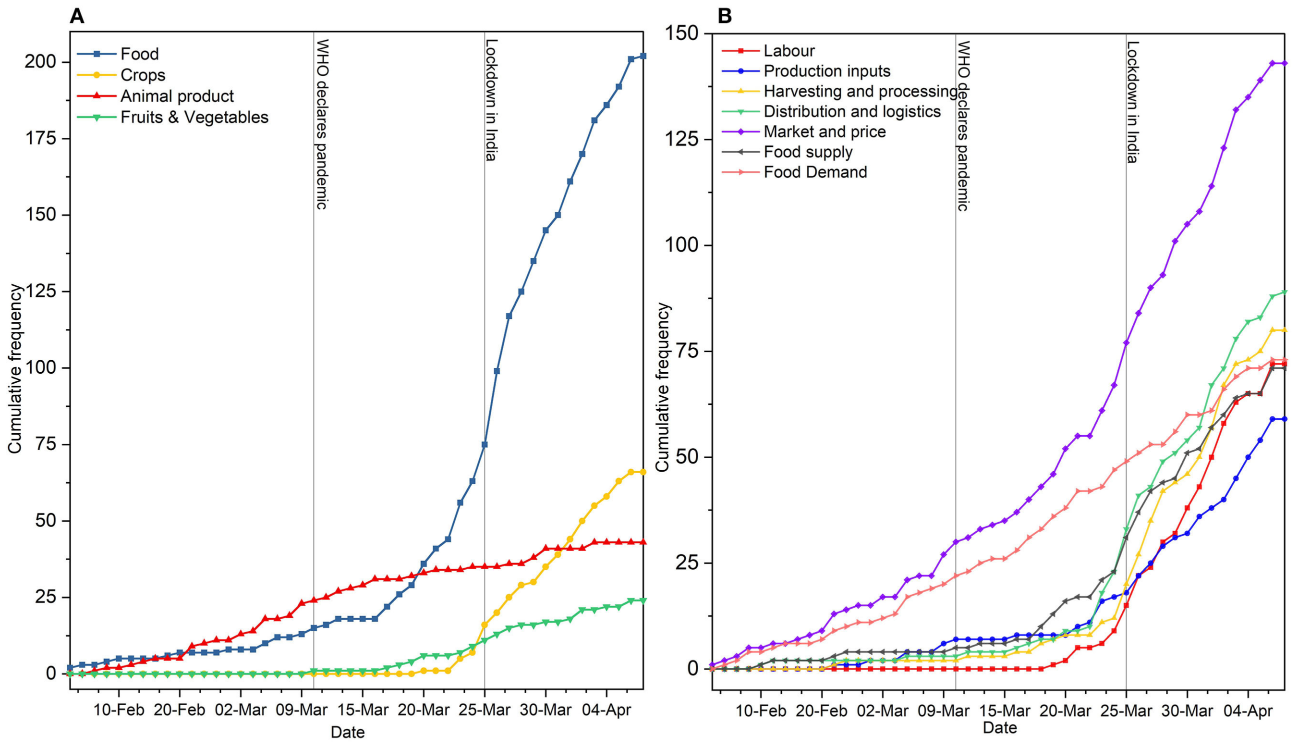

FIGURE 4 | Time series of cumulative frequency of articles by **(A)** commodity and **(B)** supply chain component focused upon.

consumer demand decreased by almost 50%, and chicken prices fell by up to 70% across the country, resulting in an industry-wide loss of INR 1,750 crore[3] during January–February, as also reported in many articles (PTI, 2020a,b). Ex-farm gate prices fell from INR 100 to INR 35 a kilogram, while retail prices reduced from INR 180–200 to INR 100–150 a kilogram in the country in early March—as highlighted by the news articles in the review (IANS, 2020; PTI, 2020c). A few articles also mentioned a 64% decline in the wholesale prices of eggs (from INR 4.25 to INR 2.7 per egg) and 25% decline (by INR 5–7 per liter) in farm price of milk resulting from reduced demand by consumers for similar reasons (DHNS, 2020; Jha, 2020a).

No clear pattern and trends were observed for food prices in other commodity groups. Shutting down of markets and international trade restrictions resulted in price volatility in some wholesale and retail markets for "Fruits and Vegetables" commodity in the country. Before the lockdown, a decline in export demand resulted in reduced prices for fruits and vegetables in some regions, for instance, a few news articles highlighted how farm-gate prices for grapes and bananas (in western and southern India) fell by 30% in the first 2 weeks of March. In addition to this, the news articles also mentioned reduced demand from bulk buyers including hotels and restaurants, also reduced wholesale prices for perishable vegetables by 15–20%. This trend is also supported by literature (Arya, 2020; Bera, 2020). On the other hand, there were reports of spike in the retail prices due to panic buying from individual consumers during the lockdown in some cities. This price rise ranged from 50% in North India to 200–400% in South India for some vegetables following rumors of food shortage due to market closures (Express News Service, 2020; Staff Reporter, 2020). Wholesale prices, however, varied across regions and no clear trends were observed, as prices either increased as a result of lower market arrivals (North and Central India) or in a few cases, declined due to a fall in demand by consumers (North India). As a case study illustration, a 5-year (2016–2020) time-series analysis using secondary wholesale price data for potato crop for the same date (20th April) shows that the highest price rise was observed for the year 2020 when the price increased by 77% over the previous year[4] (**Supplementary Figure 3**). The analysis is shown for the Azadpur market in Delhi, the biggest wholesale market in India.

The news articles, also reported diverse trends infarm-gate prices after lockdown (a decline in farm gate prices was observed in some regions) (Mukherjee et al., 2020). In these regions, supply chain bottlenecks caused the farmers to sell their produce at low prices (Jha, 2020b). The limited focus of media articles on farm gate prices, therefore, pointed to a possible under-representation of producer distress. A formal analysis of food prices for different commodity groups and supply chain components in India (farm gate, wholesale and retail prices) can help in understanding these patterns (Elleby et al., 2020; Höhler and Lansink, 2021).

[3] 1 INR = 0.014USD (as of 22th January,2021); 1 crore = 10 million.

[4] http://www.apmcazadpurdelhi.com/.

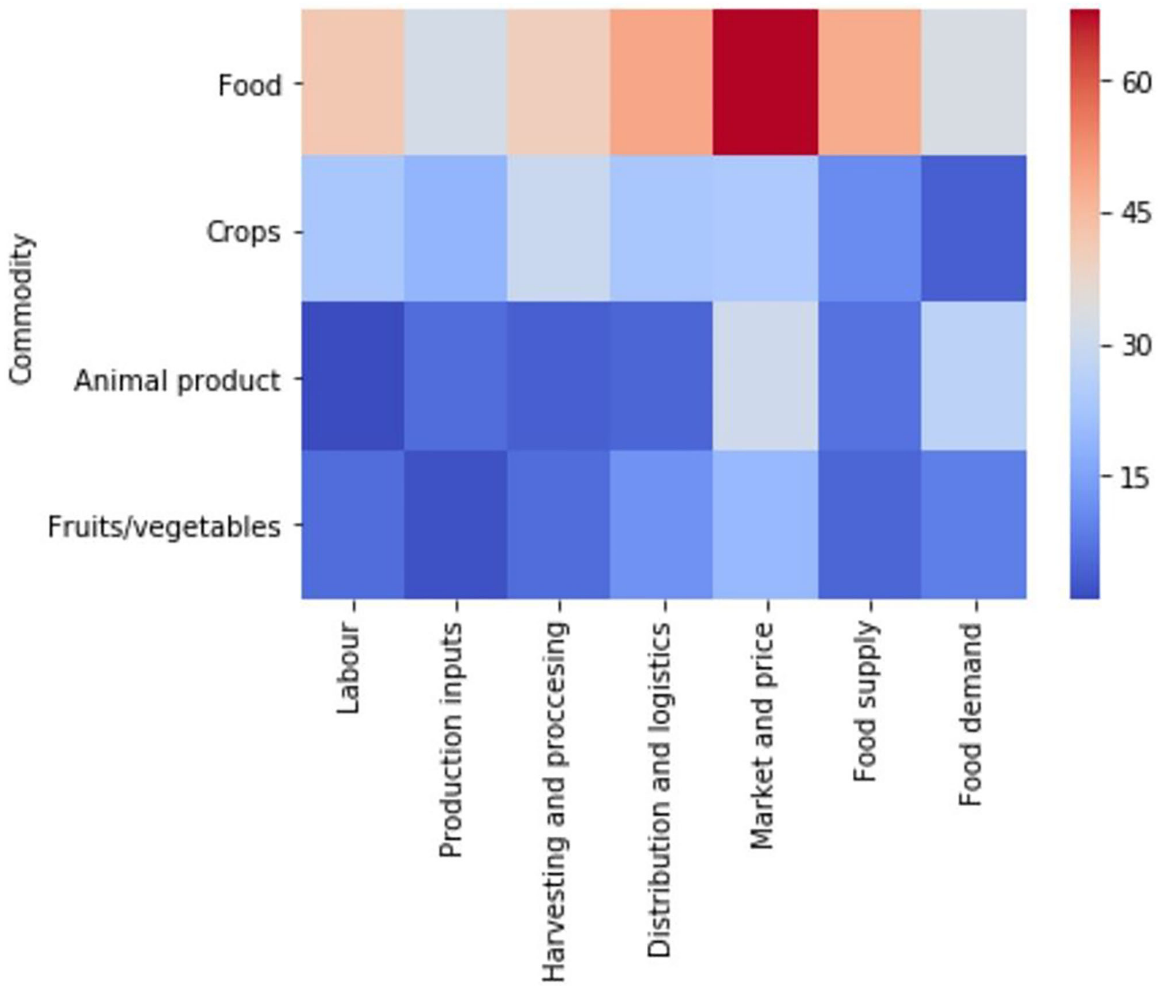

FIGURE 5 | Article frequencies of different themes and commodities.

Other than the supply chain disruptions, certain social concerns also emerged from the review. A key example was the closure of schools and consequently, the mid-day meal scheme, one of the largest government-sponsored school feeding programs of the world, and important food and nutritional safety-net for children in India (Singh et al., 2014; Alvi and Gupta, 2020). Consequently, the government implemented measures including at-home delivery of mid-day meals or food security allowance for the children. The lockdown also resulted in job and income losses of daily wage earners, migrant laborers, street vendors in urban areas resulting in food security and hunger issues in major cities.

Cross-Tabulation Using Correspondence Analysis

To further support the findings from the qualitative review of media articles on India, a correspondence analysis of the keywords was also conducted (**Figure 6**). These keywords were analyzed by commodity. To have a deeper understanding, the category of Animal products was further bifurcated into poultry and fisheries. Correspondence analysis highlights the relationship strength between keywords and commodities by their angular placement. Some of the most closely associated words with "Food" commodity were "shops," "markets," "distribution," "essential," "relief," and "credit." Similarly, with "Fruits and Vegetables" it was "APMC," "Mandi," "Consumption," "wholesale," and "prices." For "Cereals," these words were "operations," "transportation," "harvesting," "seed," "wheat." These keywords point to specific problem areas for different commodities. For "Food" commodity, the keywords related to supply or access to food, along with government action were most significant. For "Crops," farmer and production issues like harvesting and logistics were highlighted and for "Fruits and Vegetables," the concern was more on the market and consumer side. The positioning of these words also highlights the presence or absence of associations. Most of the words regarding government action are on the opposite side or to the right angle of commodities like Fisheries, Poultry and Fruits and Vegetables, indicating that most of the economic relief

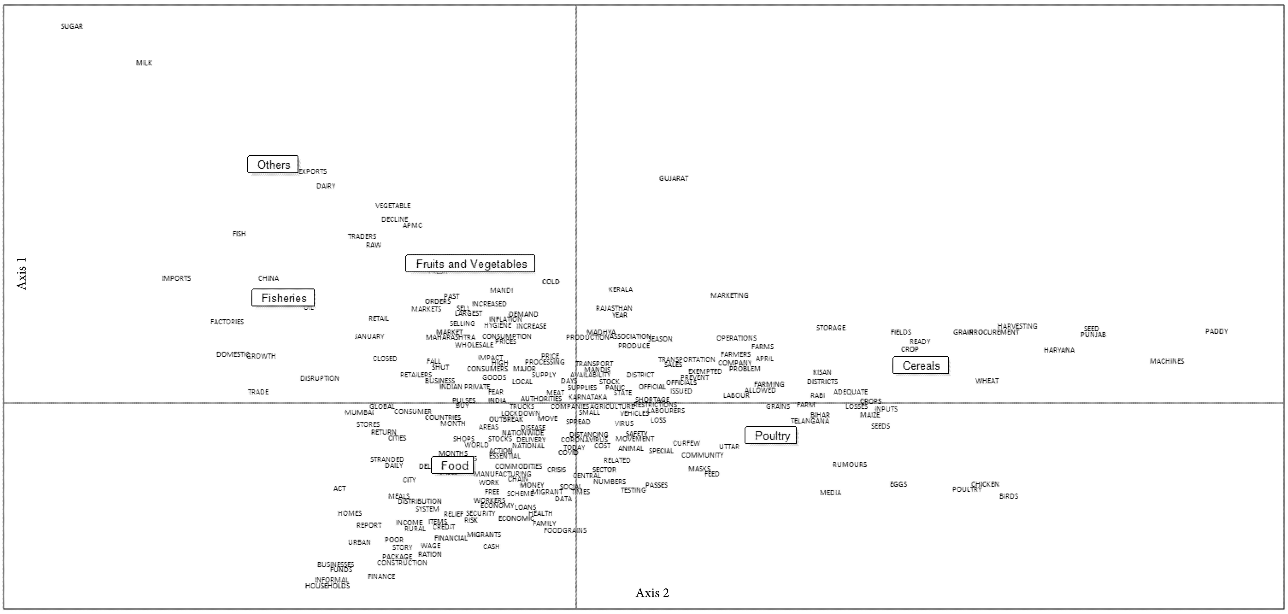

FIGURE 6 | Two-dimensional representation of the correspondence analysis of the text. Please note only two dimensions are shown, the three-dimensional coordinates of the keywords are available in the **Supplementary Material**.

packages were announced for either cereal crops or to ensure food supply in general. Similarly, words related to logistics and production which were strongly associated with cereals, have zero to negative association with poultry. This again highlights how the COVID-19 pandemic and the resulting lockdown resulted in different impacts for different commodity groups.

Sentiment Analysis

Sentiment analysis of the media articles in the review shows a significant increase in articles with overall negative sentiment, especially after the lockdown (**Figure 7**), which is expected. The trend, however, shows marginal improvement post lockdown due to several initiatives taken by the government and community relief efforts to address some of the challenges. Among them was the significant economic stimulus package of INR 1.70 lakh crores (approximately USD 23 billion) under the Pradhan Mantri Garib Kalyan Yojana (PMGKY) involving a direct cash benefit transfer along with food grain provision for two-thirds of the country's population, which many news articles focused upon post-lockdown (Goyal, 2020).

The results from sentiment analysis by commodity highlighted the highest frequency of articles with negative sentiment for the "Animal Products" group. This was not just attributed to the significant losses incurred as a result of reduced demand but was also exacerbated by the lack of government relief measures for this group. High negative sentiment for "Fruits and Vegetables" was driven by panic-driven consumer demand as well as price volatility across markets. In contrast, the large scale relief measures announced by the government including cash transfers led to comparatively lower negative sentiment for commodity groups such as food and crops. Most of the government relief measures reported in the news articles focused on crops (mainly cereals like wheat and rice).

Around 60% of the articles focused on India, were of negative sentiment and 23% were negative-neutral, highlighting an overall negative sentiment, as seen in the media articles. Among regions, over 50% of the articles from western and southern India had a negative sentiment, largely driven by a large share of "Animal Products" and "Fruits and Vegetables" articles from these areas. Comparatively lower negative sentiments were found for northern India, as most of the articles here focused on crops. The sentiment analysis by supply chain components also shows the highest negative sentiment for food supply (78%), followed by markets (71%) and labor (51%)—indicating these as the most affected parts of the food supply chain. Food demand was least affected with 41% of the articles with negative sentiment.

Compound Risks From COVID-19 and Extreme Weather Events

Media analysis highlighted compound risks faced by farmers over the study period. In addition to the impact of the COVID-19 pandemic, farmers also suffered extreme weather events. Phrases such as "loss of crops," "delay in wheat harvesting," "severely damaged," "excess rainfall" in the media articles highlight how climatic stress affected the crop production in 2020, especially in the case of wheat and mustard crops in North India (**Supplementary Figure 1**). A private weather forecasting agency estimated economic losses up to INR 255 crores from unseasonal rain in the cropping season, affecting 650,000 farmers (Sangomla, 2020).

Results from extreme weather analysis (excess rainfall events) for the study period also highlighted these issues (**Figure 8**). Also

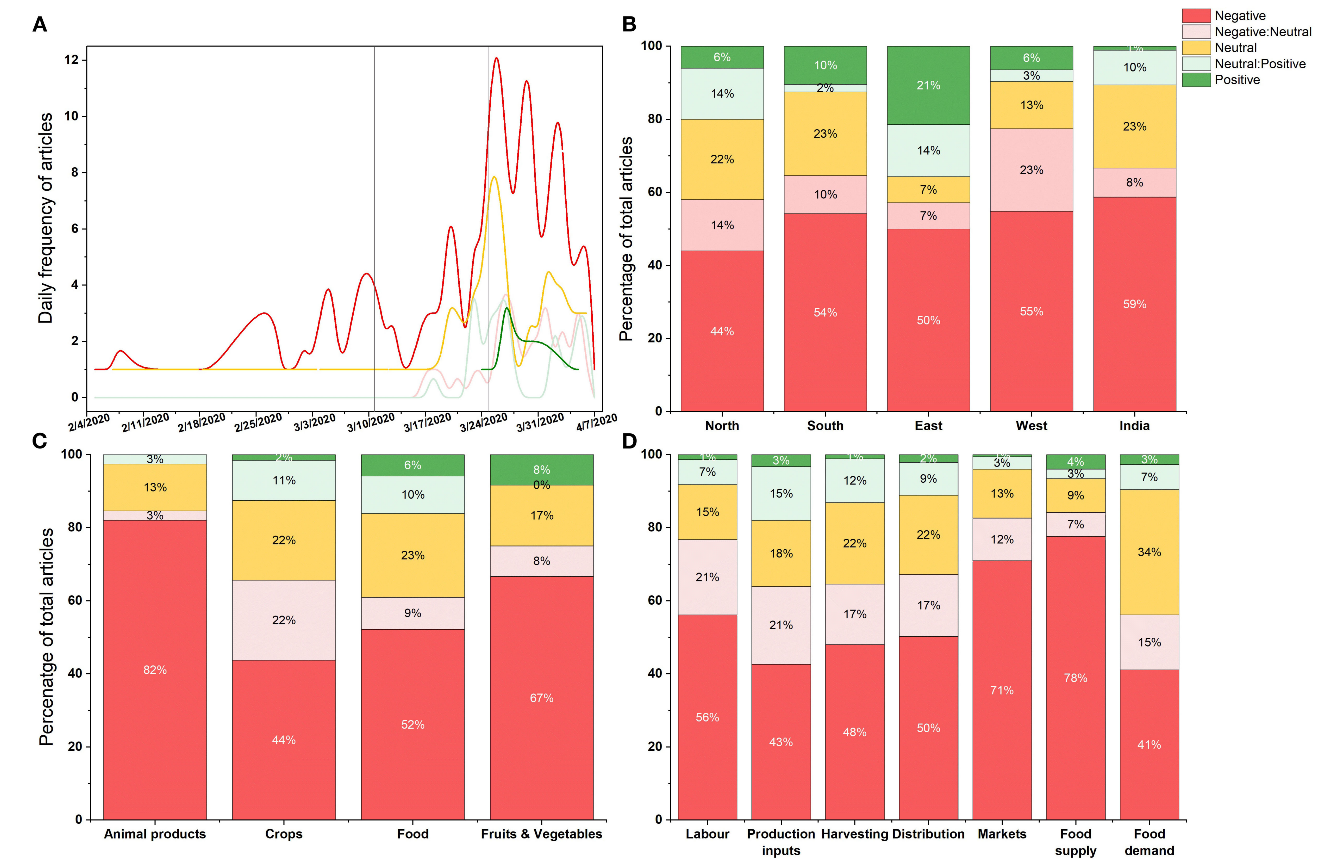

FIGURE 7 | (A) Sentiment trend analysis [the two lines refer to the lockdown date in India (25th March 2020) and the stimulus package announced by the government (26th March 2020)]; **(B)** share of articles highlighting sentiment classification by region (India refers to articles which focused on the entire country and not any specific region or location, please note that it is a separate category and not a sum of all regions), **(C)** share of articles highlighting sentiment classification by commodity and **(D)** sentiment classification by the supply chain component.

shown in the figure is the number of news articles in the state where impacts of COVID-19 and excessive rainfall events on the farming sector were both recorded. There were instances of very high rainfall (up to 750 mm) in March in northern and eastern India. This was observed especially in wheat-producing regions of Haryana, Punjab and Uttar Pradesh along with eastern states of Chhattisgarh, Jharkhand and Orissa. This is significantly higher than the normal rainfall received during this time (https://mausam.imd.gov.in/). These regions received rainfall volume of 100–750 mm in 6–10 days, with states like Haryana and Punjab witnessing up to 10 rainy days in March 2020. The high volume of rainfall over a span of few days has the potential to adversely affect the harvesting and maturing stage of crops, especially wheat, in the field through lodging and flooding (Mukherjee et al., 2020). The extreme rainfall risk in the study period was also shown by the maximum rainfall received in a single day (1-day maximum rainfall)—farms in Uttar Pradesh and Haryana received up to 100 mm of rainfall in a single day, while central states Chhattisgarh and Madhya Pradesh received 100–450 mm rainfall in a single day. Producers in those regions suffered compound risks from both the pandemic and extreme weather during the same time, exacerbating their loss, as also reported by the news articles. The focus of the articles, however, remained skewed toward the COVID-19 impacts on the food systems, with limited attention on the compound effects (of both the pandemic and extreme weather) on the Producers.

Policy and Community Action

News articles highlighted many policies and community initiatives undertaken to help the farmers and other supply chain actors, and the different measures which were undertaken by local governments, private sectors and individuals to distribute food to those who were severely impacted. Apart from the national farm stimulus announced by the government, state governments issued health guidelines for farmers to be followed during harvesting and marketing operations with social distancing. Some state governments also created specialized disinfection tunnels before entry gates of certain food markets (ANI, 2020). Simultaneously, the government officials interviewed in the news articles, highlighted the availability of

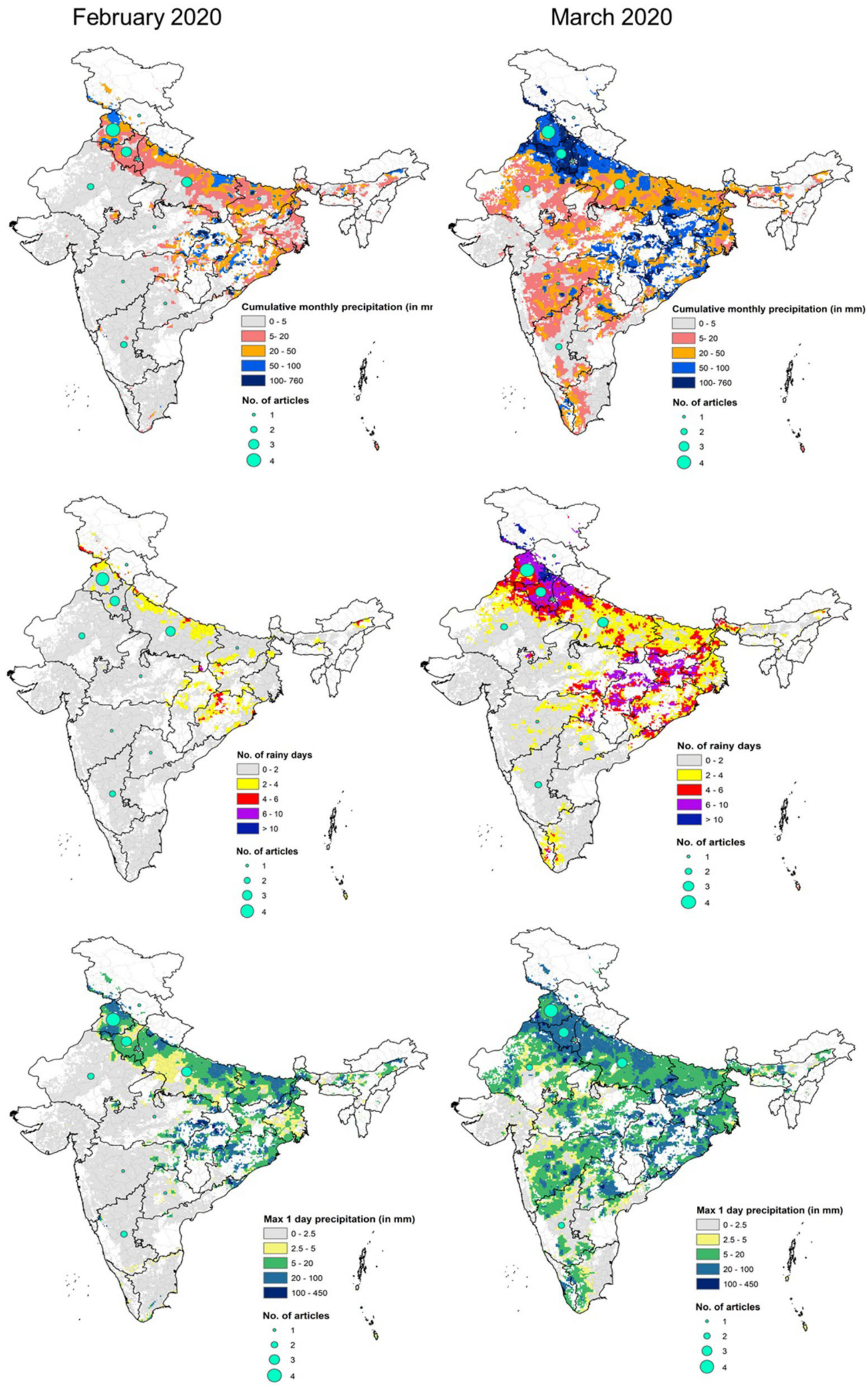

FIGURE 8 | Extreme weather analysis for precipitation (excess rainfall events) in India for the study period (February and March 2020). Three different rainfall indices—monthly precipitation, number of rainy days and maximum 1-day rainfall are shown, along with the frequency of articles mentioning compound risks from COVID-19 pandemic and extreme weather events.

enough food stock for the country's population to mitigate food insecurity fears. Apart from this, several private initiatives were also reported in the news media. In many places, consumers directly contacted farmers (through local farmers markets) and established localized food delivery networks, to overcome logistical bottlenecks. Private and development agencies also initiated food delivery services for migrant laborers during the lockdown.

DISCUSSION

The study highlights the immediate effects of the pandemic-induced lockdown on the Indian food supply chain by combining news mining techniques with content analysis tools. It highlights the key areas of disruption across different commodities and themes. A sharp spike in articles immediately after lockdown was observed (and expected), however different trends were noticed for commodity groups and components of the supply chain. Key areas of impact were Animal products and Fruits and Vegetables (commodity groups), and wholesale and retail markets, food distribution and logistics challenges (supply chain components) as well as concern over food supply and availability. On the other hand, despite agriculture being exempted from the lockdown restrictions, labor and input availability were observed as major bottleneck areas as reported by the farmers. The food supply chain in India is disorganized, fragmented and inefficient due to several challenges like small landholdings, lack of infrastructure like post-harvest storage and processing units, among many others (Parwez, 2016; Meena et al., 2019). These challenges further magnify the impact of both biotic and abiotic risks as mentioned in the news articles. This is especially true for perishable commodity groups like Animal products, Fisheries and Fruits and vegetables; which were found to be disproportionately affected in the media analysis than others. At the same time, these commodity groups play a significant role in the livelihood security of millions of farmers—India has the highest cattle population in the world, and a fast-growing fisheries sector (Islam et al., 2016). The fisheries sector in India provides livelihood support to 16 million people directly and 20 million people are supported by the livestock sector (http://dahd.nic.in/about-us/divisions/statistics). Most of these farmers are smallholders with a limited resource base (as also evidenced in the media articles), and the production is thus disorganized and scattered, thereby making the supply chains more vulnerable to shocks. The consolidation and organization through mutuals, formal and informal producer organizations can be one way to improve the efficiency of the supply chains (Meuwissen M. P. et al., 2019).

The scope of the study is temporally limited and does not allow an analysis of medium to long term trends. However, the analysis is aimed at providing immediate and short-term insights into the impacts of the lockdown on the food supply chain. The study results highlight the potential of this methodology to enable near real-time monitoring of farm distress. Additionally, the dis-aggregation of challenges by actors and categories, along with their interactions with each other, also provides a unique opportunity to timely identify and address key issues within the food supply chain.

The current crisis, while disruptive, also necessitates a detailed assessment of existing preparedness and resilience of the food systems to adapt to multiple external shocks, including extreme weather risks. Results also highlight the extreme weather risks faced by producers in the country during the pandemic. The analysis shows limited attention to this issue, which could be due to the localized nature of extreme events as compared to the global impact of the pandemic. However, it can serve as a starting point to understanding the potential impacts and compound risks in near future. Further research is required to understand how multiple shocks interact within the food systems and impact different actors.

Drawing from this study's results, the following recommendations can help agrarian countries such as India, in recovering from the current crisis as well as to enable better planning for the future. First, incorporating a broad range of unforeseen risk factors is essential in food security planning. Our case study results show how farmers in India faced multiple risks from COVID-19 induced supply chain bottlenecks (including both production and market risks), and extreme weather events in a single cropping season. Concurrent risks have the potential to significantly affect farm production (Toreti et al., 2019) and agricultural operations for the subsequent cropping seasons, reducing farm resilience and creating poverty traps in smallholder economies. Integrating a resilience approach (which recognizes the role of different risks in food systems) in policy planning is an important research agenda (Meuwissen M. P. M. et al., 2019; Komarek et al., 2020; Davis et al., 2021). A combination of different risk management strategies including early warning systems (Krishnamurthy et al., 2020), ICT-enabled climate services (Born et al., 2021), climate-resilient agricultural technologies (Sarker et al., 2019) and insurance can play a crucial role in building farm resilience. Second, leveraging the strengths of local and regional knowledge systems and supply chains, and providing opportunities to further strengthen them can help in overcoming risks, in addition to promoting timely reforms for strengthening social and physical infrastructure for last-mile connectivity. This can also be achieved by pursuing blended finance mechanisms and engaging all stakeholders including government, private sector, local community organizations and international agencies to scale up socially inclusive measures for building more robust and efficient supply chains. Our results show how local food supply chains can innovate (for example, media articles highlighting how consumers engaged directly with farmers during lockdown) and their strengths can be leveraged to create supply chain resilience (Thilmany et al., 2021). There were also several examples of how collective action was able to reduce some of the supply chain disruptions in the country. Government agencies collaborated with farmer producer organizations in the state of Maharashtra by directly selling farm produce to consumers through social media, thus overcoming supply chain bottlenecks. Similarly, women groups also played a key role in providing food to the vulnerable social groups in urban as well as rural areas (Ragasa, 2020). Timely planned and forward-looking policy measures can support supply chain resilience. For instance, India's post-pandemic stimulus measure aimed to address some of the disruptions caused by COVID-19 and further develop agricultural infrastructure to advance producer well-being. While this measure was in the form of a relief package and was thus a reactive policy, similar strategies if proactively implemented can help in strengthening the resilience of the existing food systems toward future shocks.

Last and most importantly, we combine multiple data sources and present a methodology that can be used for a rapid near-real-time assessment of farm distress. With significant advances in data sciences, we believe the use of social media and news mining methods have immense potential for application in agriculture and food systems. Multiple case studies have highlighted the use of social media analysis in climate sciences (Buckingham et al., 2020) and disaster management (Kryvasheyeu et al., 2016; Kibanov et al., 2017; Cecinati et al., 2019). Future research agenda can focus on utilizing big data analytics for farm risk management, particularly localized weather events (like hailstorms, landslides, inundation, cloud burst and lightning-induced fire events, among others) which are difficult to monitor due to data scarcity (especially in developing countries) and cause significant farm distress (Prein and Holland, 2018).

CONCLUSION

The paper demonstrates a methodology where detailed and structured analysis of media articles helps in assessing the early impacts of the COVID-19 on the food supply chain. This can be used as an analytical tool by policymakers to develop a timely response strategy to deal with such unprecedented crisis events in future. Results also point to the need for targeted responses, as impacts vary across commodities, regions and supply chain actors. The results also show the emergence of compound and concurrent risks in agriculture, and appropriate policy measures are needed to overcome the same, especially in countries with smallholder agriculture. The COVID-19 pandemic has come as a sudden tipping point for food supply chains in many countries, where they are not only required to adapt, but also transform the way supply chains operate right from farm to fork. The above analyses and recommendations, therefore, provide important inputs to build better pathways to food security in the post-COVID-19 era.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

SV, NC, and PA conceptualized the study and designed the methodology. SV, MC, and NC worked on the analysis. SV and NC majorly contributed to the writing and editing of the manuscript and supervised the entire study. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2021.658290/full#supplementary-material

REFERENCES

Abhishek, B. V., Gupta, P., Kaushik, M., Kishore, A., Kumar, R., Sharma, A., et al. (2020). India's food system in the time of COVID-19. *Econ. Polit. Wkly*. 55, 12–14. Available online at: https://www.epw.in/journal/2020/15/commentary/indias-food-system-time-covid-19.html

Aggarwal, P., Shirsath, P., Vyas, S., Arumugam, P., Goroshi, S., Aravind, S., et al. (2020). Application note: crop-loss assessment monitor—a multi-model and multi-stage decision support system. *Comput. Electron. Agric*. 175:105619. doi: 10.1016/j.compag.2020.105619

Alvi, M., and Gupta, M. (2020). Learning in times of lockdown: how COVID-19 is affecting education and food security in India. *Food Secur*. 12, 793–796. doi: 10.1007/s12571-020-01065-4

ANI. (2020, April 6). Coronavirus, Karnataka: tunnel at agriculture market in Karnataka to "disinfect bacteria of body." *ANI*

Arya, N. (2020). *COVID-19 Outbreak: A Sharp Decline of 20% in the Prices of Agricultural Commodities.* Krishi Jagran.

Avtar, R., Singh, D., Umarhadi, D. A., Yunus, A. P., Misra, P., Desai, P. N., et al. (2021). Impact of COVID-19 lockdown on the fisheries sector: a case study from three harbors in Western India. *Remote Sens*. 13:183. doi: 10.3390/rs13020183

Bai, Y., Jia, S., and Chen, L. (2020). Topic evolution analysis of COVID-19 news articles. *J. Phys. Conf. Ser*. 1601:052009. doi: 10.1088/1742-6596/1601/5/052009

Balwinder-Singh, S. P. B., Jat, M. L., McDonald, A. J., Srivastava, A. K., Craufurd, P., Rana, D. S., et al. (2020). Agricultural labor, COVID-19, and potential implications for food security and air quality in the breadbasket of India. *Agric. Syst*. 185:102954. doi: 10.1016/j.agsy.2020.102954

Bera, S. (2020). *Indian Agri Export Business Hit Hard by Outbreak in European Union, West Asia.* Mint.

Bjerge, B., and Trifkovic, N. (2018). Extreme weather and demand for index insurance in rural India. *Eur. Rev. Agric. Econ*. 45, 397–431. doi: 10.1093/erae/jbx037

Born, L., Prager, S., Ramirez-Villegas, J., and Imbach, P. (2021). A global meta-analysis of climate services and decision-making in agriculture. *Clim. Serv*. 22:100231. doi: 10.1016/j.cliser.2021.100231

Brunette, M., Bourke, R., Hanewinkel, M., and Yousefpour, R. (2018). Adaptation to climate change in forestry: a multiple correspondence analysis (MCA). *Forests* 9:20. doi: 10.3390/f9010020

Buckingham, K., Brandt, J., Anderson, W., Luiz Fernando do, A., and Singh, R. (2020). The untapped potential of mining news media events for understanding environmental change. *Curr. Opin. Environ. Sustain*. doi: 10.1016/j.cosust.2020.08.015

Buheji, M., da Costa Cunha, K., Beka, G., Mavrić, B., Leandro do Carmo de Souza, Y., Souza da Costa Silva, S., et al. (2020). The extent of COVID-19 pandemic socio-economic impact on global poverty. A global integrative multidisciplinary review. *Am. J. Econ*. 10, 213–224. doi: 10.5923/j.economics.20201004.02

Cecinati, F., Matthews, T., Natarajan, S., McCullen, N., and Coley, D. (2019). Mining social media to identify heat waves. *Int. J. Environ. Res. Public Health* 16:762. doi: 10.3390/ijerph16050762

Davis, K. F., Downs, S., and Gephart, J. A. (2021). Towards food supply chain resilience to environmental shocks. *Nat. Food* 2, 54–65. doi: 10.1038/s43016-020-00196-3

DHNS. (2020). False coronavirus alarm on social media hits poultry sector in Karnataka. *Deccan Herald.*

Directorate of Economics and Statistics. (2018). *Pocket Book of Agricultural Statistics 2018*. New Delhi: Directorate of Economics and Statistics.

Elleby, C., Domínguez, I. P., Adenauer, M., and Genovese, G. (2020). Impacts of the COVID-19 pandemic on the global agricultural markets. *Environ. Resour. Econ*. 76, 1067–1079. doi: 10.1007/s10640-020-00473-6

Express News Service. (2020). Coronavirus lockdown: as panicky public hoards, vegetable prices soar in Hyderabad. *The New Indian Express*.

FAO. (2016). *Impact of the Ebola Virus Disease Outbreak on Market Chains and Trade of Agricultural Products in West Africa*. Dakar: FAO.

FAO. (2020a). *COVID-19 and the Risk to Food Supply Chains: How to respond?* Rome: Policy Support and Governance, Food and Agriculture Organization of the United Nations.

FAO. (2020b). *COVID-19 and Smallholder Producers' Access to Markets, COVID-19 and Smallholder Producers' Access to Markets*. Rome: FAO.

Fritz, S., See, L., Bayas, J. C. L., Waldner, F., Jacques, D., Becker-Reshef, I., et al. (2019). A comparison of global agricultural monitoring systems and current gaps. *Agric. Syst*. 168, 258–272. doi: 10.1016/j.agsy.2018.05.010

Goyal, A. Post Covid-19: recovering and sustaining India92s growth. *Ind. Econ. Rev*. 55:161-96181. doi: 10.1007/s41775-020-00089-z

Harris, J., Depenbusch, L., Pal, A. A., Nair, R. M., and Ramasamy, S. (2020). Food system disruption: initial livelihood and dietary effects of COVID-19 on vegetable producers in India. *Food Secur*. 12, 841–851. doi: 10.1007/s12571-020-01064-5

Headey, D., and Ruel, M. (2020). *The COVID-19 Nutrition Crisis: What to Expect and How to Protect*. IFPRI: International Food Policy Research Institute [WWW Document].

Hjellbrekke, J. (2018). *Multiple Correspondence Analysis for the Social Sciences*. London: Routledge.

Höhler, J., and Lansink, A. O. (2021). Measuring the impact of COVID-19 on stock prices and profits in the food supply chain. *Agribusiness* 37, 171–186. doi: 10.1002/agr.21678

IANS. (2020). Coronavirus: Chicken prices fall, poultry industry affected. *Retail News, ET Retail.*

Islam, M. M., Anjum, S., Modi, R. J., and Wadhwani, K. N. (2016). Scenario of livestock and poultry in India and their contribution to national economy. *Int. J. Sci. Environ. Technol*. 5, 956–965. Available online at: https://www.ijset.net/journal/956.pdf

Jacobs, A. M. (2019). Sentiment analysis for words and fiction characters from the perspective of computational (neuro-)poetics. *Front. Robot.* 6:53. doi: 10.3389/frobt.2019.00053

Jahanbin, K., and Rahmanian, V. (2020). Using twitter and web news mining to predict COVID-19 outbreak. *Asian Pac. J. Trop. Med.* 13:378. doi: 10.4103/1995-7645.279651

Jha, D. K. (2020a). COVID-19: milk consumption down 25% in one month as eateries remain shut. *Business Standard News.*

Jha, D. K. (2020b). Covid-19 impact: farmers panic as onion slips to season's lowest of Rs 3/kg. *Business Standard News.*

Kibanov, M., Stumme, G., Amin, I., and Lee, J. G. (2017). Mining social media to inform peatland fire and haze disaster management. *Soc. Netw. Anal. Min*. 7:30. doi: 10.1007/s13278-017-0446-1

Kolluri, G., Tyagi, J. S., and Sasidhar, P. V. K. (2020). Research Note: Indian poultry industry vis-à-vis coronavirus disease 2019: a situation analysis report. *Poult. Sci.* 100:100828. doi: 10.1016/j.psj.2020.11.011

Komarek, A. M., De Pinto, A., and Smith, V. H. (2020). A review of types of risks in agriculture: what we know and what we need to know. *Agric. Syst*. 178:102738. doi: 10.1016/j.agsy.2019.102738

Krishnamurthy, R. P. K., Fisher, J. B., Schimel, D. S., and Kareiva, P. M. (2020). Applying tipping point theory to remote sensing science to improve early warning drought signals for food security. *Earth's Futur*. 8:e2019EF001456. doi: 10.1029/2019EF001456

Kryvasheyeu, Y., Chen, H., Obradovich, N., Moro, E., Van Hentenryck, P., Fowler, J., et al. (2016). Rapid assessment of disaster damage using social media activity. *Sci. Adv*. 2:e1500779. doi: 10.1126/sciadv.1500779

Kumaran, M., Geetha, R., Antony, J., Vasagam, K. P. K., Anand, P. R., Ravisankar, T., et al. (2021). Prospective impact of Corona virus disease (COVID-19) related lockdown on shrimp aquaculture sector in India—a sectoral assessment. *Aquaculture* 531:735922. doi: 10.1016/j.aquaculture.2020.735922

Laborde, D., Martin, W., and Vos, R. (2020). *Poverty and Food Insecurity Could Grow Dramatically as COVID-19 Spreads*. Washington, DC: IFPRI: International Food Policy Research Institute [WWW Document].

Laguna, L., Fiszman, S., Puerta, P., Chaya, C., and Tárrega, A. (2020). The impact of COVID-19 lockdown on food priorities. Results from a preliminary study using social media and an online survey with Spanish consumers. *Food Qual. Prefer*. 86:104028. doi: 10.1016/j.foodqual.2020.104028

Li, Y., Guan, K., Schnitkey, G. D., DeLucia, E., and Peng, B. (2019). Excessive rainfall leads to maize yield loss of a comparable magnitude to extreme drought in the United States. *Glob. Chang. Biol*. 25, 2325–2337. doi: 10.1111/gcb.14628

Maliszewska, M., Mattoo, A., and van der Mensbrugghe, D. (2020). The potential impact of COVID-19 on GDP and trade: a preliminary assessment. *World Bank Policy Research*. doi: 10.1596/1813-9450-9211

McKibbin, W. J., and Fernando, R. (2020). The global macroeconomic impacts of COVID-19: seven Scenarios. *SSRN Electron. J*. doi: 10.2139/ssrn.3547729

Meena, S. R., Meena, S. D., Pratap, S., Patidar, R., and Daultani, Y. (2019). Strategic analysis of the Indian agri-food supply chain. *Opsearch* 56, 965–982. doi: 10.1007/s12597-019-00380-5

Meuwissen, M. P., Bottema, M. J., Hong Ho, L., Chamsai, S., Manjur, K., and de Mey, Y. (2019). The role of group-based contracts for risk-sharing; what are the opportunities to cover catastrophic risk? *Curr. Opin. Environ. Sustain*. 41, 80–84. doi: 10.1016/j.cosust.2019.11.004

Meuwissen, M. P. M., Feindt, P. H., Spiegel, A., Termeer, C. J. A. M., Mathijs, E., Mey, Y., et al. (2019). A framework to assess the resilience of farming systems. *Agric. Syst*. 176, 102656. doi: 10.1016/j.agsy.2019.102656

Moriom Khatun, M., Siddik, M. S., Rahman, M. A., and Khaled, S. (2021). Content analysis of COVID-19 and agriculture news in Bangladesh using topic modeling algorithm. *Curr. Appl. Sci. Technol*. 21, 296–314. doi: 10.14456/cast.2021.26

Mukherjee, A., Kumar, U., Shubha, K., and Anand, S. (2020). Implications of COVID-19 on agriculture in Eastern Region. *Food Sci. Rep.* 1, 63–66. Available online at: https://foodandscientificreports.com/details/implications-of-covid-19-on-agriculture-in-eastern-region.html

Nicola, M., Alsafi, Z., Sohrabi, C., Kerwan, A., Al-Jabir, A., Iosifidis, C., et al. (2020). The socio-economic implications of the coronavirus and COVID-19 pandemic: a review. *Int. J. Surg*. 78, 185–193. doi: 10.1016/j.ijsu.2020.04.018

Parwez, S. (2016). A conceptual model for integration of indian food supply chains. *Glob. Bus. Rev*. 17, 834–850. doi: 10.1177/0972150916645681

Pastor, C. K. (2020). Sentiment analysis of filipinos and effects of extreme community quarantine due to coronavirus (COVID-19) pandemic. *SSRN Electron. J*. 3, 1–6. doi: 10.2139/ssrn.3574385

Prein, A. F., and Holland, G. J. (2018). Global estimates of damaging hail hazard. *Weather Clim. Extrem*. 22, 10–23. doi: 10.1016/j.wace.2018.10.004

PTI. (2020a). Poultry industry: "Chicken sales down 50%, prices by 70% in India on coronavirus rumour". *Retail News, ET Retail.*

PTI. (2020b). Poultry sector faces Rs1,750cr losses due to coronavirus rumours; demands relief package from govt. *Deccan Herald.*

PTI. (2020c). *Coronavirus Takes Toll on Chicken Sales, Demand Down 50%, Prices by 70%*. Available online at: cnbctv18.com. (accessed June 30, 2020).

Ragasa, C., and Lambrecht, I. (2020). COVID-19 and the food system: setback or opportunity for gender equality? *Food Security* 12:877-96880. doi: 10.1007/s12571-020-01089-w

Rakshit, B., and Basistha, D. (2020). Can India stay immune enough to combat COVID-19 pandemic? An economic query. *J. Public Aff.* 20:pa.2157. doi: 10.1002/pa.2157

Sadman, N., Anjum, N., Datta Gupta, K., and Parvez Mahmud, M. A. (2021). *Understanding the Pandemic Through Mining COVID News Using Natural Language Processing*. Piscataway, NJ: Institute of Electrical and Electronics Engineers (IEEE), 0362–0367.

Sangomla, A. (2020). Excess march rainfall: what it means for COVID-19 outbreak. *WWW Document.*

Sarker, M. N. I., Wu, M., Alam, G. M. M., and Islam, M. S. (2019). Role of climate smart agriculture in promoting sustainable agriculture: a systematic literature review. *Int. J. Agric. Resour. Gov. Ecol*. 15:323. doi: 10.1504/IJARGE.2019.104199

Saura, J. R., Palos-Sanchez, P., and Grilo, A. (2019). Detecting indicators for startup business success: sentiment analysis using text data mining. *Sustainability* 11:917. doi: 10.3390/su11030917

Sethi, C. K. (2020). *Punjab and Haryana Stare at Massive Farm Crisis as Lockdown Leads to Labour Shortage*. Chandigarh: The Print.

Singh, A., Park, A., and Dercon, S. (2014). School meals as a safety net: an evaluation of the midday meal scheme in India. *Econ. Dev. Cult. Change* 62, 275–306. doi: 10.1086/674097

Soo, C., Khoo, G., Nourbakhsh, A., and Na, J.-C. (2012). Sentiment analysis of online news text: a case study of appraisal theory. *Online Inf. Rev.* 36, 858–878. doi: 10.1108/14684521211287936

Staff Reporter. (2020). *Vegetable Prices Rise Over Mandi Closure Rumour Due to Virus*. Hyderabad: The New Indian Express.

Sumner, A., Hoy, C., and Ortiz-Juarez, E. (2020). *WIDER Working Paper 2020/43-Estimates of the Impact of COVID-19 on Global Poverty*. (No. WIDER Working Paper 2020/43), 2020/43. Helsinki.

Suryadi, D. (2021). "Does it make you sad? A lexicon-based sentiment analysis on COVID-19 news tweets," in *IOP Conf. Ser. Mater. Sci. Eng.* 1077, 012042. doi: 10.1088/1757-899X/1077/1/012042

Thilmany, D., Canales, E., Low, S. A., and Boys, K. (2021). Local food supply chain dynamics and resilience during COVID-19. *Appl. Econ. Perspect. Policy* 43, 86–104. doi: 10.1002/aepp.13121

Thomas, T., Wilson, A., Tonkin, E., Miller, E. R., and Ward, P. R. (2020). How the media places responsibility for the COVID-19 pandemic—an Australian media analysis. *Front. Public Heal*. 8:483. doi: 10.3389/fpubh.2020.00483

Toreti, A., Cronie, O., and Zampieri, M. (2019). Concurrent climate extremes in the key wheat producing regions of the world. *Sci. Rep*. 9, 1–8. doi: 10.1038/s41598-019-41932-5

UNDP. (2020). *The Social and Economic Impact of COVID-19 in the Asia-Pacific Region.* New York, NY: UNDP.

United Nations. (2020). *UN Working to Avert Dual Crises as COVID-19 Hits Hunger Hotspots.* United Nations [WWW Document].

van der Velde, M., and Nisini, L. (2019). Performance of the MARS-crop yield forecasting system for the European Union: assessing accuracy, in-season, and year-to-year improvements from 1993 to 2015. *Agric. Syst*. 168, 203–212. doi: 10.1016/j.agsy.2018.06.009

Workie, E., Mackolil, J., Nyika, J., and Ramadas, S. (2020). Deciphering the impact of COVID-19 pandemic on food security, agriculture, and livelihoods: a review of the evidence from developing countries. *Curr. Res. Environ. Sustain.* 2:100014. doi: 10.1016/j.crsust.2020.100014

World Health Organization. (2021). *COVID-19 Weekly Epidemiological Update 22.* Geneva: WHO, 1–3.

Zampieri, M., Ceglar, A., Dentener, F., and Toreti, A. (2017). Wheat yield loss attributable to heat waves, drought and water excess at the global, national and subnational scales. *Environ. Res. Lett*. 12:064008. doi: 10.1088/1748-9326/aa723b

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SYSTEMATIC REVIEW
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Systematic Review on Food Safety and Supply Chain Risk Assessment Post Pandemic: Malaysian Perspective

Md Saad Nurul Eiman[1], *Firdaus Muhammad Nurul Azmi Aida*[1], *Trias Mahmudiono*[2] and *Siva Raseetha*[1]*

[1] *Faculty of Applied Sciences, Universiti Teknologi MARA, Shah Alam, Malaysia,* [2] *Department of Nutrition, Faculty of Publlic Health, Universitas Airlangga, Surabaya, Indonesia*

The novel coronavirus disease 2019, or COVID-19, is a recent disease that has struck the entire world. This review is conducted to study the impacts of the COVID-19 pandemic to food safety as well as the food supply chain. The pandemic has caused various changes around the world as numerous countries and governments have implemented lockdowns and restrictions to help curb the rising cases due to COVID-19. However, these restrictions have impacted many aspects of everyday life, including the economic sectors such as the food industry. An overview of the current COVID-19 situation in Malaysia was discussed in this review along with its implication on food safety and food supply chain. This is followed by a discussion on the definition of food safety, the impact of the pandemic to food safety, as well as the steps to be taken to ensure food safety. Hygiene of food handlers, complete vaccination requirement, kitchen sanitation and strict standard operating procedures (SOPs) should be in place to ensure the safety of food products, either in food industries or small scale business. Additionally, the aspect of the food supply chain was also discussed, including the definition of the food supply chain and the impact of COVID-19 to the food supply chain. Travel restriction and lack of manpower had impacted the usual operation and production activities. Lack of customers and financial difficulties to sustain business operational costs had even resulted in business closure. As a conclusion, this article provides insight into crucial factors that need to be considered to effectively contain COVID-19 cases and highlights the precaution methods to be taken through continuous monitoring and implementation by Malaysian government.

Keywords: food safety, food supply chain, post pandemic, Malaysia, threat

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Elliot Berry,
Hebrew University of Jerusalem, Israel

Reviewed by:
Gabriel da Silva Medina,
University of Brasilia, Brazil
Elena Lioubimtseva,
Grand Valley State University, United States

***Correspondence:**
Siva Raseetha
raseetha@uitm.edu.my
orcid.org/0000-0002-4106-4903

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INTRODUCTION

Recently, the entire world has been plagued with the sudden appearance of a new disease commonly known as COVID-19 that was brought about by the severe acute respiratory syndrome corona virus 2 (SARS-CoV-2), (Olaimat et al., 2020). On the 11th of March 2020, the World Health Organization (WHO) has declared the COVID-19 outbreak as a global pandemic as the number of cases worldwide rose to a concerning amount, with an expected increase in the number of cases in the coming months (Cucinotta and Vanelli, 2020). According to World Health Organization (2020), the new strain of the coronavirus disease was first identified in a cluster of pneumonia patients in Wuhan, China where the Chinese authorities later confirmed to be the cause of the pneumonia. COVID-19 is a respiratory illness characterized by symptoms such as fatigue, dry cough, fever, as well as lymphopenia (Cucinotta and Vanelli, 2020).

This recent pandemic has brought about many changes around the world as numerous countries have implemented various lockdowns and the closure of many economic sectors in order to curb the number of rising COVID-19 cases due to the spread of the infection among the citizens. During these lockdowns, essential services were allowed to operate on strict standard operating procedures (SOPs). As a result, a new norm has been introduced where social and physical distancing must always be adhered to with masks to be worn at all times while being in public areas, as well as the prioritization of hygiene and sanitation. This pandemic has affected many aspects of day-to-day life, including social life, as well as many economic sectors. Rozaki (2020) found that many companies and businesses, including the agricultural practices and food industries have been affected by the economic uncertainty since the start of the pandemic. This study highlights the current issue of the COVID-19 pandemic that has affected the food industry, mainly in the aspect of food safety and the food supply chain in Malaysia. Due to COVID-19, many sectors in the economy were affected as companies have been forced to close down or took strict restrictions on their manufacturing and production as required by the health guidelines set by the government and authorizing bodies such as the WHO (Rashid et al., 2021). Due to these restrictions, most companies had to cut down and minimize on the production and manufacturing of their products, which has caused shortages and delays of a particular product. Therefore, the objectives of this study were to review the impact and threats of the COVID-19 pandemic to food safety as well as to the food supply chain in Malaysia. Additionally, precaution and solution taken by the government were also discussed in order to provide an insight as a form of improvement to the current situation while managing the pandemic.

LITERATURE REVIEW

Overview of the COVID-19 Situation

The recent COVID-19 pandemic has affected many countries in the world. As cases continued to rise, more and more countries have implemented lockdowns and restrictions. In China, where the first reported cases of COVID-19 originated, the Chinese government had enacted control measures which was described as "the strictest control measures since the founding of the People's Republic of China" (Min et al., 2020). These measures include suspension of intra-city public transport, banning of public gatherings, and the shutdown of entertainment outlets. Additionally, restrictions had also been enforced in other countries such as the United Kingdom, where a lockdown that has restricted non-essential public gatherings, closure of businesses and educational institutions, and an order to stay at home aside for essential tasks and exercise was imposed (Choi et al., 2020). In South East Asia, countries such as the Philippines have also implemented control measures which had included restrictions such as curfews, travel restrictions and check-points, as well as the indefinite suspension of business and education activities (Tee et al., 2020). Globally, the government agencies have tried imposing restriction and control measures in order to closely monitor and manage the number of COVID-19 cases within each country. Nowadays, these restrictions are analyzed according to the state of each country and re-opening of other sub-economic sector were taken into consideration. However, tight SOPs are still in place as the pandemic is still far from being over globally which has eventually affected the food purchasing and consumption behavior (Li et al., 2022).

In Malaysia, the first positive COVID-19 case was identified on the 25th of January 2020, and within 6 days, a total of eight positive cases were then reported, all of which were imported cases from Wuhan, China (Shah et al., 2020). Furthermore, on 17th of March 2020, Malaysia recorded its first confirmed death (Koh et al., 2020). Subsequently, the number of positive cases recorded skyrocketed following a religious mass gathering which has also included international participants from India, Brunei, Thailand, South Korea, China, and Japan (Che Mat et al., 2020). Minhat and Shahar (2020) have expressed that the rapid transmission in positive cases was predicted to have been caused by exported cases from other countries. Following the continual increase in the number of cases in Malaysia from 99 positive to 200 positive in less than a week (Shah et al., 2020), the government of Malaysia has implemented the Movement Control Order (MCO) on the 18th of March 2020. The MCO implemented has required all businesses to underwent a close down, with the exception of those that provide essential services and items (Tang, 2020). Consequently, most businesses were forced to halt their activities as a form of compliance to the new MCO implemented by the government. Some of the restrictions during MCO include social distancing guidelines implemented in public places, limited operating hours, travel restrictions which have been further enforced by road blocks all over the country, in addition to the limitation of movement of a 10-km travel radius for all citizens (Tang, 2020). However, even with the implementation of the MCO, after 1.5 years, Malaysia is seen still struggling to lower the number of cases among its population due to emerging new variants being transmitted.

These control measures had affected many walks of life, from workers, business owners, students, as well as children. Social life, education system and non-essential businesses have been placed on a halt. These restrictions, although implemented to stop the rising cases of COVID-19, have also impacted many economic sectors. While many companies were able to keep their businesses going by allowing their employees to work from home, the same cannot be applied for most food industries as many food companies require their workers to work hands-on with the product, especially for smaller businesses. Therefore, COVID-19 has caused some effects to the food industry, such as impacting food safety as well as the food supply chain, with similar impact found in over 16 countries. Hence, managing the whole system during a severe pandemic is utterly crucial (Djekic et al., 2021).

Selection of Articles

In this study, the systematic review of articles was searched and selected from three databases (Science Direct, Scopus and

Google Scholar). The literature search was conducted from Oct 2020 to September 2021. The search terms used were "food safety" and "food supply chain" under the (Article title, Abstracts, Keywords). In addition, the term "COVID-19" was used under the [Search within results] to be specific. About 1698 articles were identified through the database search and an additional 12 articles were identified (including governmental reports and newspaper articles) as indicated in **Supplementary Figure 1**. Thorough screening was conducted to eliminate bias and subsequently, eligible literature were included in this study so that an overview of the food safety and supply chain during and post pandemic situations in Malaysia were able to be reflected in this study.

COVID-19 and Food Safety

What Is Food Safety?

Food safety is a very important aspect in the food industry. According to Uçar et al. (2016), food safety is described as the preparation of food that shall not cause any harm to the consumer when it is eaten according to its intended use. Moreover, the Australian Institute of Food Safety (2019) describes food safety as the handling, preparation, and storage of food which can best lower the risk of sickness caused by foodborne illnesses. Food related diseases caused by foodborne pathogens can be very dangerous, and even fatal, therefore, food safety is a crucial aspect during food preparation to avoid any undesirable consequences. According to Uçar et al. (2016) there are a few factors which affects food safety: food hygiene, personal hygiene of food handlers, and kitchen sanitation, as shown in **Supplementary Figure 2**. Previously, the responses of food safety system and management during pandemic in over 16 countries indicated that staff awareness and hygiene were the most important attributes that needed to be enforced in food industries (Djekic et al., 2021).

Not only is food safety important to protect the consumers directly from foodborne diseases, but it is also significant as the consumption of safe and nutritious food will help maintain good health and well-being. Uddin et al. (2020) stated that the consumption of nutritious and safe foods helps to generate body immunity, thus, it also helps in fighting against diseases such as COVID-19. Additionally, a proper diet can guarantee that the body is strong enough to fight the virus. A healthy body and immunity are especially important during this pandemic where a sick or unhealthy person may be more susceptible to fall victim to COVID-19 as compared to a healthy person. Furthermore, it has been reported that the food consumption pattern during the pandemic has changed along with limited physical activities which could affect health condition in the long term (Mahar et al., 2021). However, alongside the intake of healthy and nutritious foods in the diet, other measures such as food safety management and the good food practices are also necessary in combating the virus (Aman and Masood, 2020). Thus, food safety should not be taken lightly during this pandemic. In fact, a huge shift of consumer perception toward food safety during the pandemic has influenced the purchasing power (Thomas and Feng, 2021).

Impact of COVID-19 to Food Safety

Early on at the start of the pandemic, many food consumers have been concerned with the safety of their food as there was not much well-known information about COVID-19 and its transmission via food products. There were concerns of the virus being transmitted through food products as well as by the packaging of the food itself, which has caused many companies to enforce stricter hygiene rules in the manufacturing and production of their products. In this case, sanitation and sanitization is vital to ensure food safety. Sanitation is the utmost important criteria for hygienic condition so that the whole food preparation, handling area, amongst others, is in a clean environment. Additionally, during this pandemic outbreak, another step such as sanitization is needed to ensure that the surface is free from any kind of microbes and viruses that could potentially pose a threat to human health.

As more research was conducted, it was revealed that up until now, there was no study which had reported on the spread of COVID-19 through food products and the human digestive system (Duda-Chodak et al., 2020; Olaimat et al., 2020). Food handlers in US practiced frequent hand-washing to eliminate the possibilities of contracting COVID-19 from food items (Thomas and Feng, 2021). The World Health Organization (WHO), Food and Agriculture Organization (FAO), as well as the United States Food and Drug Administration (US-FDA) has advised that COVID-19 is not transmitted by the consumption of food contaminated by the virus (Uddin et al., 2020). Moreover, Cable et al. (2020) reported that there was no evidence which has suggested that SARS-CoV-2, the virus causing COVID-19, is a foodborne virus, based on the conclusion brought about by the French Agency for Food, Environmental, and Occupational Health and Safety. Cable et al. (2020) has continued to state that, SARS-CoV-2 should be able to be inactivated during cooking as well as under normal pasteurization conditions, based on research conducted on other coronaviruses. This was also in agreement with the study conducted by Jawed et al. (2020) where high temperature heating of over 70°C has been found to inactivate viruses, including the Coronavirus. Thus, it is important for handlers to maintain good food safety etiquette, like cooking foods until the correct temperature was achieved in making sure that the food is safe for consumption. On the other hand, Cook and Richards (2013) has stated that even cooked foods may transmit viral diseases, if they come into contact with other contaminated foods or surfaces such as food that has been handled by a person with contaminated hands or coming into contact with food items that have previously been contaminated during processing or preparation. In the study, it has been further illustrated that viral droplets are typically considered heavy when they are more than 5 µm in size, resulting in a need for a space to land which could be any object, packaging or surfaces that in turn, could be the possible mode of transmission. Meanwhile, when the viral droplets are <5 µm in size, corona virus could be circulated in the air (Cook, 2020).

Therefore, food safety is still a concern as this does not rule out the possibility of contamination through other means, such as from person-to-person, or from person-to-object. In light of recent events, food-related companies have faced even more challenges in maintaining food safety. Not only that they have been responsible in ensuring that their products were safe and free from foodborne pathogens, these companies must now also ensure that they are not exposing their employees and customers to COVID-19 (Jawed et al., 2020). Hence, maintaining food safety among food handlers is still important and should not be taken lightly in food industries.

As person-to-person transmission is the main mode of transmission for COVID-19, it is of the upmost importance that safety and hygiene guidelines are implemented and enforced in food industries. For example, an infected person who does not follow social distancing and sanitation guidelines can come into contact with other co-workers and may infect them. Thus, Malaysian government has imposed strict rules to only allow workers that have completed full doses of vaccination to resume work in the food preparation area. On another note, infection among staff members is not the only concern. Uddin et al. (2020) has added that there is a great chance of exposure of infection to healthy individuals if an infected person handles the food packaging, contaminates the packaging, and gives the infected product to a healthy, unassuming customer. This is because the virus may be able to enter the body of an healthy individual via oral, nasal, or optic routes (Pressman et al., 2020). Moreover, the virus may reach fresh food products such as fruits, vegetables, and baked goods, or food packaging by means of an infected person through coughing or sneezing directly on them (Duda-Chodak et al., 2020; Rizou et al., 2020). Therefore, personal hygiene of food handlers is paramount in food safety, more so during this COVID-19 pandemic, which should include proper handwashing procedures, strict SOPs, frequent cleaning and sanitization, maintaining food respiratory hygiene and frequent usage of alcohol based sanitisers (Jyoti and Bhattacharya, 2021).

Although transmission through surface contact is not the common mode of transmission for COVID-19, there is still a possibility of transmission through food packaging materials. For example, an infected worker may expose other people to the virus by contaminating environmental surfaces or objects, which will lead to an infection when an unsuspecting person comes into contact with the item (Duda-Chodak et al., 2020; Pressman et al., 2020). It is a complex situation as we are unable to view the virus with naked eyes to postulate which site needs to be cleaned or sanitized. Under this situation, it could lead to a rather secondary or indirect transmission. Additionally, Duda-Chodak et al. (2020) has stated that the indirect transmission of coronaviruses from contaminated surfaces has been postulated. It was reported that the coronaviruses can remain for prolonged periods in environmental samples, which may boost the chance of transmission through package contact surfaces (Olaimat et al., 2020). This was further supported by Desai and Aronoff (2020) where they have stated that SARS-CoV-2 may remain active on objects or surfaces for up to 72 h. Cable et al. (2020) supported this by expressing that there has been evidence of viral RNA identified on various types of surfaces, including doorknobs and gloves, and depending on the surface, the viral half-life ranges from 1 to 2 days. In addition, Pressman et al. (2020) revealed that the SARS-CoV-2 was able to remain on cardboard for up to 24 h, and on plastic and stainless steel objects, for up to 72 h. This may come as a concern as most food packages are made of cardboard or plastic. Under such scenario, it may be speculated that food packages are able to transmit the virus to consumers or employees if it is contaminated. Thus, it is important to make sure that safety measures are enforced in restaurants and food processing or manufacturing factories to avoid any sort of contamination from workers to the food packaging materials, and from the packaging to workers or consumers. Proper sanitization performed at frequent intervals is crucial to ensure cross-contamination of the virus is not available at the industry or operational sites prior to reaching the consumers. On the other hand, consumers are also encouraged to sanitize their hands and surroundings accordingly after receiving food or groceries from restaurants or shops (Desai and Aronoff, 2020). Additionally, food safety in terms on kitchen sanitation and sanitization is important to minimize the risk of transmission through tools, cooking utensils, and packaging materials from workers to workers or workers to customers. **Supplementary Figure 3** shows customers adhering to social distancing guidelines while dining in (Free Malaysia Today, 2020).

Therefore, although COVID-19 is not a foodborne illness, it may still be transmitted during food manufacturing and processing activities. Thus, some aspects of food safety such as personal hygiene, kitchen sanitation and sanitization process should still be emphasized greatly during this pandemic. Strict protocols must be enforced during processing and handling of foods such as not allowing individuals who are showing signs of sickness to work, increase in sanitation (handwashing with soap or disinfecting with an alcohol-based sanitiser), social distancing between individuals, as well as the use of face coverings such as face masks and face shields (Cable et al., 2020). In fact, completion of two doses of vaccination is important at this stage in National Recovery Plan as enforced by the Malaysian government. **Supplementary Figure 4** shows a restaurant worker complying to MCO guidelines by screening individuals who wish to enter the food premises (Lim, 2020).

Steps to Ensure Food Safety

Pivotal steps must be taken to ensure the food safety in order to prevent the spread of COVID-19 by operations conducted in the food industry. As what have been mentioned previously, there are a few factors which affect food safety in the COVID-19 pandemic, which are personal hygiene of food handlers as well as kitchen sanitation and sanitization. The normal practices in personal hygiene and kitchen sanitation must be followed strictly to avoid the spread of COVID-19 through food processing activities such as manufacturing, packaging, transporting, and regular restaurant operations. Frequent sanitization is important at this point of pandemic regardless of whether dine-in is allowed. According to Djekic et al. (2021), staff awareness and hygiene has been reported to be the two of the most important aspects of the COVID-19 pandemic which affect food safety. **Supplementary Figure 5** shows some practices that are conducted to maintain personal hygiene of food handlers as well as kitchen sanitation in the food industry.

Personal hygiene of food handlers is extremely important as these handlers have prolonged contact with the food products. According to Djekic et al. (2021), many food companies have taken the initiative to implement strict hygiene procedures as well as purchasing additional personal protective equipment (PPE) for their employees in light of the COVID-19 pandemic. Furthermore, Lacombe et al. (2020) has stated that many processing plants have also reopened with the implementation of physical barriers in support of social distancing as well as the use of PPE and completion of vaccination among workers. Thus, one of the key steps which will need to be taken to ensure food safety during the COVID-19 pandemic is in the use of proper protective attire, which includes face masks, bonnets, gloves, as well as face shields (Cable et al., 2020). This step has been made compulsory to stop the transmission of the virus from person-to-person or person-to-object. Since the transmission of the COVID-19 virus is mainly through respiratory droplets produced by sneezing, coughing, or talking, the use of face coverings such as face masks and face shields are extremely crucial to stop the transmission and the contamination of food products, food contact surfaces as well as food packaging. Furthermore, the use of gloves and bonnets are important to make sure that the food does not become contaminated by the handler's hair or microorganisms which live on human skin. Not only that, the use of clean clothes by handlers is also important as the virus may also contaminate clothing items (Duda-Chodak et al., 2020). Hence, the handler must ensure that their clothes are clean and they should not wear items of clothing that have been previously worn before in public places as they may be contaminated by the virus. Moreover, it is also necessary to avoid smoking, coughing, sneezing, chewing, or eating in food processing areas as these activities may cause the transmission of the virus to the environment, and not to mention to other employees.

Next, kitchen sanitation is also beneficial in stopping the transmission of the virus and to maintain the safety of the food products. The hygiene of the kitchen or production area where food is prepared is extremely important as many types of contamination to foods can arise from a dirty environment. According to Redmond and Griffith (2009), some of the reasons as to why the hygiene of a kitchen may be compromised was due to inadequate design, lacking equipment of safe food preparation, and may be used for other non-food related purposes. Thus, several steps must be taken to make sure that the environment where food is processed is safe for its quality for human consumption. Firstly, the kitchen must be set up as to allow for the ease of proper hygiene practices such as sanitation and cleaning of floors and countertops. For instance, the kitchen should be built with materials that are suitable, durable and easy to be cleaned, in addition to being safe and not to harbor microorganisms (Uçar et al., 2016). Additionally, a kitchen which has been built to cater to proper hygiene practices will ensure that the employees are able to easily carry out cleaning and sanitation practices, which in turn, will motivate them to be more inclined to continue the practice. This is vital as the continuity of cleaning and sanitation practices is as important as the design and plan of the kitchen (Uçar et al., 2016). If the procedures are not carried out continuously then the kitchen cannot maintain its cleanliness. Furthermore, a cleaning and disinfection plan should be developed by the management, and the plan must be enforced and adhered to by the kitchen staff. This plan should be developed to ensure that the hygienic procedures are carried out effectively. Furthermore, it is also important to train employees on the proper sanitation and disinfection of a kitchen. In this regard, Byun et al. (2005) has stated that the level of awareness of kitchen sanitation among food service were determined by the management systems employed in the workplace as well as the extent of their sanitation training. Thus, education and training must be administered frequently and continuously to employees to strengthen the food handlers' knowledge in the area (Abdul-Mutalib et al., 2012). Lastly, utensils and equipment should also be cleaned and sanitized frequently. Among various chemical disinfectants that are being used against SARS-CoV-2 virus, alcohol based solution has been the best to be used in food industries. Ethanol and isopropanol (concentration 70–90%) kills SARS-CoV-2 virus within 30 s and causes membrane damage by disrupting the tertiary structure of proteins while denaturing the virus's protein and rupturing the RNA (Al-Sayah, 2020).

This is especially important in the era of the COVID-19 pandemic as the virus may contaminate kitchen utensils and equipment, which may lead to transmission to other employees or to food products or food packaging. Hence, these sanitation and sanitization plan should be in place, well-documented and included in trainings so that it can be practiced when it is necessary. Since pandemic was unexpected, management system regarding food safety should be adhered according to WHO and local Ministry of Health guidelines.

Aspects of personal hygiene of handlers and kitchen sanitation are not only important for large scale food industries or restaurants, but also necessary to be adhered to by small businesses or street food vendors. During the pandemic, it will only take one infected vendor to potentially spread the virus to a countless number of customers, vendors and even delivery personnel. For example, street food vendors or small-scale food businesses should still adhere to personal hygiene practices such as the wearing of clean clothes and proper protective attire, such as face coverings and gloves. Not only that, but vendors should also avoid doing activities that might spread diseases near food preparation areas such as smoking, coughing, eating, and sneezing. Additionally, Pritwani et al. (2015) has also stated that proper handwashing during all stages of processing must be followed strictly, as this is crucial not only to stop the spread of foodborne illnesses, but also to avoid spreading the COVID-19 virus. **Supplementary Figure 6** shows a scene with street food vendors and customers seen wearing masks and adhering to social distancing guidelines.

Furthermore, kitchen sanitation is also important for street food vendors and small-scale food industries. Moreover, access to clean and safe water supply should be monitored in order to conduct proper cleaning and sanitation and sanitization activities (Pritwani et al., 2015; Cortese et al., 2016). Additionally, it is also important for the relevant authorities to regularly monitor and supervise small-scale food vendors to ensure they are complying with proper food safety practices (Cortese et al., 2016). Training must also be given as most of these small-scale vendors have not been formally educated to emphasize food safety, thus it is necessary for the relevant authorities to provide education and support to ensure that these vendors can still operate their businesses without the danger of selling food that are not safe for human consumption. For example, a recent case of food poisoning that occurred in Malaysia involved 99 victims that have consumed a local food product, "puding buih" (Malay Mail, 2020). According to an article reported by New Straits Times (2020), the dessert has been purchased online from a local vendor by the victims. Following the incident, the local authorities have provided SOPs to home-based food traders to ensure that they are able to generate income during this pandemic while at the same time able to guarantee the safety of the food being sold (Malay Mail, 2020).

COVID-19 and the Food Supply Chain

What Is the Food Supply Chain?

The food supply chain can be described as the different processes that occur to bring food from production to the consumer or from farm to fork. Generally, the supply chain consists of processes such as agricultural production, post-harvest handling, processing, distribution and retail, and lastly consumption (Rizou et al., 2020). The food supply chain is not a singular chain of fixed entities, instead it is a complex web of interconnected entities which work together to make the food available to the consumers (Dani, 2015).

The maintenance of a functional food supply chain is very important in ensuring food can be provided to the consumers continuously. The closure of a single factory may pose a risk to a certain amount of people whom work at the factory, however the obstruction of key processes in the food supply chain such as production or distribution, may endanger a larger portion of the population that depend on the food to live (Aday and Aday, 2020). This is because the disruption in the supply chain will cause a snowball effect in the food industry such as halting the processing and production of food, leading to the creation of insufficient products in the market, which in turn results in the inability to attain food by the consumers for nourishment. Thus, the COVID-19 pandemic may have serious effects to the food supply chain.

Impact of COVID-19 to the Food Supply Chain

As what have been mentioned, the COVID-19 pandemic has brought on many difficulties, especially in the food industry as many companies have been forced to either partially or even fully shut down. Many countries, including Malaysia, have implemented lockdowns and partial lockdowns periodically in order to curb the rising cases of infections as well as deaths. The overall impact on agricultural practices and business entities along the food supply chain are depicted in **Supplementary Figure 7**.

One of the impacts of COVID-19 is the restriction of movement which has caused issues in the supply chain. As an example, in Malaysia, the MCO implemented by the government restricted movement by implementing travel restrictions that has further enforced by road blocks all over the country, as well as the limitation of a 10-km travel radius for all citizens (Tang, 2020). When workers are unable to get to work due to travel restrictions, then the processes in the supply chain will be incapacitated (Aday and Aday, 2020). During the first few weeks of the implementation of the MCO in Malaysia, many food supply chains, especially those in urban areas, have been disrupted due to these travel restrictions. Many of these supply chains rely on the use of land transports such as lorries to carry their products from farms located far from the urban cities (Chin, 2020). This was supported by Tumin et al. (2020) which has stated that the MCO has affected the supply chain or organic food products in Malaysia in which these restrictions have heavily impacted the distribution of products from the producers to the consumers. As a result, some farmers or growers have resorted to send their produce out to charity, or those who had rose up white flags at their homes due to financial difficulties. The raising of the white flags started initially in front of residential homes; with further neighbors tend to help out with groceries and home basic necessities. Later on, several apps such as Bendera Putih and White Flag were developed by local Malaysians to track suffering families and anyone nearby can help out based on the app. Website Kita Jaga Malaysia (kitajaga.co) has also been developed for this cause (Angelin, 2021).

Furthermore, lockdowns have led to other disruptions in the food supply chain, which was due to a shortage of labor (Singh et al., 2020). Verma and Prakash (2020) have stated that about 13 million people all over the world may face unemployment, according to the International Labor Organization (ILO). Moreover, Nicola et al. (2020) has further indicated that the restrictions brought on by the pandemic has led to a reduction in the workforce across all economic sectors, causing many jobs to be lost. The National Recovery Plan has been introduced in June 2021 to minimize the surging number of COVID-19 cases in Malaysia due to the third-wave. Under this plan, the workers were encouraged to get vaccinated to reduce the overloading the hospitals.

As an example, Dr. Tey Yeong Sheng, a researcher at the Institute of Agricultural and Food Policy Studies at Universiti Putra Malaysia has stated that labor shortages was one of the main difficulties faced by local farmers in food production (Chung, 2020). These farmers were faced with many obstacles as they are reliant on workers to harvest crops as well as for preparation of land. Thus, when these workers face difficulty in crossing states and traveling, the food production will be disrupted. This has affected the processing of crops, livestock, and fishery sub-sectors in the food industry, and it has impacted the agriculture value chain as well as the availability of these foods (Vaghefi, 2020). **Supplementary Figure 8** shows a lone farmer working in a field (Man, 2020).

Labor shortages affect many levels of the food supply chain as each process requires workers to complete hands-on tasks such as harvesting, processing, and manufacturing. Even though some companies manage by allowing their employees to work from home, the same cannot be applied for the food industry as most businesses require workers to work hands on, such as in agricultural production or post-harvest handling. For instance, a vegetable producer may experience problems from shortage of labor, thus not allowing the farmer to harvest as many vegetables as usual. Therefore, there will be a shortage in the production of fresh vegetables.

Moreover, labor shortages will also affect the food distribution system due to the unavailability of workers, such as truck drivers to transport the food products from the distributors to the consumers (Mahajan and Tomar, 2020; Singh et al., 2020). Surendran (2020) also pointed out that the number of employees working in day-to-day operations on farms has also been limited during the period of MCO in Malaysia. This view was supported by Nicola et al. (2020), where the restrictions imposed due to the COVID-19 pandemic has been found to have impacted the availability of workers such as inspectors as well as delivery staff in ensuring the verification and transportation of food products. This in turn will cause a lack of food items being made available to the consumers (Singh et al., 2020).

In addition, labor shortages also cause losses for the farmers. For example, due to the MCO conducted in Malaysia, 2,300 farmers had suffered a reported loss of RM1 million per day due to their inability in selling harvested produce, thus they were discarded as waste (Man, 2020). Similarly, it has been reported that about 200 farmers were unable to sell their vegetables in Gua Musang, leading to a total loss of RM400,000 a day. They had been forced to discard up to 200 metric tons of vegetables per day. This is because agricultural produce such as vegetables and fruits are perishable items, and as such, when there are not enough workers available to harvest, process, and transport the products for sale, then the produce will not be sold and has to be discarded as waste. Furthermore, this situation occurs as consumers opt for online purchases rather than to go out to obtain their weekly groceries.

Additionally, the farmers also suffered loss as the MCO had required closure of many businesses as well as restriction of the number of people allowed in a certain area. This was due to the difficulty of exercising social distancing in many markets where farmers usually sell their produce, thus many of these markets have been forced to close down, or allowed to open but with limitations (Chin, 2020). **Supplementary Figure 9** shows a vendor in a market wearing protective clothing while waiting for customers (Hassan and Leong, 2020). In order to support the current economic situation, National Recovery Plan has been introduced in a few phases based on number of cases and utilization of ICU beds in hospitals in different states. Hence, workforce is allowed with 2 completed doses of vaccination and to maintain strict SOP at the workplace.

For example, a wholesale market in Selayang, Selangor has been ordered to reduce the amount of workers and its operating hours, which has caused vegetable farmers and fishermen to forcefully dump their stock of produce as the products were unable to be sold (Hassan and Leong, 2020). This situation had also been seen occurring in farmers in Cameron Highlands that had to dump or gave away their produce due to the perishable nature of their products (Ng and Wahid, 2020). **Supplementary Figure 10** shows a photograph of a worker destroying vegetables on a farm as they cannot be sold due to issues arising from the COVID-19 pandemic (Surendran, 2020).

In addition, unavailability of food products is also a resulting effect from the COVID-19 pandemic on the food supply chain. For example, during the start of the pandemic where initial lockdowns were announced, many consumers have exhibited panic buying and hoarding (Aday and Aday, 2020; Singh et al., 2020). As COVID-19 was still unknown then, consumers were uncertain of the severity of this virus and how to handle the lockdown restrictions, thus many had been seen buying large amounts of food items that they could store and use in an emergency such as canned foods. Furthermore, Koh et al. (2020) has stated that panic buying may occur when people observe other people in buying certain products, then mass fear infects the individual as they do not want to be left out of owning an item that appears to be running out. This was seen when people kept buying items even if they did not necessarily need them. However, these hoarding and panic buying have caused the sudden surge of demand for food items (Singh et al., 2020), As a result, many manufacturers and retailers had not been able to keep up with the demand, thus some less unfortunate people were unable to buy any food products to stock up during the lockdown. Furthermore, panic buying has also caused the increase in concerns of food shortages, including long-life foods like UHT milk, rice, pasta, as well as canned foods (Nicola et al., 2020). The unavailability of food products would also induce price spikes due to high demand (Aday and Aday, 2020; Mahajan and Tomar, 2020; Reardon et al., 2020). The increase in prices will negatively affect poorer households as certain food items will no longer become accessible to them (Mahajan and Tomar, 2020). Lastly, the lack of food products in the market will give health repercussions as well-due to a decrease in intake of nutritionally balanced foods and lack of diversity in the diet (Mahajan and Tomar, 2020). This is especially dangerous during a pandemic as maintaining one's health is of upmost importance in order to avoid contracting COVID-19 (Uddin et al., 2020). **Supplementary Figure 11** shows consumers crowding at a grocery store following announcements of a MCO (Free Malaysia Today, 2021).

CONCLUSION AND RECOMMENDATIONS

In conclusion, the COVID-19 pandemic has brought on some effects to food safety and the food supply chain. Although COVID-19 is said to not be a foodborne virus, it is still important to maintain proper food safety protocols in the food industry. The novelty of this study is to highlight that maintaining good personal hygiene of handlers is utterly important in food industries. Completion of the vaccination dosage is vital to achieve herd immunity. Besides, it is significant to point that the maintenance of kitchen sanitation is essential during this pandemic. This is due to the possibility of transmission of COVID-19 through the food handlers as well as by food packaging materials. It is important for food handlers to maintain good hygiene and kitchen sanitation to help keep themselves safe, as well as their surroundings clean and free from contamination, which in turn will minimize the spread of COVID-19. It seems like a complex mechanism, however, the safety of food and handlers can be maintained altogether if managed properly. Furthermore, COVID-19 has also made an impact on the food supply chain. Due to the strict lockdowns as well as many protocols involving social distancing and travel restrictions, the food supply chain has seen some negative effects in light of this pandemic. Some of these effects include shortages in labor which have caused disruption in the supply chain, as well as the lack of distribution of food products to consumers. Next, other effects include shortages of food, increase in prices, and health repercussions to the consumers due a lack of diversity in the diet and a decrease intake of nutritious foods. It is therefore crucial to ensure that the food supply chain has a smooth progression to maintain the constant supply of food commodity for consumption in Malaysia. At the moment, it is quite common to have delays in supply than usual due to current supply chain situation. All the threats and implication presented in this review have been assessed thoroughly, where the information was extracted from reports, local newspaper articles and manuscripts. This study is important to policymakers in the food industries, enabling designing management system and training needed during and post-pandemic situation to ensure continuous food safety and supply chain are in good progression.

As a recommendation, more research must be conducted in the future to combat this virus. Since there are currently no official guidelines and protocols that exist to detect the presence of the SARS-CoV-2 virus on surfaces as well as public places (Lacombe et al., 2020), relevant bioanalytical tools such as a method of tracing and detection of SARS-CoV-2 in the environment where food is processed, manufactured, and handled (Rizou et al., 2020) should be developed. This would be useful in distinguishing the presence of the virus on environmental surfaces, as well as help minimize and eliminate the possibility of transmission through food products, food packaging materials and surrounding environments. Lockdown cannot be considered a permanent solution to fight this pandemic in the long run due to its many implications in the social perspective as well as in the economical perspective (Singh et al., 2020). Until then, everyone must do their part to protect themselves, and everyone around them from this virus by practicing social distancing, frequent handwashing, and sanitization, in addition to using face masks in public as well as in achieving herd immunity by completing the vaccination doses required. At the same time, minimizing transmission within places where food is handled, including food processing facilities, restaurants, and grocery stores, is key in protecting workers and customers, as well as in combating the spread of COVID-19 (Cable et al., 2020).

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

NE conducted the research, as well as literature search. AF and SR gave input on drafting the review article and conceptual the article based on current pandemic situation. TM gave constructive comments to improve the article. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2021.682263/full#supplementary-material

REFERENCES

Abdul-Mutalib, N.-A., Abdul-Rashid, M.-F., Mustafa, S., Amin-Nordin, S., Hamat, R. A., and Osman, M. (2012). Knowledge, attitude and practices regarding food hygiene and sanitation of food handlers in kuala pilah, malaysia. *Food Control* 27, 289–293. doi: 10.1016/j.foodcont.2012.04.001

Aday, S., and Aday, M. S. (2020). Impacts of covid-19 on food supply chain. *Food Qual. Safety* 4, 1–35. doi: 10.1093/fqsafe/fyaa024

Al-Sayah, M. H. (2020). Chemical disinfectants of COVID-19: An overview. *J Water Health* 18, 843–848. doi: 10.21666/wh.2020.108

Aman, F., and Masood, S. (2020). How nutrition can help to fight against covid-19 pandemic. *Pak. J. Med. Sci. Q.* 36, 121–123. doi: 10.12669/pjms.36.COVID19-S4.2776

Angelin, Y. (2021). *Want to Help Those in Need? Search for White Flags in Your Area with the Kita Jaga Malaysia Website. The Star.* Available online at: https://www.thestar.com.my/tech/tech-news/2021/07/07/want-to-help-those-in-need-search-for-white-flags-in-your-area-with-the-kita-jaga-malaysia-website (accessed July 08, 2021).

Australian Institute of Food Safety (2019). *What is Food Safety?* Available online at: https://www.foodsafety.com.au/blog/what-is-food-safety (accessed December 03, 2020).

Byun, J. S., Park, S. S., and Cho, C. B. (2005). A fact analysis on the level of perception and performance for the haccp system: emphasized on the hotel kitchen employees. *J. Hotel Res.* 4, 423–427.

Cable, J., Jaykus, L.-A., Hoelzer, K., Newton, J., and Torero, M. (2020). The impact of covid-19 on food systems, safety, and security—a symposium report. *Ann. N. Y. Acad. Sci.* 1484, 3–8. doi: 10.1111/nyas.14482

Che Mat, N. F., Edinur, H. A., Abdul Razab, M. K. A., and Safuan, S. (2020). A single mass gathering resulted in massive transmission of covid-19 infections in malaysia with further international spread. *J. Travel Med.* 27:taaa059. doi: 10.1093/jtm/taaa059

Chin, C. F. (2020). The impact of food supply chain disruptions amidst covid-19 in malaysia. *J. Agric. Food Syst. Community Dev.* 9, 161–163. doi: 10.5304/jafscd.2020.094.031

Choi, B., Jegatheeswaran, L., Minocha, A., Alhilani, M., Nakhoul, M., and Mutengesa, E. (2020). The impact of the covid-19 pandemic on final year medical students in the united kingdom: a national survey. *BMC Med. Educ.* 20:206. doi: 10.1186/s12909-020-02117-1

Chung, C. (2020). *FaQ Need Aid to Face Food Production Challenges. The Star*. Available online at: https://www.thestar.com.my/news/nation/2020/04/

21/farmers-need-aid-to-face-food-production-challenges (accessed January 10, 2021).

Cook, N., and Richards, G. P. (2013). "An introduction to food-and waterborne viral disease," in *Viruses in Food and Water: Risks, Surveillance and Control*, ed N. Cook (Cambridge: Woodhead Publishing). 3–18. doi: 10.1533/9780857098870.1.3

Cook, T. M. (2020). Personal protective equipment during the COVID-19 pandemic–a narrative review. *Anaesthesia* 75, 920–927. doi: 10.1111/anae.15071

Cortese, R., Veiros, M., Feldman, C., and Cavalli, S. (2016). Food safety and hygiene practices of vendors during the chain of street food production in florianopolis, brazil: a cross-sectional study. *Food Control* 62, 178–186. doi: 10.1016/j.foodcont.2015.10.027

Cucinotta, D., and Vanelli, M. (2020). Who declares covid-19 a pandemic. *Acta Bio-Med. Atenei Parmensis* 91, 157–160. doi: 10.23750/abm.v91i1.9397

Dani, S. (2015). *Food Supply Chain Management and Logistics: From Farm to Fork*. London: Kogan Page Ltd.

Desai, A. N., and Aronoff, D. M. (2020). Food safety and covid-19. *JAMA* 323, 1982–1982. doi: 10.1001/jama.2020.5877

Djekic, I., Nikolić, A., Uzunović, M., Marijke, A., Liu, A., Han, J., et al. (2021). Covid-19 pandemic effects on food safety-multi-country survey study. *Food Control* 122:107800. doi: 10.1016/j.foodcont.2020.107800

Duda-Chodak, A., Lukasiewicz, M., Zieć, G., Florkiewicz, A., and Filipiak-Florkiewicz, A. (2020). Covid-19 pandemic and food: present knowledge, risks, consumers fears and safety. *Trends Food Sci. Technol.* 105, 145–160. doi: 10.1016/j.tifs.2020.08.020

Free Malaysia Today (2020). *Will Cloud Kitchens Save the Fandb Sector Post Covid-19? Free Malaysia Today*. Available online at: https://www.freemalaysiatoday.com/category/leisure/2020/09/22/will-cloud-kitchens-save-the-fb-sector-post-covid-19/ (accessed January 9, 2021).

Free Malaysia Today (2021). *Don't Let Rumours Cause More Panic Buying, Says Ismail Sabri. Free Malaysia Today*. Available online at: https://www.freemalaysiatoday.com/category/nation/2021/01/09/dont-let-rumours-cause-more-panic-buying-says-ismail-sabri/ (accessed January 12, 2021).

Hassan, H., and Leong, T. (2020). *Coronavirus: Farmers Dump Their Stock After Police Impose Restrictions at Wholesale Market. The Straits Times*. Available online at: https://www.straitstimes.com/asia/se-asia/coronavirus-farmers-dump-their-stock-after-police-impose-restrictions-at-wholesale (accessed January 08, 2021).

Jawed, I., Tareen, F. R., Cauhan, K., and Nayeem, M. (2020). Food safety and covid-19: limitations of haccp and the way forward. *Pharm. Innov. J.* 9, 1–4. doi: 10.22271/tpi.2020.v9.i5a.4616

Jyoti, and Bhattacharya, B. (2021). Impact of COVID-19 in Food Industries and potential innovations in food packaging to combat the pandemic a review. *Sci. Agro.* 12, 133–140. doi: 10.17268/sci.agropecu.2021.015

Koh, E. B. Y., Pang, N. T. P., Shoesmith, W. D., James, S., Nor Hadi, N. M., and Jiann, L. L. (2020). The behaviour changes in response to covid-19 pandemic within Malaysia. *Malays. J. Med. Sci.* 27, 45–50. doi: 10.21315/mjms2020.27.2.5

Lacombe, A., Quintela, I., Liao, Y.-,t., and Wu, V. C. H. (2020). Food safety lessons learned from the covid-19 pandemic. *J. Food Safety* 41:e12878. doi: 10.1111/jfs.12878

Li, S., Kallas, Z., and Rahmani, D. (2022). Did the COVID-19 lockdown affect consumers' sustainable behaviour in food purchasing and consumption in China? *Food Control* 132:108352. doi: 10.1016/j.foodcont.2021.108352

Lim, I. (2020). *Kl Mayor Instructs 24-Hour Restaurants to Limit Hours During Covid-19 Shutdown. Malay Mail*. Available online at: https://www.malaymail.com/news/malaysia/2020/03/19/kl-mayor-instructs-24-hour-restaurants-to-limit-hours-during-covid-19-shutd/1848095 (accessed January 10, 2021).

Mahajan, K., and Tomar, S. (2020). Covid-19 and supply chain disruption: Evidence from food markets in India. *Am. J. Agric. Econ.* 103, 35-52. doi: 10.1111/ajae.12158

Mahar, B., Warsim, J., and Shah, T. (2021). Eating disorders and eating pattern during covid-19 pandemic: a short bulletin. *J. Liaquat Univ. Med. Health Sci.* 20, 157–162. doi: 10.22442/jlumhs.2021.00776

Malay Mail (2020). *"Puding Buih" Food Poisoning Case Due to Use of Expired Eggs, Says Terengganu Exco. Malay Mail*. Available online at: https://www.malaymail.com/news/malaysia/2020/05/31/puding-buih-food-poisoning-case-due-to-use-of-expired-eggs-says-terengganu/1871122 (accessed January 10, 2021).

Man, N. (2020). *Helping Farmers to Cope With Challenges. New Straits Times*. Available online at: https://www.nst.com.my/opinion/letters/2020/05/589885/helping-farmers-cope-challenges (accessed January 09, 2021).

Min, S., Xiang, C., and Zhang, X.-h. (2020). Impacts of the covid-19 pandemic on consumers' food safety knowledge and behavior in china. *J. Integr. Agric.* 19, 2926–2936. doi: 10.1016/S2095-3119(20)63388-3

Minhat, H. S., and Shahar, H. K. (2020). The trajectory of covid-19 scenario in malaysia: facing the unprecedented. *Curr. Med. Res. Opin.* 36, 1309–1311. doi: 10.1080/03007995.2020.1786680

New Straits Times (2020). *Q Fiasco: Number of Victims Climbs to 74. New Straits Times*. Available online at: https://www.nst.com.my/news/nation/2020/05/595511/puding-buih-fiasco-number-victims-climbs-74 (accessed January 10, 2021).

Ng, X. Y., and Wahid, R. (2020). *Cameron Highlands Farmers Dump Hundreds of Tonnes of Vegetables. Malaysiakini*. Available online at: https://www.malaysiakini.com/news/516704 (accessed January 09, 2021).

Nicola, M., Alsafi, Z., Sohrabi, C., Kerwan, A., Al-Jabir, A., Iosifidis, C., et al. (2020). The socio-economic implications of the coronavirus pandemic (covid-19): a review. *Int. J. Surg.* 78, 185–193. doi: 10.1016/j.ijsu.2020.04.018

Olaimat, A. N., Shahbaz, H. M., Fatima, N., Munir, S., and Holley, R. A. (2020). Food safety during and after the era of covid-19 pandemic. *Front. Microbiol.* 11:1854. doi: 10.3389/fmicb.2020.01854

Pressman, P., Naidu, A. S., and Clemens, R. (2020). Covid-19 and food safety. *Nutr. Today* 55, 125–128. doi: 10.1097/NT.0000000000000415

Pritwani, R., Singh, K., and Mathur, P. (2015). *Improving Food Safety in Small Scale Food Catering Units: A Haccp Approach. Paper Presented at the National Seminar on Food and Textile Industry—Emerging Trends and Perspectives*. University of Delhi.

Rashid, S. M. R. A., Hassan, F., Sharif, N. M., Rahman, A. A., and Mahamud, M. A. (2021). The role of digital marketing in assisting small rural entrepreneurs amidst Covid-19 movement control order (MCO): a case study in Peninsular Malaysia. *Academic Journal of Interdiscip. Stud.* 10, 70–80. doi: 10.36941/ajis-2021-0099

Reardon, T., Bellemare, M. F., and Zilberman, D. (2020). *How covid-19 May Disrupt Food Supply Chains in Developing Countries*. International Food Policy Research Institute (IFPRI). doi: 10.2499/p15738coll2.133762_17

Redmond, E. C., and Griffith, C. J. (2009). The importance of hygiene in the domestic kitchen: implications for preparation and storage of food and infant formula. *Perspect. Public Health* 129, 69-76. doi: 10.1177/1757913908101604

Rizou, M., Galanakis, I. M., Aldawoud, T. M. S., and Galanakis, C. M. (2020). Safety of foods, food supply chain and environment within the covid-19 pandemic. *Trends Food Sci. Technol.* 102, 293–299. doi: 10.1016/j.tifs.2020.06.008

Rozaki, Z. (2020). Covid-19, agriculture, and food security in indonesia. *Rev. Agric. Sci.* 8, 243–260. doi: 10.7831/ras.8.0_243

Shah, A. U. M., Safri, S. N. A., Thevadas, R., Noordin, N. K., Rahman, A. A., Sekawi, Z., et al. (2020). Covid-19 outbreak in malaysia: actions taken by the malaysian government. *Int. J. Infect. Dis.* 97, 108–116. doi: 10.1016/j.ijid.2020.05.093

Singh, S., Kumar, R., Panchal, R., and Tiwari, M. K. (2020). Impact of covid-19 on logistics systems and disruptions in food supply chain. *Int. J. Product. Res*. 59, 1-16. doi: 10.1080/00207543.2020.1792000

Surendran, S. (2020). *Cover Story: Mco Casts Spotlight On "Disconnect" in Agribusiness Supply Chain. The Edge Markets*. Available online at: https://www.theedgemarkets.com/article/cover-story-mco-casts-spotlight-disconnect-agribusiness-supply-chain (accessed January 08, 2021).

Tang, K. H. D. (2020). Movement control as an effective measure against covid-19 spread in malaysia: an overview. *J. Public Health*, 1, 1-4. doi: 10.1007/s10389-020-01316-w

Tee, M. L., Tee, C. A., Anlacan, J. P., Aligam, K. J. G., Reyes, P. W. C., Kuruchittham, V., et al. (2020). Psychological impact of covid-19 pandemic in the philippines. *J. Affect. Disord.* 277, 379–391. doi: 10.1016/j.jad.2020.08.043

Thomas, M. S., and Feng, Y. (2021). Consumer risk perception and trusted sources of food safety information during the COVID-19 pandemic, *Food Control* 130:108279. doi: 10.1016/j.foodcont.2021.108279

Tumin, S. A., Ramasamy, R., Newaz, F. T., Noh, I., and Abdul Latip, M. (2020). How do food safety knowledge and trust affect individual's green considerations during the covid-19 pandemic in Malaysia? *Malays. J. Consum. Fam. Econ.* 24, 261–285.

Uçar, A., Yilmaz, M. V., and Çakiroglu, F. P. (2016). Food safety–problems and solutions. *IntechOpen*. 1, 1–25. doi: 10.5772/63176

Uddin, M. N., Alam, B., Islam, S. S., Arif, M., Alam, M. M., and Kabir, S. M. L. (2020). Impact of covid-19 on food safety and security in low and middle income countries. *Asian J. Med. Biol. Res.* 6, 130–137. doi: 10.3329/ajmbr.v6i2.48043

Vaghefi, N. (2020). *The Heavy Impact of Covid-19 on the Agriculture Sector and the Food Supply Chain.* Penang Institute.

Verma, A. K., and Prakash, S. (2020). Impact of covid-19 on environment and society. *J. Glob. Biosci.* 9, 7352–7363.

World Health Organization (2020). *2019 Novel Coronovirus (2019-ncov): Strategic Preparedness and ReQse Plan*. Available online at https://www.who.int/publications/i/item/strategic-preparedness-and-response-plan-for-the-new-coronavirus (accessed December 03, 2020).

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Building Resilient Value Chains After the Impact of the COVID-19 Disruption: Challenges for the Coffee Sector in Central America

*Ingrid Fromm**

Bern University of Applied Sciences, School of Agricultural, Forest and Food Sciences, Bern, Switzerland

Coffee is an important agricultural sector in Central American, directly employing over 1.2 million people in Guatemala, Honduras, El Salvador, Nicaragua, and Costa Rica. Although export revenues from coffee trade have an overall positive effect on the gross domestic product (GDP) of these countries, poverty still prevails. The COVID-19 pandemic has placed additional pressure on the sector which is vulnerable to fluctuations in the international coffee prices, low productivity levels, and climate change effects and damages caused by pest and diseases. This paper examines the effects of the COVID-19 pandemic and analyzes if the sector is resilient to withstand unexpected external shocks such as the pandemic and the hurricanes which impacted the region in the last months of 2020. The capacity to absorb, adapt, and/or transform to these shocks was assessed from the perspective of small-scale coffee farmers, traders, exporters and the entire sector in two time periods—immediately after the start of the pandemic and after the coffee harvest. Although the actors in the coffee value chain absorbed these shocks and could withstand them, adaptation to the disruptions has been challenging for small-scale farmers. Despite the vulnerability to unexpected external shocks, results indicate that a long-term transformation of the sector to build resilience is likely to be slow.

Keywords: coffee, small-scale farmers, resilience, Central America, climate-change

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Gabriel da Silva Medina,
University of Brasilia, Brazil
Luis F. Aristizabal,
Consultant, Kailua-Kona, United States

****Correspondence:***
Ingrid Fromm
ingrid.fromm@bfh.ch

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INTRODUCTION

Coffee (*Coffea arabica* L.) is one of the most important global agricultural commodities. For many developing countries, coffee is the top agricultural export, accounting for a substantial part of the gross domestic product (GDP). In Central American countries, coffee is one of the top agricultural sectors. In El Salvador, Honduras, and Nicaragua, coffee is the main agricultural export and second largest agricultural export in Guatemala and Costa Rica. In all countries, the coffee sector represents a main source of rural employment. It is estimated that 1.2 million people are directly employed in the coffee sector in Central America (ICO, 2018), and the figure would be larger if indirect employment would also be accounted (Bathrick, 2017). Most of the coffee production in Central America takes place in small-scale family farms. In rural areas where coffee is cultivated, poverty still prevails. The problem of poverty, hunger, and malnutrition in coffee growing regions in Central America has been documented for years (Lewin et al., 2004; Bacon et al., 2008; Caswell et al., 2012). Households normally receive only one annual paycheck for their crop which has to be distributed throughout the year until the next harvest season. Fluctuating market price patterns severely affect farmers. When international coffee prices drop below production price, as it did in 2018 when the average price dropped 30% below the average, farmers in Central America face severe poverty. Additionally, coffee farmers in this region are facing climate change risks, which will affect their livelihood and in general, the future of coffee production (Watts, 2016). Donatti et al. (2019) point out that smallholder farmers in the region are particularly vulnerable to climate change events. The 2020 Atlantic hurricane season has been particularly devastating. Within a period of 2 weeks, two hurricanes hit Central America, causing massive loss in agriculture and infrastructure. Honduras, Guatemala, and Nicaragua have been particularly affected by floods and landslides.

Despite the problems and impending risks on the production side, global coffee consumption has steadily increased in the last decades. According to the ICO (2020), coffee consumption has increased by 2% annually since 1990. In recent years, coffee consumption has increased in Europe, North and South America, and Asia, while remaining stagnant in Central America, and decreasing in Africa. In industrialized countries, consumption patterns have changed as coffee has evolved from a plain cup of black coffee to a multitude of forms, flavors, and origins, stemming from the coffee shop culture which has dramatically evolved during this time frame. Consumers also tend to pay much more per cup of coffee than they did in 1990 (Meister, 2017). However, this increase in the price of a cup of coffee has not translated into increased farm gate prices paid to the farmers. If anything, coffee farmers have faced severe crises such as the coffee crisis of 2001 and the unstable international coffee prices since 2016. As farm incomes decline, livelihoods are increasingly at risk, since it becomes impossible to invest in the modernization of farms and in adaptation to the impact of climate change (ICO, 2020).

The challenges mentioned above already placed coffee farmers in Central America in a vulnerable situation prior to the outbreak of pandemic caused by the Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2, which will be referred to as COVID-19 in this paper) in early 2020. The coffee harvest was just about over when the first cases of COVID-19 were reported in the region. The pandemic itself, in addition to the sanitary and health measures imposed by the governments have affected the coffee sector on different levels. A second shock to the coffee sector came in the second half of 2020. In November 2020, Central America was devasted by hurricanes Eta and Iota, which brought severe flooding, landslides, and destroyed homes and infrastructure, displacing an estimated 7 million people in Honduras, Nicaragua, and Guatemala (ReliefWeb, 2020a). Landslides and loss of infrastructure in the region negatively impacted the coffee sector. How the sector will be impacted in the long run remains to be seen. Based on preliminary evidence and secondary data on exports and coffee prices, a discussion on resilience is presented.

The central question of this paper is how small-scale farmers in Central America can build resilience to cope with the disruptions caused by the COVID-19 pandemic and the extreme climatic events of 2020. Understanding and promoting smallholder resilience is critical for global food systems (Stratton et al., 2020). This paper analyzes the impact on small-scale farmers from two perspectives. First, the immediate impacts on coffee exports from Central America will be discussed. Second, price volatility and changes which affect could affect farmers in the subsequent harvest will be analyzed. Finally, options to build resilience will be addressed, using the framework proposed by Béné et al. (2014), where resilience is defined as the capacity to absorb, adapt, and/or transform to shocks or events, which are unexpected and have short or longer-term repercussions on the system.

THE COFFEE VALUE CHAIN IN CENTRAL AMERICA

Coffee has been a key economic sector in Central America for over a century. Since the introduction of coffee in the region in the mid-eighteenth century, Central America has become a favored origin for its full-bodied, fine flavored Arabica coffee. The political economy of Central America in the late nineteenth and early twentieth centuries was mainly centered around the economy of coffee cultivation and export (Paige, 1985). In El Salvador, for example, coffee production accounted for 50% of the GDP in the early 1980s. A dual system of coffee cultivation developed in Central America during the twentieth century: large plantations, run by landowners and small-scale farms, typically cultivated by peasant farmers. Historians attribute the historic and political conflicts of the 1980s in Central America largely to this duality where vast wealth was made and in parallel, harsh poverty prevailed in the coffee sector (Sedgewick, 2020). Although much has changed since the end of the guerilla conflicts in Central America, coffee cultivation still plays an important role in the livelihoods of rural families.

Coffee production in Central America in the last two decades has been challenging. Agronomic aspects pose difficulties to producers. A reduction in coffee production was caused by the coffee rust epidemic (Avelino et al., 2015). The resurgence of coffee rust (*Hemileia vastarix*) caused 31% loss in Colombia between 2008 and 2011 and 16% loss in Central America in the 2012 and 2013 season (Avelino et al., 2015). These losses in production came after the recovery from the aftermath of Hurricane Mitch, which hit Central America in October 1998. Honduras, Nicaragua, Guatemala, and El Salvador were mostly affected and according to FAO (2001) estimates, between 20 and 30% percent of the harvest was lost during that season. Only a few years after, the coffee crisis hit the sector, when it was barely recovering. Since then, coffee production has increased in Central America, reaching a peak in production this last season (**Figure 1**). Honduras has reported the highest increase in production in the last decade and surpassed Guatemala as the largest coffee producer in the region. In November 2020, the region has again experienced losses in coffee production due to Hurricanes Eta and Iota (ReliefWeb, 2020b).

Although coffee production volumes have increased steadily in the region, fluctuating international coffee prices have hit some low points over the past two decades (**Figure 2**). The coffee crisis of 2001 negatively impacted coffee producers in the region. The

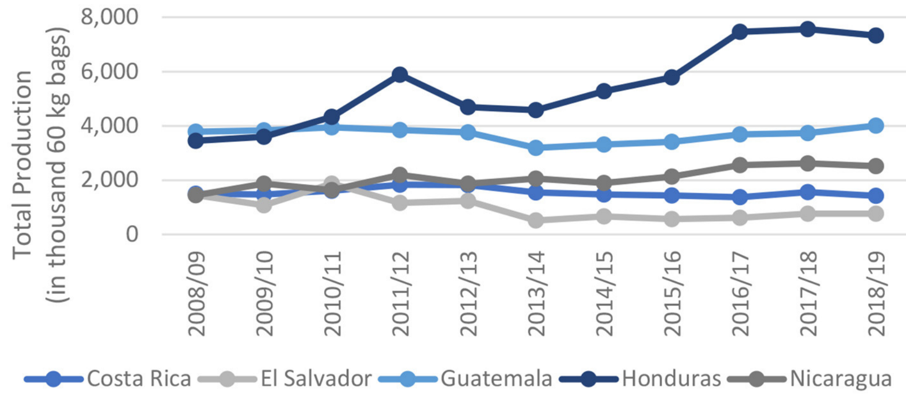

FIGURE 1 | Total coffee production in Central America 2008–2019. Source: ICO (2020).

increasing concentration of the coffee industry brought lower and more unstable prices, especially for producers (Wyss et al., 2012). Although prices picked up and reached a high in the 2010–2011 seasons, prices have decreased since then. At the farm level, international price fluctuations have a larger effect, as farmers might not even be able to cover productions costs if the prices fall below a certain threshold. In particular, small-scale farmers producing in small plots of land of <2 ha are vulnerable to these changes in the international markets.

At the farm level, and in smaller-scaled farms, which are commonly found throughout the Central American region, poverty, and food insecurity places thousands of farms in a vulnerable situation. However, poverty and food insecurity cannot be attributed to a single cause (SCAA, 2013). Unstable international coffee prices can have an immediate and severe impact on coffee livelihoods when prices plummet. Because farmers are paid upon harvest, they have one income per year, if there are no other sources to supplement this income. The risks of relying solely on the coffee income to sustain an entire household, motivate farmers also plant other crops for household consumption. Additional food production is often not sufficient to protect against the risks and it is rarely enough to support families through the months when no income flows into the household, even when coffee yields and prices are favorable (Morris et al., 2013).

In addition to the income problem, coffee farmers in Central America must cope with climate change risks such as more severe droughts, erratic rain patterns, and outbreaks of fungal coffee rust and pests. In this context, seasonal hunger among coffee communities has become more prevalent. Bacon et al. (2008) address the issue of seasonal hunger and smallholder affiliation to organizations. Virtually all coffee producing countries suffer from institutional voids. These include major gaps in infrastructure, weak legislative systems and poor governance, poor access to and/or quality of education, and restricted access to finance. This weak enabling environment plays a fundamental role in preventing rural smallholders from advancing out of poverty (SCAA, 2013). Local institutions and producers' cooperatives can create programs to help small-scale coffee farmers adapt to the changes in the global marketplace and cope with issues such as adaptation to environmental risks and food insecurity.

PRE-COVID-19 CHALLENGES

Farm-Level Productivity and Sustainability

Coffee production in Central America typically takes place in smaller farms with an area of <5 ha, although this figure can vary, depending on the country. How a smallholder farmer is defined differs from one country to another. According to the International Coffee Organization, in Honduras, 95% of the coffee farmers are smallholders with <7 ha, and they produce over half of the total coffee production. In Nicaragua, over 60% of farmers are small-scale farmers holding <2 ha. By contrast, in El Salvador, small-scale producers are considered to be those farmers that have <35 hectares (ICO, 2020). The variability in yields also varies significantly. In some areas, yields can be as lows as 400 kg/ha and in other areas, they reach 1,200 kg/ha (ICO, 2020). This can be due to different agricultural practices, such as variability in the use of farm inputs, aging coffee plantations, different coffee varieties, damages caused by insect pests and diseases, and financial aspects which may limit the investments made by some farmers more than others. Some small-scale farms in areas where access to extension services is available, might have higher yields than those farmers in the periphery of these services. In addition, some cooperatives may have better support for the farmers, such as extension services, loans to farmers in the form of agricultural inputs or information services which can help farmers cope with impediments such as disease management.

Climate Change Risks

Empirical evidence suggests that coffee production in Central America will become more difficult due to higher temperature, increasing extreme weather events, and other climate change effects (Baca et al., 2014; Rossing et al., 2014; Reyes et al., 2016; Läderach et al., 2017; Pham et al., 2019). In the dry corridor of Central America, most of the coffee is grown under rainfed conditions. Floods and landslides in these mountainous regions will likely increase, as the drastic variation in temperature,

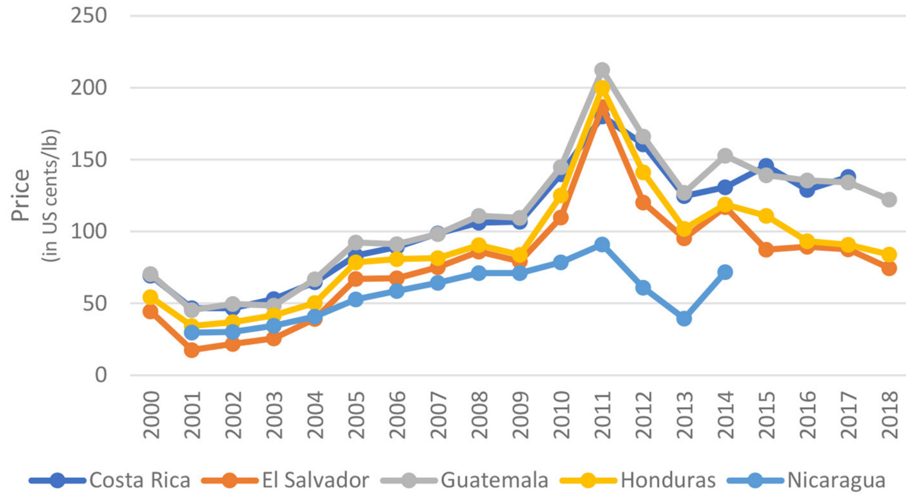

FIGURE 2 | Coffee prices in Central America 2000–2018. Source: ICO (2020).

amount of precipitation, and extreme climatic events. Because of the economic dependence of farmers on coffee exports, they increasingly face food insecurity (World Bank and CIAT, 2015; Martínez-Valle et al., 2017). These changing climate patterns in Central America are posing an additional challenge in the control of diseases like coffee rust and an increase in pests such as the coffee berry borer (*Hypothenemus hamperi*) and coffee leaf miner (*Leucoptera coffeella*) (Reyes et al., 2016). Coffee rust did not affect coffee production in higher altitudes, but with the increase in temperature in areas over 1,000 m above sea level, integrated pest management has become more challenging.

One of the main challenges for coffee production worldwide is the rising global temperature (ICO, 2020). In Central America, more specifically, elevated temperature is a serious challenge for Arabica coffee production. These coffee production systems require relatively specific ecological and meteorological conditions to produce high quality beans. Within a temperature range between 15 and 23°C, Arabica bean quality is optimal. IHCAFE (2020) reported that in 2019, hydric stress reported from May until August severely affected fruit formation in coffee farms in Honduras, thus lowering yields. Because of elevated temperatures reported in the last decades, a lot of high-altitude coffee in the region will no longer find the ecological conditions needed to maintain that quality, thus pushing the agricultural frontier to higher-altitude regions, which are already scarce and in countries like Costa Rica, these are protected areas. In Honduras and Nicaragua, coffee production has expanded in higher altitude areas and in 20 years, the coffee production has doubled in Honduras. Coffee production has increased significantly in recent years. This increase in production and productivity may be a direct effect of an improved supply chain, where significant improvements in infrastructure were made. On the other hand, agricultural practices have been a focus of many research and extension programs, which have resulted in better control of phythopathogenic outbreaks (Herrell et al., 2017). However, recent outbreaks of coffee rust (*Hemileia vastatrix*), a fungal disease, has negatively impacted coffee production in the region.

The El Niño weather phenomenon, where a variation of weather patterns is observed, represents another challenge to coffee production in the dry corridor of Central America. This phenomenon is especially harsh in this region because productivity is severely affected by rain patterns, which can also be a main factor in the incidence of pests and diseases (ICO, 2020). Severe weather patterns also affect the farm-level productivity and is a factor that combined with poor infrastructure and limited good agricultural practices, can reduce farmers' income. According to ICAFE (2020), severe climatic events forecasted for the 2020 rainy season in Costa Rica will have an impact on the dissemination of fungal rust in coffee. By far, the 2020 hurricane season has been one of the most active in recent history (WMO, 2020). Although the harvest season is not yet over and estimates of the total loss are not yet reported, the effects of hurricanes Eta and Iota will be negative.

To understand the impact of the COVID-19 pandemic on the small-scale coffee farmers in Central America, various sources were consulted. Data on coffee exports and prices published by the International Coffee Organization (ICO) were the main source of information. Two time periods were reviewed. Data on the first 3 months after sanitary and confinement measures were implemented (April, May, and June 2020) by the governments of Honduras, Guatemala, Nicaragua, Costa Rica, and El Salvador was reviewed. The second time period consulted was early 2021, after the harvest ended in the region. Secondary, qualitative data was used to analyze resilience. Official reports, briefing papers and bulletins from the main coffee associations in each of the countries were studied. To understand resilience, the framework proposed by Béné et al. (2014) was used, where "*resilience is defined by three factors—the capacity to absorb, adapt and/or transform to shocks or events, which are unexpected and have short* *or longer-term repercussions on the system.*" In this framework Béné et al. (2014) understands absorptive capacity as "*the ability of a system to prepare for, mitigate or prevent the impacts of negative events using predetermined coping responses in order to preserve and restore essential basic structures and functions.*" Finally, Béné et al. (2014) defines adaptive capacity as "*the ability of a system to adjust, modify or change its characteristics and actions to moderate potential, future damage and to take advantage of opportunities, to continue functioning without major qualitative changes in function or structural identity.*" Finally, transformative capacity is explained as the ability to create a fundamentally new social-ecological system when ecological, political, social, or economic conditions make the existing system untenable (Béné et al., 2014).

COVID-19 DISRUPTIONS

Immediate Effects

Analyzing the ICO price composite price indicator for the first half of 2020, some impacts of the COVID-19 pandemic begin to emerge. From January to March 2020, exports decreased by 5.8% to 29.01 million bags compared to 30.78 million bags in 2018/19 season. Arabica coffee exports fell by 10.1%. On this same time frame, global production fell by 0.9% to 168.71 million bags of coffee. Total consumption was projected at 169.34 million bags, but this level was not reached by 0.63 million bags for 2019/20. In the first seven months of coffee year 2019/20, exports from Central America declined by 4.9%. From October 2019 to April 2020, shipments from Honduras fell by 6.7%. Guatemala also experienced a decrease in exports, reporting a decline of 3.1%, while Nicaragua's exports during this period rose by 16.7% (ICO, 2020).

Because of the lockdown measures implemented throughout the main coffee consuming countries (i.e., Europe, North America) out-of-home sales drop, as most cafés and restaurants closed. In the first weeks of the COVID-19 lockdown, sales surged as a result of stockpiling to replace the out-of-home consumption. However, in a joint ICO and IFPRI report (ICO and IFPRI, 2020), a looming global recession was forecasted, which could impact overall coffee consumption. The report pointed out that lower household incomes due to increased unemployment would make consumers more price sensitive, resulting in reduced sales in the high-end market segment (including specialty coffee and some certified sustainable coffees) as consumer demand shifted to adapt to external shocks.

Laborde et al. (2020) suggest the global economy faced a deep recession in 2020—at least as severe as the one following the global financial crisis of 2008–2009. A downturn in global economic growth of 5% was projected for 2020. This analysis, based on IFPRI modeling scenarios, indicate that developing countries face significantly greater adversity, negatively affecting their economies, not only because of the economic slowdown caused by lockdown measures, but also because of the restrictions in labor supply for farming and other business activity. Many developing countries cannot rely on social and economic mitigation measures such as fiscal stimulus and expansion of social safety nets used by EU countries, for example.

Post-harvest Effects

Coffee exports from Central America have decreased in the first part of the 2020/2021 season, which starts in October and ends in September each year. The 2019/20 coffee season began with a decline in exports of 17.5% in comparison to the previous year, which meant that 2.62 million less bags were exported. This is a direct effect of hurricanes Iota and Eta. When observing the export numbers from the most affected countries, they all experienced declines in exports. Exports from Honduras, the region's largest producer, decreased by 40%, while those from Nicaragua fell by 20.2% and Guatemala by 15.7% (ICO, 2021). In El Salvador, exports also declined in the first 2 months of 2021. In comparison to the previous season, only a fifth of the export volume was reached (CVS, 2021). Coffee exports from Costa Rica also fell by 22% in the first months of the year (ICAFE, 2020).

The evidence collected so far indicates that although the COVID-19 pandemic has posed challenges to the coffee sector in Central America, the losses due to Hurricanes Eta and Iota have been much more severe. In fact, if the hurricanes had not struck the Central American regions, all countries would have had a favorable harvest in the 2020/2021 season and could have benefited from the recent increases in the coffee prices. Lockdown measures implemented at the onset of the pandemic in Europe and North America caused a drop in demand as coffee shops and restaurants closed, but this effect was rather short and as home consumption of coffee increased, so did the demand.

The 2020 Atlantic hurricane season has been unprecedented. Within a period of two weeks, two hurricanes, categories 4 and 5 hit Central America, causing massive devastation in agriculture and infrastructure. Honduras, Guatemala, and Nicaragua have been particularly affected by floods and landslides. Both hurricanes hit Central America in November, which is a month short of the start of the picking season. Severe loss of coffee cherries was reported (Anacafé, 2020; CLAC, 2020; IHCAFE, 2020), decimating the harvest. Climate-related impacts are likely to significantly affect the region in the long-term. The most recent Coffee Development Report (ICO, 2020) highlights how the coffee sector is highly sensitive to climate variations. Alternatives such as shifting production are limited for smallholder farmers who do not have the resources, ability, and flexibility to relocate and may be forced to abandon coffee production. Such is the case of thousands of coffee farmers in the northern triangle of Central America. Lynch (2019) explored the nexus between climate change impacts and migration and reports that thousands of people who depend on coffee production in Guatemala, Honduras, and El Salvador have been forced to migrate as a result of impacts on their livelihoods. According to the ICO (2020), potential strategies to improve resilience to climate change include access to information, technologies, financial support, and research and development for improved and agricultural practices and climate-resistant varieties.

TABLE 1 | Assessment of resilience by type (source: own findings).

	Small-scale farmers	Local traders	Exporters	Entire sector
Absorb	• Early 2020 change in market prices did not significantly affect farmers as harvest had concluded when COVID-19 pandemic started • Significant loss of crop prior to harvest due to impact of Eta and Iota, especially in Honduras, Guatemala, and Nicaragua	• No major shocks for middlemen and local traders as COVID-19 measures implemented after harvest concluded • Landslides, loss of infrastructure made access to coffee farms difficult in Honduras, Guatemala, and Nicaragua	• Initial uncertainty with regards to drops in market price, but as market price increased, more capacity to absorb shocks • Loss of infrastructure in Honduras, Guatemala, and Nicaragua after hurricanes also impacted cooperatives and exporters	• COVID-19 pandemic created disruptions which sector could absorb, as harvest had concluded when confinement measures were implemented • Hurricane impacts were severe in Honduras, Guatemala, Nicaragua, difficulties absorbing shock
Adapt	• Farmers, cooperatives, NGOs worked together to implement sanitary measures to adapt to new restrictions and protect workers, especially hired labor. In small-scale family farms, this assessment was not possible • Adaptation to cope with climate change effects not evident in all countries and within countries, it is still a challenge for the majority of farmers	• Middlemen and traders face access challenges due to loss of infrastructure caused by hurricanes. Adaptation contingent on governments' ability to quickly restore roads and improve access.	• Exporters and cooperatives supported the implementation of sanitary measures to adapt to new restrictions and protect workers, especially hired labor. In Costa Rica, these measures include the protection of migrant hired workers from Nicaragua and Panama • Online coffee auctions were an adaptation mechanism	• Evidence of institutional coordination to improve agricultural practices, but process will require time before effects are seen
Transform	• Transformation at farm-level is slow. Agricultural practices such as renovating plantations with new varieties or hybrids adapted to pests and drought takes time and resources not available to all. Access to credit still reported as a major hurdle for coffee farmers	• No evidence of longer-term transformation • Access to coffee plantations difficult, especially if infrastructure must be rebuilt in Honduras, Guatemala, and Nicaragua	• Guatemala reports higher sales of roasted coffee at the regional level, opportunity to transform coffee value chain. Costa Rica has similar strategy, also focusing on direct trade • In the future, online auctions likely to remain and exports can benefit	• Slow change in international trade patterns, although direct trade, blockchain technologies offer opportunity to transform • Central America extremely vulnerable to climate change effects • Transformation of sector remains challenging

IS IT POSSIBLE TO BUILD RESILIENCE?

Resilience, understood as the ability to absorb, adapt, and/or transform to shocks or events, which are unexpected, such as climate change impacts and the COVID-19 pandemic was analyzed. As of early 2021, the COVID-19 infection rate in the Central American region is increasing. Quarantine and confinement measures have been taken in all Central American countries. These measures did not have an effect on the 2019–2020 coffee harvest, which was over when the first cases of COVID-19 were reported in the region. Some *ad-hoc* measures were implemented by farmer cooperatives to mitigate the negative effects of price speculation and the lockdown in industrialized countries where most of the Central American coffee is consumed. Some coffee cooperatives kept drying and storing coffee in order to mitigate income loss of their members, but with a high risk of production loss if coffee is not sold and exported (AgriCord, 2020).

Table 1 summarizes the ability to build resilience, from the perspective of small-scale coffee farmers, the middlemen or local traders, the coffee cooperatives/exporters, and the entire sector. The analysis was conducted using secondary, qualitative data sourced from reports, expert panels, interviews, and newsletters published by Instituto Hondureño del Café (IHCAFE), Asociación Nacional del Café de Guatemala (Anacafé), Instituto del Café de Costa Rica (ICAFE), Consejo Salvadoreño del Café (Consejo Salvadoreño del Café, 2021), and for information on Nicaragua, the reports from Latin American and Caribbean Network of Fairtrade Small Producers and Workers (CLAC) were consulted.

For coffee farmers in the Central American region to build resilience and be in a more favorable situation to cope with impacts and externalities, innovation in the field is critical, and it requires a concerted effort at different levels. Coffee is arguably the most important agricultural export in the region and different stakeholders are involved at all levels. Institutional coordination is important to help coffee farmers adapt and cope with the challenges that have been outlined in this paper. Research organizations, local government institutions, producer associations, traders, exporters, buyers, and civil society organizations all have a specific role and sphere of action. Brining about innovation requires the active participation of all stakeholders. For example, one of the best alternatives to mitigate climate change impacts at the farm level is to work with drought tolerant hybrids.

According to IHCAFE (2020), the coffee sector in Central America urgently needs to adopt strategies to help farmers build resilience to cope with climate change effects. Through the coordinated efforts of different stakeholders in the value chain, new technology could be adopted. It's important to keep conducting research at the farm-level, to determine which methods could help farmers innovate and address issues such diminishing water resources, manage pests and diseases, conserve soils, and implement early warning systems to cope with high temperature or water stress. Using hybrids that are better adapted to hydric stress will be part of the solution. Digital technologies such as early warning systems and the adaptation of these technologies to the local context and the needs of coffee farmers will also help build resilience in the sector.

Building resilience to cope with harsh impacts such as the COVID-19 pandemic require more than simply addressing issues around the disruptions caused by lockdown measures around the world. A contingency plan for the coffee sector in Central America should be built around measures and a concerted effort to help farmers cope with the already drastic effects of volatile markets and international price fluctuations, low productivity at the farm level, slow technology adoption by small-scale farmers, and the climate change effects which are already placing coffee farmers in Central America in such a vulnerable position. Investments should be made in innovation, R&D, and technology to help the sector become more resilient. In a World Coffee Research Consultation (WCR, 2020), stakeholders addressed the need for next-generation weather forecasting systems and the dissemination of advice to farmers. Communication platforms, where data and news on production volumes, prices, and environmental events such as frosts would be shared was also highlighted by the local stakeholders as a priority.

At the local level, it is also important to work together with local cooperatives and stakeholder and at the same time with international traders and buyers to strengthen a differentiation strategy for the region, while promoting coffee trade which is transparent and pays a fair price for high quality coffee. Promoting the payment of decent and fair prices to the farmers should be an integral part of such a strategy.

The Central American coffee sector has traditionally been an export sector. Most, if not all, of the highest quality and specialty coffee is exported. Local demand for this type of coffee is still low. There is still much room for growth in consumption. The new trend of barista courses and coffee academies opening in Central America are a clear indication that specialty there is potential growth in the coffee consumption culture, which could translate to higher prices to producers if top-quality coffee is sources for this sector. In urban centers, new coffee shops are opening, offering customers a taste of the local coffee range, also offering traceable coffee where the qualities of a particular region or farm can be tasted.

Finally, it is important to consider local solutions when addressing the question of resilience.

Resilience in agriculture is a topic which merits in-dept analysis. Implementing a framework where resilience is analyzed by type allows for better strategic decisions to be made. Coffee producers in Central America are likely to face more severe climate change impacts in the next years (Furer et al., 2021). More extreme temperatures and more days without rainfall will affect coffee production and e right mitigation strategies must be devised for the coffee sector in Central America to be resilient.

CONCLUSION

At this point in time, it is difficult to have an idea of the long-term impact the COVID-19 crisis will have on the coffee value chain and how Central American coffee farmers will be affected. However, given the vulnerable position they are currently in, it is likely that any additional difficulty will have a negative impact at the farm level. Throughout the entire coffee value chain, it is clear that no business is immune to the impact of the COVID-19 disruptions. Cafés and coffee shops, big or small, located in Europe, Asia, or the Americas, have had to incur in loss due to the lockdown measures. Small businesses face similar uncertainties as the coffee farmers in terms of economic loss.

Building resilience entails a number of strategies and interventions on different points in the coffee value chain. New business and trade models can help build resilience. Direct trade schemes, for instance, could help farmers, especially because this model is built around strong relationships between the farmer and the buyer. Furthermore, coffee farmers selling certified coffee through cooperatives will likely be able to keep receiving a premium price for the sale of their coffee. These initiatives also help farmers in improving their farming practices and promote good agricultural practices. The detrimental effects of unprecedented events such as the devastating hurricanes which struck Central America in November 2020 could also be minimized with better producer prices, in addition to financial schemes (i.e., agricultural insurance, low-interest loans, and recovery subsidies) which could help small-scale farmers recover from these impacts. Finally, it is also important to consider the growth of local consumption, which could widen the market for value-added coffee at the local level, as a strategy to increase resilience in the coffee sector in Central America.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

IF: conception, review of evidence, synthesizing, and writing.

REFERENCES

AgriCord (2020). An Impact Scan Based on Reports by Farmers' Organisations from Latin America. *AgriCord News*. Available online at: https://www.agricord.org/en/impact-scan-based-reports-farmers-organisations-latin-america (accessed February 4, 2021).

Anacafé (2020). *Noticias, Asociacion Nacional del Café Guatemala*. Available online at: https://www.anacafe.org/covid19/

Avelino, J., Cristancho, M., Georgiou, S., Imbach, P., Aguilar, L., Bornemann, G., et al. (2015). The coffee rust crises in Colombia and Central America (2008-2013): impacts, plausible causes and proposed solutions. *Food Secur.* 7, 303–321. doi: 10.1007/s12571-015-0446-9

Baca, M., Läderach, P., Haggar, J., Schroth, G., and Ovalle, O. (2014). An integrated framework for assessing vulnerability to climate change and developing adaptation strategies for coffee growing families in Mesoamerica. *PLoS ONE* 9, e88463. doi: 10.1371/journal.pone.0088463

Bacon, C. M., Méndez, V. E., Gliessman, S. R., Goodman, D., and Fox, J. A. (eds). (2008). *Confronting the Coffee Crisis: Fair Trade, Sustainable Livelihoods and Ecosystems in Mexico and Central America*. Cambridge, MA: MIT Press. doi: 10.7551/mitpress/9780262026338.001.0001

Bathrick, R. (2017). Key Insights to Create Change in Central America's Coffee Sector. *Technoserve Blog Post*. Available online at: https://www.technoserve.org/blog/key-insights-to-create-change-in-central-americas-coffee-sector/ (accessed February 8, 2021).

Béné, C., Newsham, A., Davies, M., Ulrichs, M., and Godfrey-Wood, R. (2014). Review article: resilience, poverty and development. *J. Int. Dev.* 26, 598–623. doi: 10.1002/jid.2992

Caswell, M., Méndez, V. E., and Bacon, C.M. (2012). *Food Security and Smallholder Coffee Production: Current Issues and Future Directions*. ARLG Policy Brief # 1. Agroecology and Rural Livelihoods Group, University of Vermont: Burlington, VT.

CLAC (2020). *Coordinadora Latinoamericana y del Caribe de Pequeños Productores y Trabajadores de Comercio Justo. Report on the Impact of Hurricane ETA in Central America*. Available online at: http://clac-comerciojusto.org/en/2020/11/report-on-the-impact-of-hurricane-eta-in-central-america/ (accessed February 8, 2021).

Consejo Salvadoreño del Café (2021). *Estadísticas Anuales de Exportación*. Consejo Salvadoreño del Café – CSC. Feb. 28, 2021. Available online at: http://www.csc.gob.sv/estadisticas/ (accessed September 8, 2021).

Donatti, C., Harvey, C. A., Martinez-Rodriguez, R. M., Vignola, R., and Carlos Manuel Rodriguez, C. M. (2019). Vulnerability of smallholder farmers to climate change in Central America and Mexico: current knowledge and research gaps. *Clim. Dev.* 11, 264–286 doi: 10.1080/17565529.2018.1442796

FAO (2001). *Análisis de las Consecuencias a Media Plazo del Huracán Mitch Sobre la Seguridad Alimentaria en Centro América*. Estudio FAO Desarrollo Económico y Social. p. 101.

Furer, M., Jurt, C., Fromm, I., Malek, Z., Kuonen, L., Marchesi, S., et al. (2021). Fairtrade and Climate Change: Systematic Review, Hotspot Analysis and Survey. *Fairtrade International Report*. Available online at: https://files.fairtrade.net/publications/Fairtrade-and-climate-change_October2021_compressed.pdf (accessed November 19, 2021).

Herrell, K., Tewari, R., and Mehlhorn, J. (2017). "Honduran coffee trade: economic effects of fair trade certification on individual producers," *Paper presented at the 2017 Southern Agricultural Economics Association Annual Meeting* (Mobile) p. 21.

ICAFE. (2020). Condiciones climáticas actuales propician el aumento de la Roya en Costa Rica. *ICAFE Noticias*. Available online at: http://www.icafe.cr/condiciones-climaticas-actuales-propician-el-aumento-de-la-roya-en-costa-rica/ (accessed September 10, 2021).

ICO and IFPRI (2020). *Volatile Coffee Prices: COVID-19 and Market Fundamentals.* International Coffee Organization Coffee Break Series Nr. 2, May 2020. Available online at: http://www.ico.org/news/coffee-break-series-2e.pdf (accessed October 23, 2020).

ICO (2018). *Identifying Coffee Sector Challenges in Selected Central American Countries and Mexico*. Projects Committee Brief. Available online at: http://www.ico.org/documents/cy2017-18/pj-120e-challenges-central-america-mexico.pdf (accessed September 8, 2021).

ICO (2020). *Daily Coffee prices*. ICO Statistics. Available online at: http://www.ico.org/coffee_prices.asp

ICO (2021). *Coffee Market Report February 2021.* ICO Statistics. Available online at: https://www.ico.org/documents/cy2020-21/cmr-0221-e.pdf

IHCAFE (2020). *Los Retos de la Caficultura Hondureña ante el COVID-19*. IHCAFE Webinar. Available online at: https://promecafe.net/wp-content/uploads/2020/05/Analisis-de-la-caficultura-honduren%CC%83a-ante-el-COVID-19-01052020.pdf (accessed May 29, 2021).

Laborde, D., Martin, W., and Vos, R. (2020). *Poverty and Food Insecurity Could Grow Dramatically as COVID-19 Spreads, IFPRI Research Post*. Available online at: https://www.ifpri.org/blog/poverty-and-food-insecurity-could-grow-dramatically-covid-19-spreads

Läderach, P., Ramirez–Villegas, J., Navarro-Racines, C., Zelaya, C., Martínez-Valle, C., and Jarvis, A. (2017). Climate change adaptation of coffee production in space and time. *Clim. Change* 141, p. 47–62. doi: 10.1007/s10584-016-1788-9

Lewin, B., Giovannucci, D., and Varangis, P. (2004). *Coffee Markets: New Paradigms in Global Supply and Demand*. World Bank Agriculture and Rural Development Discussion Paper No. 3, p. 150. doi: 10.2139/ssrn.996111

Lynch, C. (2019). *The Impacts of Warming Coffee: The Climate Change-Coffee-Migration Nexus in the Northern Triangle of Central America*. Independent Study Project (ISP) Collection: 3008. SIT Graduate Institute, Vermont. Available online at: https://digitalcollections.sit.edu/isp_collection/3008

Martínez-Valle, A., Czaplicki, S., Collado, C., Parker, L., Bourgoin, C., Guerten, N., et al. (2017). *Pragmatic Economic Valuation of Adaptation Risk and Responses Across Scales in Nicaragua*. Working Paper No. 210. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Wageningen, The Netherlands.

Meister, E. (2017). *New York City Coffee: A Caffeinated History. American Palate Series*. Stroud: The History Press. p. 144.

Morris, K. S., Mendez, V. E., and Olson, M. B. (2013). 'Los meses flacos': seasonal food insecurity in a Salvadoran organic coffee cooperative. *J. Peas. Stud.* 40, 423–446. doi: 10.1080/03066150.2013.777708

Paige, J. (1985). "Coffee and politics in Central America," *Paper presented at the 9th Annual Conference on the Political Economy of the World System, Tulane University* (New Orleans).

Pham, Y., Reardon-Smith, K., Mushtaq, S., and Cockfield, G. (2019). The impact of climate change and variability on coffee production: a systematic review. *Clim. Change* 156: 609–630. doi: 10.1007/s10584-019-02538-y

ReliefWeb (2020a). *Centro América: Tormeta Tropical Eta y Huracán Iota: Seis Semanas Despues (as of 22 December 2020). Situation Report*. Available online at: https://reliefweb.int/report/honduras/central-america-tropical-storm-eta-hurricane-iota-six-weeks-later-22-december-2020 (accessed December 29, 2020).

ReliefWeb (2020b). *Small-Scale Farmers and Families Struggle with Economic Ruin as up to 70% of Honduras' Crops and Grains are Affected by Storms Eta and Iota*. News and Press Release, Nov. 21, 2020. Available online at: https://reliefweb.int/report/honduras/small-scale-farmers-and-families-struggle-economic-ruin-70-honduras-crops-and-grains

Reyes, B., Vasquez, M., Larosa, F., Gomez, L., Espinal, M., Wiegel, J., et al. (2016). *Traditional Markets for Poverty Reduction and Food Security: Eploring Policy Options in Honduras and Nicaragua*. CIAT Policy Brief No. 29.

Rossing, W. A. H., Modernel,. P., and Tittonell, P. (2014). "Diversity in organic and agro-ecological farming systems for mitigation of climate change impact, with examples from Latin America," in *Climate Change Impact and Adaptation in Agricultural Systems*, eds J. Fuhrer, and P. J. Gregory (Wallingford: CAB International), 69–87. doi: 10.1079/9781780642895.0069

SCAA (2013). *A Blueprint to End Hunger in the Coffeelands*. Specialty Coffee Association of America, Sustainability White Paper. p. 21.

Sedgewick, A. (2020). *Coffeeland: One Man's Dark Empire and the Making of Our Favorite Drug*. London: Penguin Press. p. 448.

Stratton, A. E., Kuhl, L., and Blesh, J. (2020). Ecological and nutritional functions of agroecosystems as indicators of smallholder resilience. *Front Sustain. Food Syst.* 4, 543914. doi: 10.3389/fsufs.2020.543914

Watts, C. (2016). *A Brewing Storm: The Climate Change Risks to Coffee*. The Climate Institute. p. 16.

WCR (2020). *Global Coffee R&D Awareness and Global Priorities Consultation 2020*. World Coffee Research.

WMO (2020). *Record-Breaking Atlantic Hurricane Season Ends*. Media Release 1 December 2020. Available online at: https://public.wmo.int/en/media/news/record-breaking-atlantic-hurricane-season-ends (accessed December 29, 2020).

World Bank and CIAT (2015). *Climate-Smart Agriculture in Nicaragua. CSA Country Profiles for Africa, Asia, and Latin America and the Caribbean Series*. Washington, DC: The World Bank Group.

Wyss, R., Fromm, I., and Garcia, M. (2012). Socio-environmental certifications: risks and opportunities for small-scale coffee farmers in Central America. *Int. J. Dev. Soc.* 1: 133–140. doi: 10.11634/216817831201162

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Perceptions and Responses of Diversified Farm Producers in the Northern Great Plains to the Early Stage of the COVID-19 Pandemic

Roland Ebel[1], Selena Ahmed[1], Teresa Warne[1], Alexandria Moxley[1], Irene Grimberg[2], Meghann Jarchow[3] and Fabian D. Menalled[4]*

[1] Food and Health Lab, Department of Health and Human Development, Montana State University, Bozeman, MT, United States, [2] Western SARE, Montana State University, Bozeman, MT, United States, [3] Department of Sustainability and Environment, University of South Dakota, Vermillion, SD, United States, [4] Department of Land Resources and Environmental Sciences, Montana State University, Bozeman, MT, United States

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***Correspondence:**
*Selena Ahmed
selena.ahmed@montana.edu*

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The initial months of the COVID-19 pandemic revealed unique vulnerabilities of the global food system with notable societal consequences, calling for the need to implement resilience strategies to support food security for all. The objective of this study was to elicit perceptions, experiences, and responses of producers of diversified farms in the Northern Great Plains of the United States to the early stage of the COVID-19 pandemic toward identifying factors for strengthening the resilience of agricultural production for supporting livelihoods and food security. Between May and August 2020, a cross-sectional online survey was administered to the emerging community of diversified farm managers in two rural U.S. states, Montana and South Dakota ($n = 53$), where monocropping and extensive livestock production are prevalent. About two-thirds of surveyed producers (68%) reported that they did not change their farming practices in response to the pandemic up until the survey period in Summer 2020. Almost three-quarters of producers (73%) indicated that access to commodities, farm inputs, and farm labor was not a concern for them during the early stage of the pandemic. Most surveyed producers (88%) were not concerned about their household food security and expressed confidence regarding a long-term increase in the demand for local food. However, almost half of surveyed producers (47%) reported that their anxiety increased because of the pandemic. Findings further highlight that small farms implemented a greater number of practices for enhancing ecological self-regulation while depending strongly on off-farm income compared to larger farms that were economically more autonomous. This study points to the promise of farm system diversification in strengthening the resilience of agricultural systems. We conclude by outlining pathways for increasing diversity on farms toward supporting food security during extreme food system shocks.

Keywords: food system shock, agrobiodiversity, food security, organic farming, rural livelihood, resilience assessment

INTRODUCTION

The COVID-19 pandemic unprecedentedly impacted food systems around the world (Afshin et al., 2019) in terms of scope and immediateness (Baldwin and Tomiura, 2020), revealing unique vulnerabilities (Altieri and Nicholls, 2020a) as well as resilience (Orden, 2020) across supply chains. On the production side of food systems, lockdown and "stay at home" measures during the initial phase of the COVID-19 pandemic had severe impacts on agricultural production and food commodity prices (Elleby et al., 2020), with repercussions for producers and consumers worldwide. Producer income, purchasing power, planning, access to markets, and emotional wellbeing were impacted (Reissman et al., 2006; Laborde et al., 2020). Recent data shows that the pandemic has been a rare case of a global supply chain disruption due to restricted transportation, unavailability of raw material supply, and shutdowns of food processing, distribution, and sale (Taqi et al., 2020; Shahed et al., 2021). While evidence demonstrates how unprepared food systems were to respond appropriately to the COVID-19 pandemic, emerging research is showing how some communities and sectors of the food system were more resilient than others in their responses (Ahmed et al., 2020).

Failure to learn from previous disasters, laxity to adopt early preparedness strategies from warnings by health organizations and scientists, market globalization, as well as highly interconnected living systems contributed to spreading the pandemic with significant impacts on agriculture (Saqr and Wasson, 2020). COVID-19 affected agriculture in both supply and demand (Siche, 2020). On the supply side, there have been restrictions on travel, transportation, and trade, reinforced sanitary controls, and labor shortages with many food system workers becoming sick or not able to travel to their workplaces (Elleby et al., 2020). During the first few months of the pandemic when this study was conducted, these limitations constrained the distribution and processing of foods, the circulation of farm inputs, and resulted in a vast decay of perishable products; a further enduring effect of COVID-19 on the food system has been the uncertainty farmers confront regarding their production management decisions and consumer demand (Benton, 2020). On the demand side, mobility restrictions and reduced purchasing power due to the related economic slowdown have been impacting consumers worldwide, especially the most vulnerable population groups (Siche, 2020).

An increasing body of evidence demonstrates that elevated levels of agrobiodiversity allow for quicker recovery after environmental disturbances such as hurricanes (Philpott et al., 2008; Rosset et al., 2011) or drought (Murgueitio et al., 2011). Agrobiodiversity is also associated with greater success in achieving food security (Thornton et al., 2019). Given the role of agrobiodiversity for resilience, the study presented here focused on surveying farms with an elevated level of diversification in their farm management. The overall goals of this study were to: (1) identify the challenges and opportunities faced by diversified farms during the initial months of the COVID-19 pandemic; (2) evaluate the resilience and vulnerabilities of diversified farms to the early stages of the COVID-19 pandemic; and (3) characterize responses to the COVID-19 pandemic to identify factors contributing to resilience to inform future preparedness efforts.

To address our study goals, we deployed an online cross-sectional survey to managers of diversified farms in two states of the Northern Great Plains (NGP) in the U.S., Montana (MT) and South Dakota (SD). Survey questions assessed producer perceptions in response to COVID-19 (including impacts on the farms' economy and producers' emotional wellbeing), farm management and crop diversity, and food security concerns of farms and farming communities based on the perceptions of 53 farm managers of diversified farms in MT and SD. We used the agroecosystem resilience assessment framework by Cabell and Oelofse (2012) as well as the rapid C-SCAN (COVID-19 Surveillance Community Action Network for Food Systems) survey (Ahmed et al., 2020) as baselines for developing our survey instrument. We acknowledge that the sample size of this study is relatively small due to: (1) the circumstance that the diversified farming community in MT and SD is small; (2) the travel constraints imposed by the COVID-19 pandemic that did not enable us to travel to administer the surveys and rather relied on a purely online format; (3) the short time window due to the aim of capturing producers' perceptions during the early stages of the COVID-19 pandemic. Despite the relatively small sample size, the survey findings presented here cover a unique time, the first growing season since the start of the pandemic characterized by extreme uncertainty.

BACKGROUND

To situate the context of this study, the following section provides background on the theoretical foundations of this study regarding the concepts of resilience and agrobiodiversity, as well as a comprehensive review on the impact of the COVID-19 pandemic on agricultural and food systems.

Agroecosystem Resilience and Agrobiodiversity

Food system resilience is the capacity of a food system and its units at multiple levels to constantly provide food security, even while facing unforeseen (internal or external) disturbances such as natural, political, social, or economic shocks (Tendall et al., 2015). Food system resilience is characterized by five capacities: (1) capacity to withstand disturbances (robustness); (2) disturbance absorption capacity; (3) capacity to react (rapidity and flexibility); (4) capacity to restore (resourcefulness); and (5) capacity to learn or adaptability (Carpenter et al., 2001; Tendall et al., 2015). In contrast, the vulnerability of a food system is dependent on its propensity or predisposition to external shocks or disturbances. Accordingly, a vulnerable food system is characterized by low decision-making autonomy, connectivity, and diversity (Ericksen et al., 2012; Intergovernmental Panel on Climate Change, 2014).

Agroecosystems are managed to produce, distribute, and consume food, biofuel, and fiber. Boundaries of agroecosystems encompass the physical space dedicated to the production, as well as the resources, infrastructure, markets, institutions, and people operating within these boundaries (Cabell and Oelofse, 2012). This definition characterizes agroecosystems as socio-environmental systems which are part of the production subsystem of food systems (Ericksen, 2008). Agroecosystem resilience is a fundamental component of overall food system resilience. Specifically, it describes the capacity of an agroecosystem to maintain the ability to feed, clothe, and provide energy to people in the face of shocks while building the natural capital base upon which they depend and providing a livelihood for the people who make it function (Cabell and Oelofse, 2012).

Apart from redundancy, diversity is the key attribute for any system's capacity to cope with change, as a greater range of options reduces its vulnerability after the loss of specific elements (Folke et al., 2004; Hodbod and Eakin, 2015). Previous studies have promoted diversification as the core strategy to increase the robustness, absorption capacity, flexibility, resourcefulness, and adaptability of agricultural systems to external shocks (Zimmerer et al., 2019). Two types of diversity enhance resilience: functional diversity, i.e., the number of functionally different groups in a system, and response diversity, i.e., the number of different groups providing the same function (Walker and Salt, 2012). While functional diversity enhances a system's learning and adaptation capacity, response diversity increases its absorption capacity (Elmqvist et al., 2003; Hodbod and Eakin, 2015).

Agrobiodiversity is defined as the diversity of wild and domesticated genetic resources involved in obtaining agricultural products as well as non-harvested species that contribute to the functioning of an agroecosystem (Howard, 2010; Herforth et al., 2019). In general, diversified and sustainable farming systems mimic the biodiversity levels and functioning of local ecosystems (Altieri and Nicholls, 2020b) to generate multiple ecosystem services including increased nutrient and water efficiency; stimulation of the soil microflora and organic matter content; improved resilience to pests and meteorological perturbations; increased per-plant yield; and the sequestration of atmospheric carbon (Gliessman, 1985; Altieri, 1994; Letourneau et al., 2011; Altieri and Nicholls, 2020b). Agrobiodiversity also creates health and nutrition benefits. For example, a variety of crops offers farmers diverse diets comprised of vitamins, minerals, and phytochemicals that support the immune system (Yousafzai et al., 2013). Until the second half of the twentieth century, agricultural systems have been widely characterized by diversified farming (Rosset et al., 2011; Béné et al., 2015).

Despite the advantages of agrobiodiversity, the globalization and industrialization of food systems during the past decades have resulted in the simplification of farming systems and dominance of mechanized, high-input monocropping (Jäger et al., 2019; Hobbs, 2020). Consequently, diversified agriculture at present is widely limited to subsistent farms in low- and middle-income countries (Howard, 2010) and only 15 crops provide over 80% of the world's food calorie intake (Motley et al., 2006). This homogenization of farming systems has negatively impacted the functionality of ecosystem services and weakened their ability to prevent the development and spread of communicable diseases (Altieri and Nicholls, 2020b). For example, habitat simplification due to monocropping has increased human contact rates with disease vectors such as Lyme disease (Pongsiri et al., 2009; Rohr et al., 2019). Large-scale animal production has created opportunities for many viruses to mutate and spread directly to humans (Altieri and Nicholls, 2020b), including the H1N1 virus (causing "swine flu"), the H5N1 virus (cause of "bird flu"), and potentially SARS-CoV-2, the virus that causes COVID-19 (Jackson et al., 2007). The homogenization of farming systems also affects the socio-cultural resilience of farming communities by impacting social organizations, local culture, language, and cuisine (Ebel et al., 2021).

After an increased worldwide focus on restoring agrobiodiversity in the 1990s and early 2000s, the 2008 food crisis resulted in a global call for monocropping of staple crops (Renkow and Byerlee, 2010; Kahane et al., 2013). Nevertheless, a countermovement has continued to demand more local, diversified, and sustainable farming methods that are expanding worldwide, including in high-income countries such as the U.S. (Kolodinsky et al., 2020). However, diversified farms in the U.S. are still limited to niche sectors including certified organic farming and other sustainably managed, often horticultural, systems (Youngberg and DeMuth, 2013; Rosa-Schleich et al., 2019).

Farming Systems in the Northern Great Plains

The states where this study was carried out, MT and SD, are part of the NGP ecoregion, which includes smaller parts of North Dakota, Wyoming, Nebraska, and southwestern Canada (Padbury et al., 2002). Agriculture is an integral component of the economy, history, and culture of the region (Conant et al., 2018). While only 1.6% of the U.S. population live in the NGP, the region contributes notably to the U.S. food supply, especially to the production of spring and durum wheat, sunflower seed (>70% of U.S. production), barley, lentils, and dry beans (>40% of U.S. production), winter wheat, oats, corn, sugar beets, and cattle, where the region generates over 20% of U.S. production (Ebel and Thornton, under review)[1]. The NGP are currently experiencing a transition in agricultural land use, mainly the conversion of grass and rangeland to the monocropping of annual crops (Sayre et al., 2012). Historically, wheat has been the dominant crop in the NGP; more recently, monocropping of barley, corn, soybeans, and pulses is gaining prominence (Heinemann et al., 2014; Conant et al., 2018; Herforth et al., 2019; Jäger et al., 2019).

Diversified cropping systems have not played an important role in the NGP during the past 100 years (Padbury et al., 2002; Conant et al., 2018). However, numerous NGP dryland farmers have recently begun to diversify their agricultural portfolio, especially by including pulses into their crop rotations. Also, small-scale diversified horticultural production is emerging in urban areas and fruit-producing regions, particularly in the

[1]Ebel, R., and Thornton, A. (under review). *The Importance of the Food System for Maintaining Rural Population Densities in the Northern Great Plains.* Unpublished manuscript.

western NGP (Gough, 1997; Long et al., 2014; Miller et al., 2015; Carlisle, 2016; Stoy et al., 2018; Warne et al., 2019).

Effects of the COVID-19 Pandemic on U.S. Agriculture

The COVID-19 pandemic affected food, fiber, and bioenergy production and the associated industry of most commodities and scales of production (Naja and Hamadeh, 2020; Zurayk, 2020). One of the most immediate consequences of the pandemic was a series of bankruptcies of farms, particularly in the fresh-market horticultural sector (Richards and Rickard, 2020), which was triggered by three core factors: (1) shift toward the consumption of processed items (Altieri and Nicholls, 2020b; Béné, 2020); (2) decreased demand from hotels and restaurants because of health regulations and changes in consumer habits (Nicola et al., 2020); and (3) limited service or closure by food banks and other institutions that provide nutrition assistance and support the food security (Stephens et al., 2020).

In addition to decreasing consumer demand for many foods, farms in the U.S. faced disruptions and price increases in the supply chain for agricultural inputs including seeds and fertilizers (Altieri and Nicholls, 2020b; Béné, 2020). Although farmworkers were classified as essential workers and widely exempt from working and mobility restrictions (Béné, 2020; Benton, 2020), many seasonal foreign farm workers were unable to travel to their workplaces because of virus-related regulation measures as well as visa restrictions and delays (Torero, 2020). Livestock production systems, meat processors and packers, and horticultural producers were most affected by labor shortages (Stephens et al., 2020).

Before the pandemic, small-scale producers of locally marketed foods saw constant growth despite accounting for only 1.5% of the U.S. agricultural production (Low et al., 2015). During the pandemic, small producers, especially in the vegetable and fruit sector, were challenged by social-distancing regulations and decreased availability of farmworkers while production costs increased (Laborde et al., 2020; Orden, 2020). Whereas small-scale horticultural producers who sell their produce close to urban centers benefited from the lockdown measures (as many consumers opted for local food purchases and avoided large food retailers), small producers in rural settings faced economic challenges (Kolodinsky et al., 2020; Westervelt, 2020).

The pandemic created uncertainty among U.S. farmers (Reissman et al., 2006; Laborde et al., 2020), including about how to adapt their operations (farm management, crop choices) and impacts on their sales (Benton, 2020). Producer stress caused by uncertainty can result in unhealthy lifestyle patterns such as dietary choices with long-lasting effects on nutrition and health (Yousafzai et al., 2013). Globally, several studies indicate that the uncertainty related to the COVID-19 pandemic impacted a range of mental health conditions including loneliness, anxiety, stress, insomnia, denial, anger, post-traumatic stress disorder, psychological distress, and depression (Galea et al., 2020; Torales et al., 2020; Xiong et al., 2020) that have instigated an overall increase in substance abuse and domestic violence (Galea et al., 2020; Kalil, 2020).

Effects of the COVID-19 Pandemic on Farming Systems in the Northern Great Plains

Farming systems in the NGP were impacted by pandemic mitigation measures carried out during the initial phase of COVID-19. In MT, a stay-at-home order was implemented in April 2020 based on state and federal State of Emergency regulations (State of Montana, 2020a,b,c). In SD, despite the declaration of a state of emergency in March 2020, COVID-19 control measures did not include a stay-at-home order (South Dakota Department of Health, 2020).

Consequences of the lockdown and "stay at home" measures for farmers in the NGP included interrupted supply chains caused by bankruptcies of food distributors and processors, transport limitations (US Department of Agriculture, 2018; Afshin et al., 2019; Pyatt, 2020; Sy, 2020; Taylor, 2020), reduced commodity prices (DeLeon, 2020; Lynch et al., 2020), uncertain export markets (Kerr, 2020), and unpredictable demand due to changes in consumer behavior and spending (Nicosia, 2005; Bhattacharya, 2012). By April 2020, the economy of more than 85% of NGP farm operations was negatively affected by COVID-19 (Grimberg, 2020). While grain and oilseed producers were confronted with minor commodity price and supply chain issues (Brewin, 2020), livestock production was severely hit. Numerous dairy farmers in the region had to pour milk away during the first months of the pandemic (Torero, 2020). While direct sales were an area of opportunity for small-scale farms across the U.S., most NGP farms could not benefit from this trend as they serve commodity markets (Grimberg, 2020).

Despite a later normalization in food transportation and retail, the economy of most farms in the NGP started to recover long after the lockdown ended in May 2020 (Cates-Carney, 2020). In MT, many ranchers postponed selling their calves or feeder cattle for the late Fall months (Belasco, 2020). In contrast, grain sales were more stable (Cates-Carney, 2020). The situation in SD was similar, especially in the livestock sector. Ranchers in SD were not only affected by closings of processing facilities but also by limited exportation opportunities (Birkeland, 2020).

METHODS

Study Population

Research was carried out during the first growing season of the COVID-19 pandemic with managers of diversified farms in MT and SD, two states within the Northern Great Plains. Our study focused on producers of diversified farms given that diversification is a core strategy for increasing the resilience of farms facing external shocks (Zimmerer et al., 2019). Specifically, we assessed producer perceptions in response to COVID-19, characterization of farm management practices and crop diversity, and food security of farms and food security concerns of farming communities based on the perceptions of 53 farm managers.

For our study, diversified farms were identified as operations using a whole system approach to agriculture that is based on promoting biodiversity and ecosystem services from field to

TABLE 1 | Food systems resilience and vulnerability parameters.

Parameter	Question topics (examples)	Questionnaire sections	Results section
Agroecosystem resilience			
Ecological self-regulation	Existence of riparian buffers, hedgerows, pollinator strips, and/or trees on farm	Farm background; farm management and crop diversity	Impact of COVID-19 on farm management and crop choices
Connectedness	Use of intercropping, cover cropping, intraspecific diversity		
Spatial and temporal heterogeneity	Diversity of cultivation practices; use of crop rotations		
Integration of local natural capital	Use of compost and manure		
Food system resilience			
Autonomy and local interdependence	Contribution of farming to household income	Farm background; food system resilience and vulnerability; effects of COVID-19 pandemic on farm management, farm economy and food systems	Producer perceptions of the impact of COVID-19 on food security and livelihoods
Food security	Access to food; community food security		
Food system vulnerability			
Shock exposure	Access to commodities and farm inputs; available farm labor	Food system resilience and vulnerability; effects of COVID-19 pandemic on farm management, farm economy and food systems	Impact of COVID-19 on farm economy
Shock sensitivity	Anxiety		Impact of COVID-19 on producers' emotional well-being

Parameters of the adapted agroecosystem assessment framework (Cabell and Oelofse, 2012) enhanced with food system resilience and vulnerability parameters, their relation to the survey questionnaire, and results section where findings are presented.

landscape scales based on one or more of the following types of farm management practices to enhance diversity (UC Berkley, 2020): (1) polycropping (multiple crops and/or varieties); (2) complex crop rotations; (3) holding of different livestock species; (4) integration of fish and/or livestock in plant production; (5) maintenance of hedgerows or live fences around farming areas; and (6) adoption of techniques to increase the biodiversity of a farm's surrounding landscape.

The study inclusion criteria involved: (1) producers (those who own, lease, are hired, or have some other arrangement of working on a farm) working on a farm located in MT or SD; (2) producers who have grown crops or held animals for at least one season; and (3) producers that classify their agricultural systems as diversified farms based on the aforementioned definition.

Development and Distribution of Survey Instrument

The development of the survey was informed by two research questions (1) *What were producer perceptions, experiences, and responses to the COVID-19 pandemic during its initial phase?* and (2) *How did the early phase of the COVID-19 pandemic impact crop diversity, farm management practices, the emotional well-being of surveyed producers, and the economy of farms and farming communities?*

We used the agroecosystem resilience assessment framework developed by Cabell and Oelofse (2012) as a baseline for developing a self-administered online survey, and for interpreting participant responses. The agroecosystem resilience assessment framework consists of 12 resilience indicators, out of which five were considered suitable to address our study questions and applied in the survey section "Farm management and crop diversity" (**Table 1**). To address producer perceptions of the impact of COVID-19 on their agroecosystems more broadly, we drew questions from the rapid C-SCAN (COVID-19 Surveillance Community Action Network for Food Systems) survey tool (Ahmed et al., 2020). Furthermore, the survey included the validated 2-item measure to screen for food insecurity by Gundersen et al. (2017).

The survey instrument was subsequently modified and refined through pilot testing for input from field experts. The final tool included a self-administered survey with a total of 31 questions divided into five sections. In this article, data from a subset of 13 survey questions were used (see **Supplementary Appendix 1** for survey questions). The survey questions addressed in this article comprise of six single-select multiple-choice questions (all framed as binary yes/no questions with the possibility to specify information using text inputs), three multi-select multiple-choice questions, two open-ended questions, and two three-step Likert-Scale questions (Brown, 2011; Gundersen et al., 2017).

Participation in the study was voluntary and anonymous. Prior informed consent was obtained from all participants. The consent form, study introduction, and survey instrument were approved by the Montana State University Institutional Review Board (approval number SA042720-EX) in April 2020. The introduction to the survey presented the aims and procedures of the survey, including the anonymity and confidentiality of responses, inclusion criteria, and contact details of the research team and Institutional Review Board.

The survey was distributed online and included the study introduction and informed consent using the online platform

Qualtrics (SAP, Provo, UT) (Oppenheimer et al., 2011). Data were collected May 1st through August 7th, 2020. The research team distributed the survey using farming listservs in the study area as well as posting a link to the survey and study introduction in various social media venues and newsletters. To encourage responses, a \$15 gift card was provided as an incentive for participants upon completion of the survey. Completed surveys were given identifiers for tracking purposes only. We obtained 120 responses (response rate of a∼20%) of which 53 were validated and included in the study analysis.

Data Validation

We excluded incomplete and inconsistent responses and the remaining survey data was validated using Cronbach's Alpha Test as a measure for data consistency (Ferketich, 1990; Vaske, 2019). We obtained a value of 0.67, which is adequate for scales in human dimension research (Vaske et al., 2017).

Survey Sample Characteristics

Of the 53 validated responses, 31 were from producers with farms in MT and 22 from producers with farms in SD. Surveyed farms in MT were smaller than in SD (**Table 2**, **Supplementary Appendix 2**). In the majority of farms, agriculture generates <75% of the household income and most surveyed producers own their farmland. Surveyed producers with more than 5 years of farming experience tended to work on larger farms (>100 acres), less experienced producers on smaller ones (**Supplementary Appendix 3**). On larger farms, more than 90% of production was designated for sale, while this share was lower for smaller farms (**Supplementary Appendix 3**). Thirty-eight surveyed farms were dedicated to plant production (out of which ten can be classified as strictly horticultural producers), four produced livestock, five have a mixed farm, and six producers did not specify their farm products. Only eight farms produced one single commodity (in addition to non-commercial diversification measures such as pollinator strips). The median number of commodities per farm was four. In 2020, the most common crops on surveyed farms were annual vegetables, followed by corn, wheat, berries, dry legumes, oats, and soybean. The most common livestock was cattle (**Supplementary Appendix 4**).

TABLE 2 | Characteristics of farms managed by surveyed producers: farm size, farm's contribution to household economy, destination of farm outputs, farm ownership, and farming experience of farm manager per state where farm is located.

Indicator	Montana	South Dakota	No response
Farm size			
Farm > 100 acres	12	18	0
Farm < 100 acres	19	4	
Farm's contribution to household economy			
Farming < 75% of income	19	13	1
Farming > 75% of income	12	8	
Destination of farm outputs			
>90% of production for sale	14	12	2
50–90% of production for sale	10	5	
<50% of production for sale	7	3	
Farm ownership			
Own farmland	23	19	0
Lease farmland or employed	8	3	
Farming experience of (surveyed) farm manager			
Farming experience 1 year	6	2	0
Farming experience > 1 < 5 years	9	1	
Farming experience > 5 years	16	19	

Data Analysis

The survey responses generated quantitative data from multiple-choice and Likert-type questions (these data were also used for the overall assessment of agroecosystem resilience), as well as qualitative data from the responses of the open-ended questions, and the explanations elicited from the multiple-choice questions.

Quantitative Data

All analyses were conducted using SPSS for Windows, v 26 (IBM, Armonk, NY) (De Sá, 2007). First, we described the perceived impact of COVID-19 on farms, producers, and their communities from the responses to binary (yes/no) survey questions. Responses were transformed into numeric binary values (Brown, 2011). For all data, we conducted descriptive statistics, which included frequency and percentage response distributions as well as dispersion measures.

For the analysis of the farm management practices, we grouped the practices into three categories: (1) sustainable tillage (including conservation tillage or direct seeding), (2) sustainable fertilization (use of compost, compost tea, charcoal, and/or manure), and (3) cropping system diversification (crop rotations, intercropping, and/or cover cropping). Inter-associations were assessed using the two-sided Fishers Exact Test at $p < 0.05$ (Upton, 1992).

Regarding the impact of COVID-19 on farm management and crop diversity, farm economy, producers' emotional well-being, and producer food insecurity, we used cross-tabulations and chi-square tests to identify significant ($p < 0.05$) di?erences on how the pandemic affected several characteristics of farm management and food security (Chambers and Skinner, 2003).

To identify factors that influence producers' perceptions of COVID-19, we contrasted the responses of the perceived impact of COVID-19, with data about farm management practices, including diversification. This data originated from multi-option questions, which we converted into ordinal integer numbers (Brown, 2011) with 0 as the lowest value (example question on farm size: 0 for < 5 acres; 4 for > 1,000 acres). We conducted univariate association analysis using the Chi-square test for categorical, non-parametric variables. Significance was considered at $p < 0.05$ (Chambers and Skinner, 2003). To quantify relationships, we applied a two-tailed Cramer's V test, where a value <0.2 indicated a weak association, $0.2 \leq 0.3$ a moderate association, and >0.3 strong association (Santos-Díaz et al., 2019).

TABLE 3 | Equations, adapted from Cabell and Oelofse (2012), processed for the overall assessment of the resilience of the participating farms.

Parameter	Processed values	Equation
Ecological self-regulation (ES)	Number of farms using riparian buffers (x_{RB}), hedgerows (x_{HR}), pollinator strips (x_{PS}), and having trees on the farm (x_{TR})	$\bar{x}_{ES} = (\Sigma \frac{100\ x_i}{n})$
Connectedness (CO)	Number of farms using intercropping (x_{IC}), cover cropping (x_{CC}), and cultivating intraspecific diversity (x_{ID}).	$\bar{x}_{CO} = (\Sigma \frac{100\ x_j}{n})$
Spatial and temporal heterogeneity (HE)	Diversity of cultivation practices (DCP); use of crop rotations (x_{ID})	$\tilde{x}_{DCP} = (\frac{\Sigma\ x_{i,j,ID}}{n})$ $HE = \frac{\left(\Sigma \frac{100\ x_{ID}}{n}\right) + \frac{DCP}{8}}{2}$
Integration of local natural capital (IN)	Number of farms using (x_{CO}) and manure (x_{MA})	$\bar{x}_{IN} = (\Sigma \frac{100\ x_k}{n})$
Autonomy and local interdependence (AU)	Percentual contribution of farming to household income (CO)	$\bar{x}_{AU} = (\Sigma \frac{x_{CO}}{n})$
Food security (FS)	Number of farmers who did not perceive an impact of COVID-19 on their diet (x_{DI}) and community food security (x_{CFS})	$\bar{x}_{FS} = (\Sigma \frac{100\ x_l}{n})$
Shock exposure (SE)	Number of farmers who did not perceive an impact of COVID-19 on access to commodities and farm inputs (x_{CF}) and available farm labor (x_{DI})	$\bar{x}_{SE} = (\Sigma \frac{100\ x_m}{n})$
Shock sensitivity (SS)	Number of farmers who did not perceive anxiety due to COVID-19 (x_{AN})	$\bar{x}_{FS} = (\Sigma \frac{100\ x_{AN}}{n})$

Qualitative Data

For the analysis of open-ended questions, we conducted inductive, undirected content analysis to identify common themes in the responses (Kuckartz, 2014; Saldaña, 2015). The coding process was facilitated by the qualitative software NVivo 12 (QSR International, Doncaster, Australia). We applied inductive coding, where we prioritized *in viv*o codes, resumed all condensed meaning units, and calculated the frequency of meaning units per code as a percentage of total meaning units per survey question (Leech and Onwuegbuzie, 2011; Saldaña, 2015).

Assessment of Agroecosystem Resilience

The assessment of agroecosystem resilience (**Table 1**) was adapted from five parameters of the Cabell and Oelofse (2012) resilience framework as well as three additional parameters for food system resilience and vulnerability (Ericksen et al., 2012; Intergovernmental Panel on Climate Change, 2014). For each parameter, we calculated the respective values as a proxy based on response rates to quantitative survey questions. The overall assessment was calculated on a percentual scale, where 100% represents the highest resilience possible to the pandemic (see **Table 3** for equations) and visualized in a radar chart.

Study Limitations

Our study deals with diversified farmers in MT and SD, an emerging community in two states widely characterized by conventional monocropping systems (Sayre et al., 2012; Conant et al., 2018) during the initial stages of the COVID-19 pandemic. To our knowledge, there is no data available on the total number of diversified farms in these states, considering how diversification is defined in our study (UC Berkley, 2020). However, in 2019, there were 171 certified organic farms with annual revenue of <\$500,000 in MT, and 63 in SD (US Department of Agriculture, 2020). Although certified organic management was not a selection criterion for our study, based on our survey findings (see Section Characterization of Agroecosystem Management Practices) and field experience, approximately half of the diversified farms in the region are small organic farms. Hence, it can be considered that our sample of 53 surveyed farm managers represents at least 15% of diversified farms in MT and SD combined.

One reason for the relatively low response rate was the difficult working and communication conditions during the first months of the COVID-19 pandemic that limited us to reach producers by email instead of visiting farms to interact with farmers in depth. We acknowledge that our outcomes would have been more significant if obtained through a triangulation of methods, including complementary key informant interviews or mapping. Yet, the results obtained from this study address a sector of agricultural production in the NGP that is emerging and currently understudied.

It was our purpose to obtain a snapshot of the state of diversified farms in the NGP during the early phase of the pandemic, which led to a relatively short time frame for its implementation. We recognize that the short time window of the survey, despite providing important insight into the early impact of the pandemic on diversified farms, may have reduced the validity of our data, especially of aspects not directly related to the pandemic. Yet, our dataset is unique as it allows us to assess a phenomenon for which no previous information exists. For future studies, it may also be interesting to compare the responses of diversified farmers to a stressor like COVID-19 to those of a control group, for example, operators of monocropping farms, while controlling for other variables such as operation size, years of expertise, or annual income from agricultural production.

RESULTS

Characterization of Agroecosystem Management Practices

Almost half the respondents [46%, out of $n = 52$, no response (NR) = 1] reported that they follow certified organic agriculture guidelines (**Figure 1**). Overall, the surveyed producers articulated that they are using different combinations of sustainable crop management practices on their farms. Findings indicate that most of the surveyed producers who are not certified organic use crop rotations, cover cropping, and conservation tillage ($p < 0.05$).

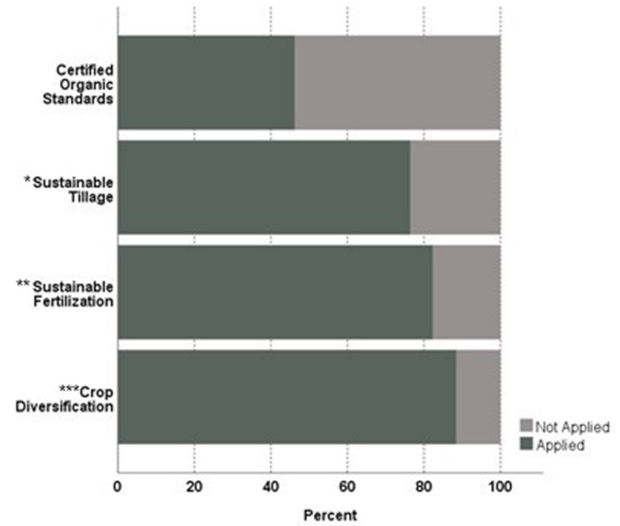

FIGURE 1 | Frequency of compliance with organic standards and use of specific agroecosystem management practices of surveyed producers (% of responses, $n = 53$). *Conservation Tillage or Direct Seeding. **Use of compost, compost tea, charcoal, and/or manure. ***Crop rotations, intercropping and/or cover cropping.

TABLE 4 | Producer perceptions on COVID-19 pandemic impacts on management.

Producer perceptions of impact of COVID-19 on	Impacted by COVID-19 (%)	Not impacted by COVID-19 (%)	*p*
Farm management practices	31.8	68.2	0.01
Cultivated crops in 2020	43.2	56.8	0.37
Plans for cultivated crops in 2021	25	75	0.01

Producer perceptions of the impact of the COVID-19 pandemic on farm management practices and cultivated crops in 2020 and cultivation plans for 2021 (% of all responses, n = 53).

Impact of COVID-19 on Farm Management and Crop Choices

The majority of surveyed producers (68% out of $n = 53$) reported they did not undertake changes in their farm management practices because of the COVID-19 pandemic. Also, 75% of producers stated that they did not intend to change their crop choices for 2021 (**Table 4**). Our findings highlight that those producers who apply sustainable fertilization techniques such as composting, application of manure, and crop rotations were more likely to modify their farm management because of COVID-19 (**Tables 5**, **6**). When asked about drivers of farming management changes before COVID-19, most respondents mentioned markets as the central motive (85%, $n = 40$), while subsidies (20%, $n = 40$), and land use (18%, $n = 40$) played a minor role (**Figure 2**).

Out of the 19 producers who changed their crop rotations and/or crop choices because of the pandemic (43% of surveyed producers, $n = 53$), the majority stated they did so for increasing production to compensate for price decreases. The notion of price-loss compensation was more frequently reported among SD producers, who manage larger and more grain-focused operations, than among MT producers. Specifically, increasing production was most common among corn and soybean producers, followed by producers of small grains other than corn. Three producers reported pandemic-related changes in their livestock production management.

Producer Perceptions of the Impact of COVID-19 on Food Security and Livelihoods

Eighty-nine percent of surveyed producers (out of $n = 53$) were concerned that the COVID-19 pandemic was impacting the future of farming in general. Most concerns were related to "unstable and shrinking markets for agricultural products." The majority of producers (62%) were anxious about their community's food security while only 16% expected their access to food to be affected by the pandemic (**Table 7**). Based on the two-item food insecurity screening tool by Gundersen et al. (2017), one producer (2% of respondents) reported having been food insecure between March and August 2020. Five producers (10% of respondents, $n = 53$) said they were food insecure for a specific period in 2020. The remaining 43 producers (88% of respondents, $n = 53$) stated they were not food insecure during the survey period. Almost half of all surveyed producers stated that they did not depend on external food sources, as most of their food comes from their farms, hunting, or gathering (40%, $n = 53$). Most producers were not apprehensive about access to fresh fruits and vegetables (91%, $n = 53$). A fifth of producers reported confidence in their local food retailers (21%, $n = 53$).

Impact of COVID-19 on Community and Farm Economy

Producers who expected a negative impact of the COVID-19 pandemic on their community (62% of all respondents, $n = 53$) were also those most concerned about the economy of their local fellow producers. Specific pandemic-related concerns shared by producers include (1) disruptions in supply chains and a corresponding shipping cost increase (9 out of the 33 producers who expected a negative community impact); and (2) decreasing consumer demand due to lower income, rising unemployment, and previous stockpiling of food (11 out of 33 producers). Specifically, producers reported anxiety about the local, higher-priced segment of the market (such as CSAs), which several producers expected to shrink. Eleven out of 33 respondents to this question were also concerned about their community's access to food, especially in remote areas of the region where grocery stores are scarce.

Most producers stated that their access to commodities, farm inputs, as well as the availability of farm labor, were not impacted during the early stages of the COVID-19 pandemic (**Table 7**).

TABLE 5 | Farm management changes due to COVID-19, based on farming practices applied by surveyed producers.

Farming practice	Apply practice % of all responses (*n*)	Not apply practice % of all responses (*n*)	No response % of all responses (*n*)	Out of farms that apply practice		
				Change due to COVID-19	No change due to COVID-19	Cramer's V coefficient
Sustainable tillage*	62% (33)	19% (10)	19% (10)	33% (11)	67% (22)	0.03[b]
Sustainable fertilization**	70% (37)	13% (7)	17% (9)	28% (14)	62% (23)	0.28[a]
Cropping system diversification***	72% (38)	11% (6)	17% (9)	32% (12)	68% (26)	0.01[b]

*Conservation tillage or direct seeding.
**Use of compost, compost tea, charcoal, and/or manure.
***Crop rotations, intercropping and/or cover cropping.
[a]Moderate relationship.
[b]Weak relationship.

TABLE 6 | Crop choice changes due to COVID-19 in the 2020 and 2021 cropping season, based on farming practices applied by surveyed producers.

Farming practice	Apply practice % of all responses (n)	Not apply practice % of all responses (n)	No response % of all responses (n)	Out of farms that apply practice					
				2020 cropping choices %(n)			2021 cropping choices %(n)		
				Change due to COVID-19	No change due to COVID-19	Cramer's V Coefficient	Change due to COVID-19	No change due to COVID-19	Cramer's V Coefficient
Sustainable Tillage*	62% (33)	19% (10)	19% (10)	45% (15)	55% (18)	**0.05**[b]	27% (9)	73% (24)	**0.07**[b]
Sustainable Fertilization**	70% (37)	13% (7)	17% (9)	49% (18)	51% (19)	**0.22**[a]	30% (11)	70% (26)	**0.23**[a]
Cropping system diversification***	72% (38)	11% (6)	17% (9)	42% (16)	58% (22)	**0.06**[b]	21% (8)	79% (30)	**0.23**[a]

*Conservation tillage or direct seeding.
**Use of compost, compost tea, charcoal, and/or manure.
***Crop rotations, intercropping and/or cover cropping.
[a]Moderate relationship.
[b]Weak relationship.

However, over half of producers (62%, $n = 53$) reported that they expected their total farm income to shrink in 2020 (**Table 7**).

Impact of COVID-19 on Producers' Emotional Wellbeing

Roughly half of the surveyed producers (47%, $n = 53$) stated that their overall anxiety increased because of the COVID-19 pandemic. Accordingly, multiple producers articulated an "anxiety of the unknown." For example, two producers reported that they were having sleepless nights due to the pandemic.

The most frequently mentioned concerns of producers during the pandemic involved financial issues, supply chain disruptions, anxiety about family and loved ones, personal health concerns, how to implement social distancing in farm work, and concerns about the negative impacts of the pandemic on society as a whole.

Out of the producers that did not report increased anxiety because of the pandemic (53%, $n = 53$), three themes were identified that kept them grounded: (1) faith or religion; (2) confidence in their food self-sufficiency; and (3) expanded market opportunities for their farm operations because of an expected increased consumer demanding for local food.

Factors of Producers' Perceptions of COVID-19

We identified three factors that shaped producers' perceptions of the effect of COVID-19 on their farming systems and communities: (1) farming experience; (2) farm size; and (3) contribution of farming to household income.

Farming experience had a considerable impact on producers' perceptions of COVID-19. Most "new" producers (those who had been in charge of their farm for <2 years) changed their farm management practices because of the pandemic (80%, $n = 42$, NR $= 9$), and 40% of them also altered their crop portfolio in 2020 (**Figure 3**; see **Supplementary Appendix 5** for details). In contrast, most producers with more than 5 years of experience

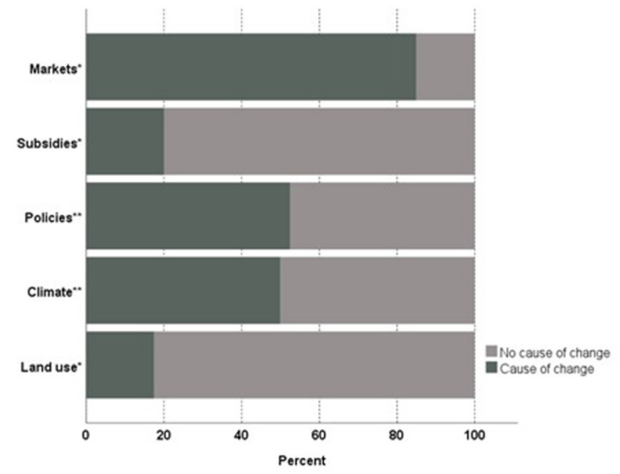

FIGURE 2 | Drivers of shifts in farm management. Factors that have influenced farming practice changes in the past ($n = 53$). *Significant ($p < 0.05$). **No significant difference between responses.

TABLE 7 | Perceived effects of COVID-19 on farm economy, food security, and livelihoods.

	Impact of COVID-19 (%)	No impact of COVID-19 (%)	*p*
Access to food	15.9	84.1	<0.01
Food prices	38.6	61.4	0.13
Diet	15.1	84.9	<0.01
Community's food security	62.3	37.7	0.07
Access to commodities and farm inputs	27.3	72.7	0.01
Price of commodities and farm inputs	47.7	52.3	0.76
Available farm labor	34.1	65.9	0.03
Farm income	62.3	37.7	0.07
Future of farming	81.1	18.9	<0.01
Household income	45.5	54.5	0.54

Perceptions of surveyed producers on the impact of the COVID-19 on their and their community's food security as well as their farm economy (% of all responses, n = 53).

did not shift their farm management practices (84%) or modified their 2020 crop rotations (81%).

In terms of farm size, only 21% ($n = 42$, NR = 9) of surveyed producers operating on farms smaller than 100 acres were concerned that the pandemic would affect the available workforce needed for their farms, while 73% of the managers of larger farms, stated that the availability of farm labor was a concerning issue. Only 10% of managers of small producers were anxious about their household diet, while this share was higher (31%) among operators of larger farms (**Figure 4**, **Supplementary Appendix 6**).

The third factor impacting the producers' perception of the impact of COVID-19 was the contribution of farming to a household's overall economy. Where farming provided more than 75% of the household income, 73% of producers ($n = 42$) were concerned about losses of household income due to the pandemic. As for part-time producers, where farming contributes to <75% of the household economy, 69% stated that they did not expect COVID-19 to seriously affect their household income (**Figure 5**, **Supplementary Appendix 7**). Among those part-time producers concerned about their income (31%), almost all lost their off-farm jobs or faced salary decreases in their side jobs.

Perceived Agroecosystem Resilience

On the basis of the adapted agroecosystem assessment framework (Cabell and Oelofse, 2012), survey responses indicated that shock exposure had the highest resilience score within the 53 farms, specifically, access to commodities, farm inputs, and farm labor. In contrast, two farm-management-related parameters, ecological self-regulation (presence of riparian buffers, pollinator strips, hedgerows, and trees) and connectedness (use of inter- and cover cropping, inter- and intraspecific diversity), revealed a low overall resilience score (**Figure 6**). The parameter of ecological self-regulation was found to have a lower resilience score for larger farms (>100 acres) than for smaller farms, while larger farms had a higher resilience score for autonomy and local interdependence (the contribution of farming to a household's income) (**Figure 7**). In terms of food security, access to food was not considered a limiting factor by most producers, which indicates high resilience and self-sufficiency. However, producers expressed considerable concern regarding the overall food security in their communities.

DISCUSSION

This study highlights that while national and global food systems experienced disruptions during the early stages of the COVID-19 pandemic, the surveyed producers of diversified farms in the NGP expressed long-term confidence regarding local food production from diversified farms during the first growing season of the pandemic. Survey findings demonstrate relatively "mild" responses by farmers to the initial phase of the pandemic compared to other national and international studies administered during this time of heightened uncertainty. The disruptions associated with the COVID-19 pandemic have emphasized the need to strengthen the resilience of food systems to future external disturbances (Orden, 2020). Given that the surveyed producers managed diversified farms to supply local food systems, the results of this study highlight the potential of diversified farming and local food systems for strengthening resilience to support food security in the context of extreme shocks.

The population highlighted in this study, farmers who practice diversified agriculture in the NGP, represents a unique sector of the regional agricultural production. The percentage of small-scale horticultural producers in our sample is disproportionally higher compared to typical farms in the NGP (Gough, 1997; Long et al., 2014; Miller et al., 2015; Carlisle, 2016; Stoy et al., 2018). In addition, the percentage of producers following certified organic

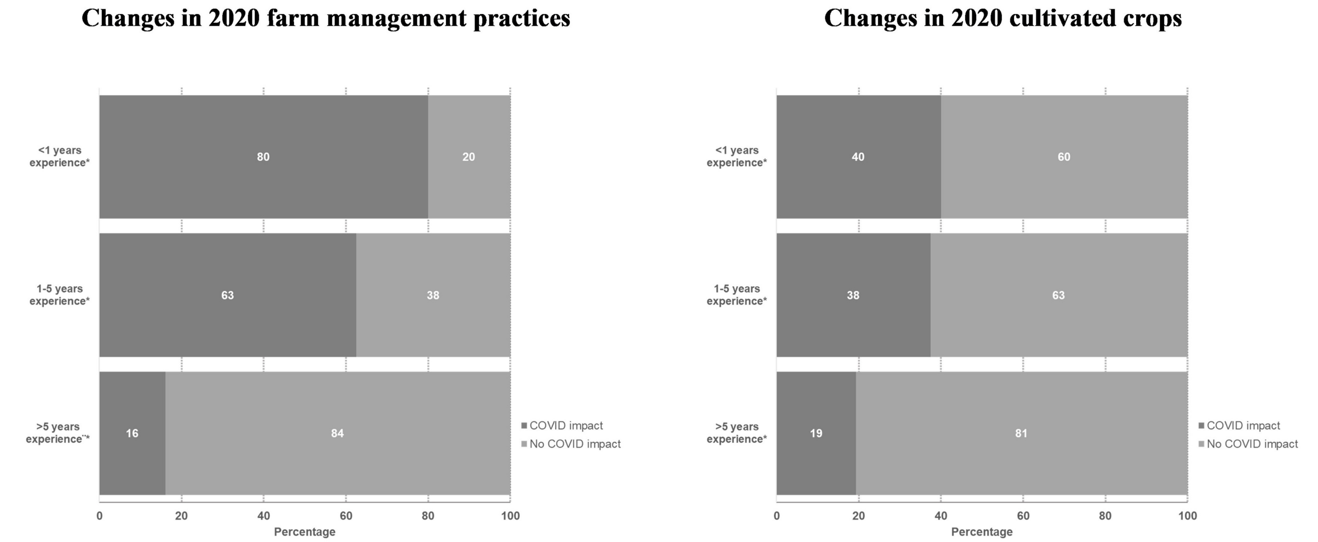

FIGURE 3 | Impact of producers' experience on farm management and cultivated crops (% of all responses, $n = 42$, NR = 9). *Strong relationship [Cramer's V >0.3 $\wedge$ p (Chi-Square) < 0.05].

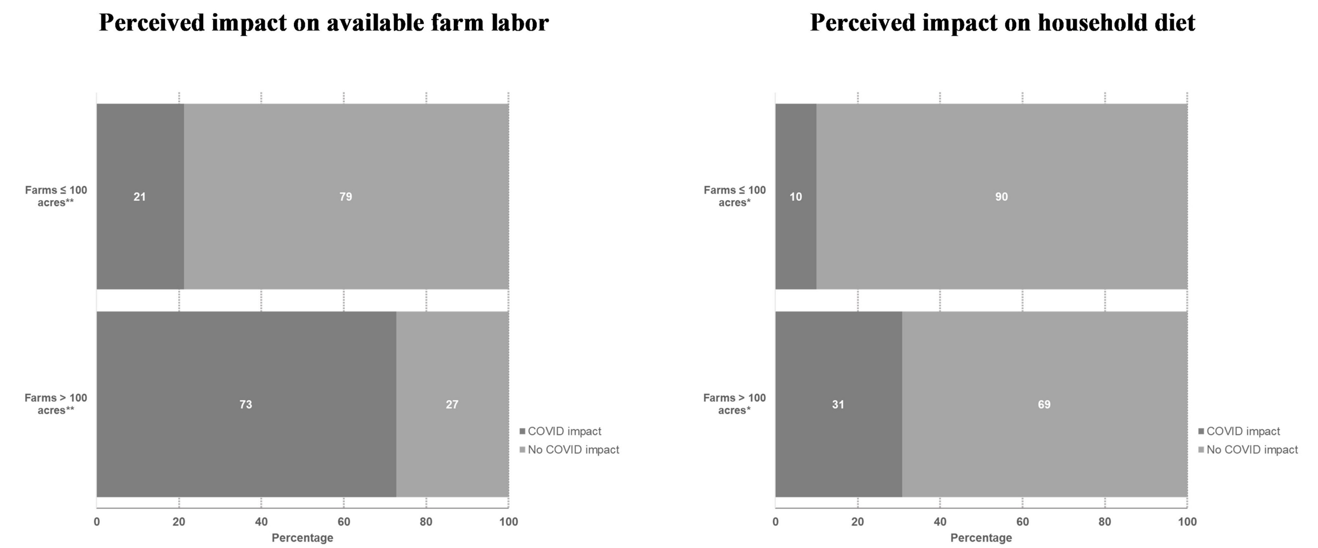

FIGURE 4 | Impact of farm size on perceived available farm labor and household diet (% of all responses, $n = 42$, NR = 9). *Moderate relationship [Cramer's V >0.2 $\wedge$ p (Chi-Square) <0.1]. **Strong relationship ($V > 0.3 \wedge p < 0.05$).

farming guidelines is higher in our sample (46%) compared to the region, where it is <3% (US Department of Agriculture, 2019). The percentage of producers following sustainable farming practices such as conservation tillage, use of manure, crop rotations, intercropping, and cover cropping is also elevated among our sample.

A further unique attribute of the surveyed producers is their history as farm owners; 15% of the respondents were recent farmers with 2020 being their second farming season, while 96% of all MT and SD farms are multiple-generation family farms (US Department of Agriculture, 2019). Thus, findings indicate that farming experience strongly impacted producer responses to the COVID-19 pandemic. While 84% of producers with more than 5 years of experience did not change their farm management practices because of the pandemic, 80% of the "newcomers" (<5 years of experience) did change their practices in adaptation to the new situation. The unique features of the surveyed farmers are important to consider in the interpretation of study findings, especially because pandemic-related supply chain disruptions were strongest among meat and dairy NGP producers (Belasco, 2020; Brewin, 2020), and both sectors were underrepresented in our study.

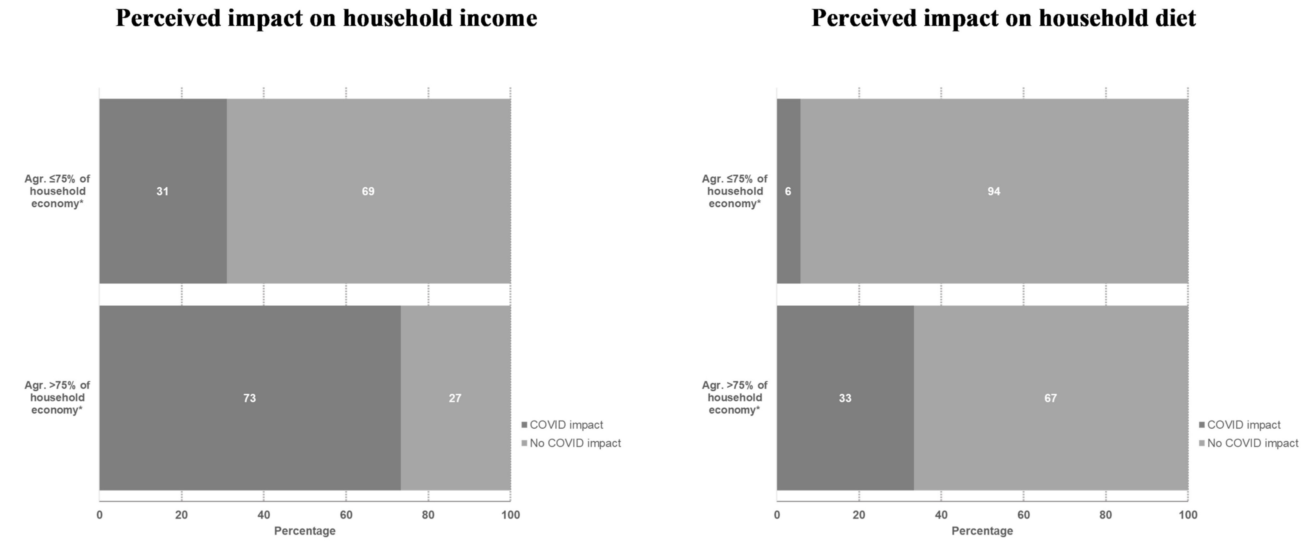

FIGURE 5 | Impact of contribution of agriculture to total household economy on perceived household income and household diet (% of all responses, $n = 42$, NR = 9). *Strong relationship (Cramer's V >0.3 ^p [Chi-Square] < 0.05).

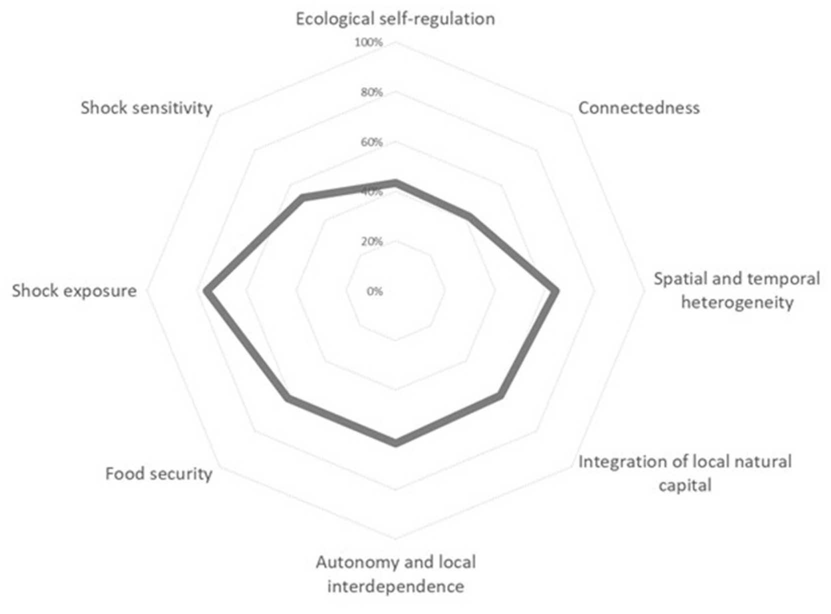

FIGURE 6 | Overall assessment of the perceived resilience of the participating farms ($n = 53$) based on Cabell and Oelofse (2012) framework and additional food system resilience parameters (Ericksen et al., 2012; Intergovernmental Panel on Climate Change, 2014), 100% represents the highest resilience.

The relatively "milder" responses to the COVID-19 pandemic among the surveyed producers compared to evidence from national (Belasco, 2020; Béné, 2020; Wolfson and Leung, 2020) and international (Benton, 2020; Elleby et al., 2020; Kerr, 2020; Torero, 2020) studies, indicate an elevated level of shock absorption capacity. For example, most surveyed producers did not extensively change their farming practices in response to the COVID-19 pandemic and associated measures, which differs from the strong disruptions of farm management practices due to COVID-19 at the global level (Torero, 2020). Also, the reduced availability of farm labor that challenged producers throughout the U.S. (Béné, 2020; Benton, 2020) was only a prevalent concern among larger-scaled surveyed farms.

We also found relatively "milder" responses regarding emotional well-being compared to other studies administered during the study period. While a more difficult access to markets and a generally perceived uncertainty affected the emotional well-being of most farmers globally (Reissman et al., 2006; Benton, 2020; Laborde et al., 2020), 53% of producers in our survey stated they were not anxious during the initial months of the pandemic. These findings demonstrate a remarkably low shock sensitivity of the surveyed producers during uncertain times. Concerns were stronger among part-time and smaller producers as they feared side-job losses and decreasing household income.

While food insecurity due to COVID-19 skyrocketed in the U.S. (Laborde et al., 2020; Swinnen and McDermott, 2020), including in MT (Montana Food Bank Network, 2020) and SD (Lowrey, 2020), access to food was not considered an alarming issue by 88% of surveyed producers. We hypothesize that there are three reasons for the low perceived food insecurity in our study. First, 40% of surveyed producers do not depend on commercial food for their diet because a considerable part of the food they consume is produced on their farms or obtained in wild food environments, including hunting and gathering in their surroundings. Almost half of the surveyed producers stated that they use at least 10% of their production for family consumption, and a quarter of farms use more than 50% of their production for family subsistence. This reliance on non-commercial food sources of food helps explain the high food security during the pandemic. Second, respondents demonstrated high confidence in their local food retailers to provide accessible food. Lastly, producers showed optimism that the COVID-19 pandemic may increase long-term demand for food produced on diversified farms.

The overall resilience self-assessment, based on producer responses and applying the agroecosystem assessment framework of Cabell and Oelofse (2012), suggested that the producers' relatively moderate response to the pandemic was enabled by diversified farm management practices and influenced by farm size. Larger farms showed a higher economic autonomy compared to smaller farms, mostly because they are operated by full-time producers and consequently do not depend on side jobs. However, larger farms had lower ecological self-regulation indices, which refer to practices such as pollinator strips. The integration of local natural resources (including fertilization with manure and compost), as well as the spatial and temporal farm system heterogeneity (including the frequent use of crop rotations and diverse farm management practices), were found to be high in both large and small farms (**Figure 7**). Our study suggests that experience with diversification influenced the producers' ability to respond to an external stressor like the COVID-19 pandemic. Farms where multi-crop rotations and sustainable soil fertility management were common before 2020, were more likely to alter crop rotations than farms with a shorter history of sustainable management practices.

CONCLUSIONS

The COVID-19 pandemic exposed the fragility of global and national food systems (Altieri and Nicholls, 2020a; Béné, 2020), with severe socio-economic and emotional consequences for food system stakeholders across scales. Diversification is increasingly recognized as a core strategy to increase food system resilience, whether it be short- and mid-termed shocks such as COVID-19, or gradually evolving complex disruptions such as climate change (Rotz and Fraser, 2015; Tendall et al., 2015; Zimmerer et al., 2019). At the individual farm, diversification includes that of plants and animals at the genetic and species levels, as well as diversity-enhancing farm management practices including complex crop rotations or the integration of plant and animal production (Béné et al., 2015; UC Berkley, 2020). During the past 70 years, diversified farms in the U.S., as in other high-income countries, have been widely pushed back by conventional high-input monocropping systems (Jäger et al., 2019; Hobbs, 2020). Nowhere in the U.S. is the simplification of farming systems more visible than in the small-grain producing breadbasket regions of the Midwest and the Great Plains (Bagley et al., 2012), including the NGP. While over the past decade, there has been a resurgence of farm system diversification in the U.S. (Kolodinsky et al., 2020), these farms represent a niche sector within millions of acres of "Big Ag," and most existing diversified farms are small in size and managed by relatively inexperienced producers. The study presented here revealed that diversified small-scale producer responses to the COVID-19 pandemic differed from those of conventional producers. We found that the majority of surveyed producers did not extensively change their farming practices during the study period comprised of the early months of the pandemic, which contrasts with profound farm management changes witnessed regionally, nationally, and globally (Torero, 2020). Several producers, especially those who operate complex and diverse farms, implemented punctual management and crop rotation changes.

While food insecurity increased across MT (Montana Food Bank Network, 2020) and SD (Lowrey, 2020) in 2020, food security and accessibility were not severe concerns of most surveyed producers. Reasons for the producers' high perceived level of food security during the pandemic include the possibility to access food from their farms and for 40% of them, the procurement of food through hunting and gathering. Additionally, the confidence of the surveyed producers in the local food system to provide sufficient food was high. Hence, this study suggests that diversified farms have an elevated capacity to absorb an external shock as severe as the COVID-19 pandemic. We also found that larger farms were economically more independent than smaller ones. For example, off-farm income allowed large farms to avoid "panic reactions" such as changing their crop rotations, indicating that the economic status and antecedents of a farm sharply determine its capacity to absorb shocks.

This study further examines potential factors that limited the surveyed farms from benefitting more from the diversification of their operations. Producers of small farms in our study were often highly dependent on off-farm income, which impacted their economic stability and emotional well-being. Larger farms that lacked an extensive diversification of their systems could benefit from a greater number of diversification practices to enhance resilience.

Diversification of agroecosystems should be recognized as a process (not a goal) across ecological, social, and institutional dimensions of farming systems (Petersen-Rockney et al., 2021a). The more advanced the level of diversification on a farm,

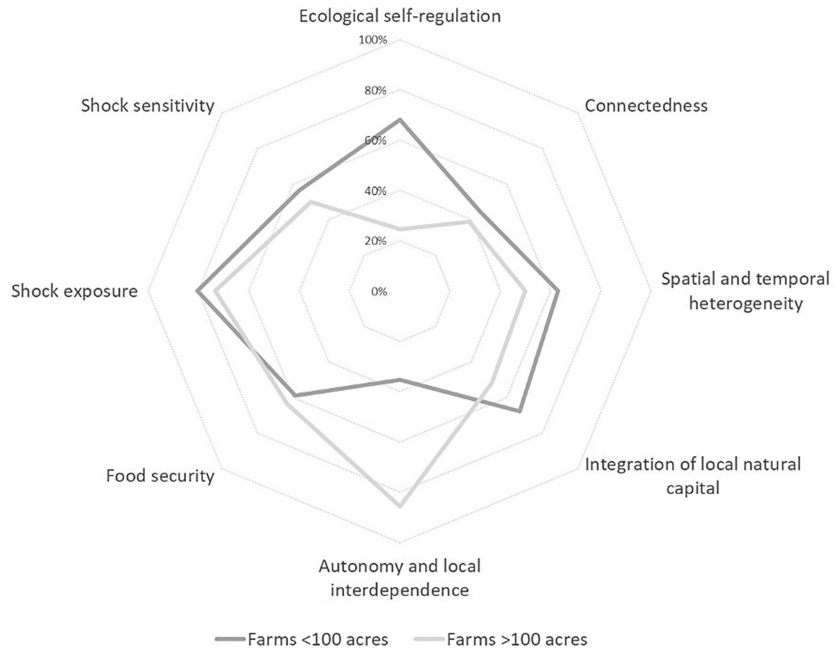

FIGURE 7 | Assessment of the perceived resilience of the participating farms ($n = 53$) divided into farms larger and smaller than 100 acres based on Cabell and Oelofse (2012) framework and additional food system resilience parameters (Ericksen et al., 2012; Intergovernmental Panel on Climate Change, 2014), 100% represents the highest resilience.

the more effective it is for enhancing resilience (Altieri, 1994). Farms in the NGP should engage in a process of constantly increasing diversification including diversifying farm business and management models, governing institutions and policies, farmer demographics, markets, values and goals, and knowledge systems toward improving adaptive capacity in the context of shocks (Petersen-Rockney et al., 2021b). Policies, market, and education programs are called for to promote the continuous enhancement of farm diversification for enhancing food system resilience. If policies, market, education, and research re-orient their efforts to enable the establishment of an increasing number of diversified farms, a whole region such as the NGP can achieve a greater ability to provide food security to their communities as well as support farmer livelihoods in the context of global challenges including climate change, population growth, and future pandemics. Based on the findings of our study and the literature cited here, we recommend the following pathways for increasing and maintaining diversification and the resilience of agricultural production systems:

(1) **Development of evidence-based agroecological farm management plans**. Evidence-based agroecological farm management plans that are tailored to different farming scales and agroclimatic regions are needed for enhancing diversification including at the functional diversity and landscape levels. For example, producers in regions such as the NGP that practice wide crop rotations can be encouraged to also conduct mixed cropping. These diversified farms, in turn, will be more resilient to local and global disruptions.
(2) **Dissemination of evidence on the benefits of agricultural diversification**. Efforts are needed to broadly disseminate evidence on the benefits of agricultural diversification and associated farm management plans to producers and other food system stakeholders through media, extension, and education to enhance the resilience of food systems.
(3) **Research on the role of agricultural diversification for producers' emotional wellbeing and personal resilience**. Research is called for to examine the potential role of agricultural diversification for producers' emotional wellbeing and personal resilience. The low anxiety rates of the surveyed producers during the initial stages of the pandemic and their optimism regarding the long-term growth of their farm operations suggest that diversity not only enhances the environmental and economic shock absorption capacity but also benefits the emotional well-being of producers.
(4) **Policy and incentives to remove barriers for new farmers and for enabling diversification**. Policy and programs are necessary to support new farmers to pursue farming full-time while providing enabling conditions for diversification. The high dependence of small-diversified farms on off-farm income lowers their flexibility in responding to shocks and their potential to experiment and observe on their farms. For example, peer-to-peer exchange platforms with experienced farmers can support new farmers build knowledge and enhance their capacity to respond to shocks.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Institutional Review Board (IRB) at Montana State University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

SA and MJ led the study conception. SA and TW developed the survey and led the study design. TW piloted the survey and led the acquisition of data. RE led data analysis with support from AM. RE, SA, IG, MJ, and FM contributed to data interpretation. RE led the drafting of the manuscript with essential contributions to writing and revising from all SA, IG, and FM. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2022.668335/full#supplementary-material

REFERENCES

Afshin, A., Sur, P. J., Fay, K. A., Cornaby, L., Ferrara, G., Salama, J. S., et al. (2019). Health effects of dietary risks in 195 countries, 1990 and 2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet* 393, 1958–1972. doi: 10.1016/S0140-6736(19)30041-8

Ahmed, S., Downs, S. M., Yang, C., Chunlin, L., ten Broek, N., and Ghosh-Jerath, S. (2020). Rapid tool based on a food environment typology framework for evaluating effects of the COVID-19 pandemic on food system resilience. *Food Security* 12, 773–778. doi: 10.1007/s12571-020-01086-z

Altieri, M. A. (1994). Bases agroecológicas para una producción agrícola sustentable. *Agric. Técnica* 54, 371–386.

Altieri, M. A., and Nicholls, C. I. (2020a). Agroecology and the emergence of a post COVID-19 agriculture. *Agric. Human Values* 37, 525–526. doi: 10.1007/s10460-020-10043-7

Altieri, M. A., and Nicholls, C. I. (2020b). Agroecology and the reconstruction of a post-COVID-19 agriculture. *J. Peasant Stud.* 47, 881–898. doi: 10.1080/03066150.2020.1782891

Bagley, J. E., Desai, A. R., Dirmeyer, P. A., and Foley, J. A. (2012). Effects of land cover change on moisture availability and potential crop yield in the world's breadbaskets. *Environ. Res. Lett.* 7, 014009. doi: 10.1088/1748-9326/7/1/014009

Baldwin, R., and Tomiura, E. (2020). "Thinking ahead about the trade impact of COVID-19," in *Economics in the Time of COVID-19*, eds. R. Baldwin and B. Weder di Mauro (London, UK: Centre for Economic Policy Research), 59–73.

Belasco, E. (2020). *Cattle Market Expectations for Fall Under COVID-19*. Bozeman MT: Montana State University.

Béné, C. (2020). Resilience of local food systems and links to food security—a review of some important concepts in the context of COVID-19 and other shocks. *Food Secur.* 12, 805–822. doi: 10.1007/s12571-020-01076-1

Béné, C., Frankenberger, T., and Nelson, S. (2015). Design, monitoring and evaluation of resilience interventions: conceptual and empirical considerations. *IDS Working Papers* 459, 1–23.

Benton, T. G. (2020). COVID-19 and disruptions to food systems. *Agric. Human Values* 37, 577–578. doi: 10.1007/s10460-020-10081-1

Bhattacharya, D. (2012). "Trade and health: Emergent paradigms and case studies in infectious diseases," in *Global Health Disputes and Disparities* (London: Routledge), 107–125

Birkeland, K. (2020). *Impact of COVID-19 on Agriculture with SDFB Executive Director Krystil Smit and Professor Chair of Economics and Decisions Sciences at USD*. Huron SD: South Dakota Farm Bureau. Available online at: https://www.youtube.com/watch?v=N0IVBlzDwq8andfeature=youtu.be (accessed Sep 12, 2020).

Brewin, D. (2020). The impact of COVID-19 on the grains and oilseeds sector. *Can. J. Agric. Econ.* 68, 185–188. doi: 10.1111/cjag.12239

Brown, J. D. (2011). Likert items and scales of measurement. *Shiken Res. Bull.* 15, 10–14.

Cabell, J. F., and Oelofse, M. (2012). An indicator framework for assessing agroecosystem resilience. *Ecol. Soc.* 17:18. doi: 10.5751/ES-04666-170118

Carlisle, L. (2016). *Lentil Underground: Renegade Farmers and the Future of Food in America*. New York City: Avery.

Carpenter, S., Walker, B., Anderies, J. M., and Abel, N. (2001). From metaphor to measurement: resilience of what to what? *Ecosystems* 4, 765–781. doi: 10.1007/s10021-001-0045-9

Cates-Carney, C. (2020). *Montana Ag Producers Say They Need More COVID-19 Relief*. Helena MT: Montana Public Radio. Available online at: https://www.mtpr.org/post/montana-ag-producers-say-they-need-more-covid-19-relief [accessed Sep 12, 2020].

Chambers, R. L., and Skinner, C. J. (2003). *Analysis of Survey Data*. New York, NY: Wiley and Sons.

Conant, R. T., Kluck, D., Anderson, M. T., Badger, A., Boustead, B. M., Derner, J. D., et al. (2018). "Northern great plains," in *Global Change Research Program*. ed USGS (Washington DC: US Global Change Research Program).

De Sá, J. P. M. (2007). *Applied Statistics Using SPSS, Statistica, MatLab*. Germany: Springer.

DeLeon, K. (2020). Ranch woes: Virus deals blows to Montana ranchers. *Billings Gazette*.

Ebel, R., Menalled, F., Ahmed, S., Gingrich, S., Baldinelli, G. M., and Félix, G. (2021). "How biodiversity loss affects society," in *Handbook on the Human Impact of Agriculture*, ed S. Harvey. (Cheltenha, UK: Edward Elgar Publishing).

Elleby, C., Domínguez, I. P., Adenauer, M., and Genovese, G. (2020). Impacts of the COVID-19 pandemic on the global agricultural markets. *Environ. Resour. Econ.* 76, 1067–1079. doi: 10.1007/s10640-020-00473-6

Elmqvist, T., Folke, C., Nyström, M., Peterson, G., Bengtsson, J., Walker, B., et al. (2003). Response diversity, ecosystem change, and resilience. *Front. Ecol. Environ.* 1, 488–494. doi: 10.1890/1540-9295(2003)001%5B0488:RDECAR%5D2.0.CO;2

Ericksen, P., Bohle, H.-G., and Stewart, B. (2012). "Vulnerability and resilience of food systems," in *Food Security and Global Environmental Change* (London, UK: Routledge), 87–97.

Ericksen, P. J. (2008). Conceptualizing food systems for global environmental change research. *Global Environ. Change* 18, 234–245. doi: 10.1016/j.gloenvcha.2007.09.002

Ferketich, S. (1990). Internal consistency estimates of reliability. *Res. Nurs. Health* 13, 437–440. doi: 10.1002/nur.4770130612

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L., et al. (2004). Regime shifts, resilience, and biodiversity in ecosystem management. *Annu. Rev. Ecol. Evol. Syst.* 35, 571–581. doi: 10.1146/annurev.ecolsys.35.021103.105711

Galea, S., Merchant, R. M., and Lurie, N. (2020). The mental health consequences of COVID-19 and physical distancing: the need for prevention and early intervention. *JAMA Intern. Med.* 180, 817–818. doi: 10.1001/jamainternmed.2020.1562

Gliessman, S. R. (1985). "Multiple cropping systems: a basis for developing an alternative agriculture," in *Innovative Biological Technologies for Lesser Developed Countries: Workshop Proceedings*, ed. OoTA US Congress (Washington, DC: Congress of the USA), 67–83.

Gough, R. (1997). Growing vegetables under the big sky. *J. Veg. Crop Prod.* 3, 79–91. doi: 10.1300/J068v03n01_10

Grimberg, I. (2020). *Western SARE COVID-19 Survey Report*. Bozeman, MT: Western SARE. Available online at: https://western.sare.org/resources/responses-to-covid-19-in-western-ag/ (accessed Feb 15, 2021).

Gundersen, C., Engelhard, E. E., Crumbaugh, A. S., and Seligman, H. K. (2017). Brief assessment of food insecurity accurately identifies high-risk US adults. *Public Health Nutr.* 20, 1367–1371. doi: 10.1017/S1368980017000180

Heinemann, J., Massaro, M., Coray, D., Agapito-Tenfen, S., and Wen, J. D. (2014). Sustainability and innovation in staple crop production in the US Midwest. *Int. J. Agric. Sustain.* 12, 71–88. doi: 10.1080/14735903.2013.806408

Herforth, A., Johns, T., Creed-Kanashiro, H. M., Jones, A. D., Khoury, C. K., Lang, T., et al. (2019). "Agrobiodiversity and feeding the world: more of the same will result in more of the same," in *Agrobiodiversity: Integrating Knowledge for a Sustainable Future*, eds. K.S. Zimmerer and S. de Haan (Cambridge, MA: MIT Press), 185–210.

Hobbs, J. E. (2020). Food supply chains during the COVID-19 pandemic. *Can. J. Agric. Econ*. 68, 171–176. doi: 10.1111/cjag.12237

Hodbod, J., and Eakin, H. (2015). Adapting a social-ecological resilience framework for food systems. *J. Environ. Stud. Sci.* 5, 474–484. doi: 10.1007/s13412-015-0280-6

Howard, P. L. (2010). "Culture and agrobiodiversity: understanding the links," in *Nature and Culture: Rebuilding Lost Connections,* eds. S. Pilgrim and J. N. Pretty (London, UK: Routledge).

Intergovernmental Panel on Climate Change (2014). "Climate change: Impacts, adaptation, and vulnerability," in *5th Assessment of the Intergovernmental Panel on Climate Change* (Geneva, Switzerland: IPCC).

Jackson, L. E., Pascual, U., and Hodgkin, T. (2007). Utilizing and conserving agrobiodiversity in agricultural landscapes. *Agric. Ecosyst. Environ.* 121, 196–210. doi: 10.1016/j.agee.2006.12.017

Jäger, M., van Loosen, I., and Giuliani, A. (2019). *How Have Markets Affected the Governance of Agrobiodiversity?* Cambridge, MA: MIT Press.

Kahane, R., Hodgkin, T., Jaenicke, H., Hoogendoorn, C., Hermann, M., Dyno Keatinge, J., et al. (2013). Agrobiodiversity for food security, health and income. *Agron. Sustain. Dev.* 33, 671–693. doi: 10.1007/s13593-013-0147-8

Kalil, A. C. (2020). Treating COVID-19—off-label drug use, compassionate use, and randomized clinical trials during pandemics. *JAMA* 323, 1897–1898. doi: 10.1001/jama.2020.4742

Kerr, W. A. (2020). The COVID-19 pandemic and agriculture—short and long run implications for international trade relations. *Can. J. Agric. Econ*. 68, 225–229. doi: 10.1111/cjag.12230

Kolodinsky, J., Sitaker, M., Chase, L., Smith, D., and Wang, W. (2020). Food systems disruptions. *J. Agric. Food Syst. Commun. Dev.* 9, 1–4. doi: 10.5304/jafscd.2020.093.013

Kuckartz, U. (2014). "Three basic methods of qualitative text analysis," in *Qualitative Text Analysis: A Guide to Methods, Practice and Using Software,* ed. U. Kuckartz. (London, UK: SAGE), 65–121.

Laborde, D., Martin, W., Swinnen, J., and Vos, R. (2020). COVID-19 risks to global food security. *Science* 369, 500–502. doi: 10.1126/science.abc4765

Leech, N. L., and Onwuegbuzie, A. J. (2011). Beyond constant comparison qualitative data analysis: Using NVivo. *School Psychol. Q.* 26:70. doi: 10.1037/a0022711

Letourneau, D. K., Armbrecht, I., Rivera, B. S., Lerma, J. M., Carmona, E. J., Daza, M. C., et al. (2011). Does plant diversity benefit agroecosystems? A synthetic review. *Ecol. Appl.* 21, 9–21. doi: 10.1890/09-2026.1

Long, J. A., Lawrence, R. L., Miller, P. R., and Marshall, L. A. (2014). Changes in field-level cropping sequences: indicators of shifting agricultural practices. *Agric. Ecosyst. Environ.* 189, 11–20. doi: 10.1016/j.agee.2014.03.015

Low, S. A., Adalja, A., Beaulieu, E., Key, N., Martinez, S., Melton, A., et al. (2015). *Trends in US Local and Regional Food Systems: A Report to Congress.* Washington, DC: USDA. Available online at: https://www.ers.usda.gov/publications/pub-details/?pubid=42807 (accessed Feb 15, 2021).

Lowrey, N. (2020, Apri 17). Need for food assistance skyrocketing for South Dakota residents during pandemic. *Argus Leader.*

Lynch, D. J., Growen, A., and Reiley, L. (2020, May 11). Farmers' hopes for respite from Trump-era struggles fade amid pandemic. *Washington Post.*

Miller, P. R., Bekkerman, A., Jones, C. A., Burgess, M. H., Holmes, J. A., and Engel, R. E. (2015). Pea in rotation with wheat reduced uncertainty of economic returns in southwest Montana. *Agron. J.* 107, 541–550. doi: 10.2134/agronj14.0185

Montana Food Bank Network (2020). *Montana Food Bank Network's Response to COVID-19.* Missoula, MT. Available online at: https://mfbn.org/2020/08/montana-food-bank-networks-response-tocovid-19/ (accessed December 1 2020).

Motley, T. J., Zerega, N., and Cross, H. (2006). Darwin's harvest: new approaches to the origins, evolution, and conservation of crops. New York, NY: Columbia University Press.

Murgueitio, E., Calle, Z., Uribe, F., Calle, A., and Solorio, B. (2011). Native trees and shrubs for the productive rehabilitation of tropical cattle ranching lands. *For. Ecol. Manag.* 261, 1654–1663. doi: 10.1016/j.foreco.2010.09.027

Naja, F., and Hamadeh, R. (2020). Nutrition amid the COVID-19 pandemic: a multi-level framework for action. *Eur. J. Clin. Nutr.* 74, 1117–1121. doi: 10.1038/s41430-020-0634-3

Nicola, M., Alsafi, Z., Sohrabi, C., Kerwan, A., Al-Jabir, A., Iosifidis, C., et al. (2020). The socio-economic implications of the coronavirus pandemic (COVID-19): a review. *Int. J. Surg.* 78, 185–193. doi: 10.1016/j.ijsu.2020.04.018

Nicosia, J. (2005). Avian flu: the consumer costs of preparing for global pandemic. *Loy. Consumer L. Rev.* 18, 479.

Oppenheimer, A. J., Pannucci, C. J., Kasten, S. J., and Haase, S. C. (2011). Survey says? A primer on web-based survey design and distribution. *Plastic Reconstruct. Surg.* 128, 299. doi: 10.1097/PRS.0b013e3182174413

Orden, D. (2020). Resilience test of the North American food system. *Can. J. Agric. Econ.* 2020, 1–3. doi: 10.1111/cjag.12238

Padbury, G., Waltman, S., Caprio, J., Coen, G., McGinn, S., Mortensen, D., et al. (2002). Agroecosystems and land resources of the northern Great Plains. *Agron. J.* 94, 251–261. doi: 10.2134/agronj2002.0251

Petersen-Rockney, M., Baur, P., Guzman, A., Bender, S. F., Calo, A., Castillo, F., et al. (2021b). Narrow and brittle or broad and nimble? Comparing adaptive capacity in simplifying and diversifying farming systems. *Front. Sustain. Food Syst.* 5, 56. doi: 10.3389/fsufs.2021.564900

Petersen-Rockney, M., Bowles, T., Ahmed, S., and Baur, P. (2021a). Editorial: diversifying farming systems for adaptive capacity. *Front. Sustain. Food Syst.* 5, 494. doi: 10.3389/fsufs.2021.806604

Philpott, S. M., Lin, B. B., Jha, S., and Brines, S. J. (2008). A multi-scale assessment of hurricane impacts on agricultural landscapes based on land use and topographic features. *Agric. Ecosyst. Environ.* 128, 12–20. doi: 10.1016/j.agee.2008.04.016

Pongsiri, M. J., Roman, J., Ezenwa, V. O., Goldberg, T. L., Koren, H. S., Newbold, S. C., et al. (2009). Biodiversity loss affects global disease ecology. *Bioscience* 59, 945–954. doi: 10.1525/bio.2009.59.11.6

Pyatt, K. (2020, April 6). Pandemic hurting ranchers in southwest Wyoming. *Buffalo Bulletin*.

Reissman, D. B., Watson, P. J., Klomp, R. W., Tanielian, T. L., and Prior, S. D. (2006). Pandemic influenza preparedness: adaptive responses to an evolving challenge. *J. Homeland Secur. Emerg. Manag.* 3, 13. doi: 10.2202/1547-7355.1233

Renkow, M., and Byerlee, D. (2010). The impacts of CGIAR research: a review of recent evidence. *Food Policy* 35, 391–402. doi: 10.1016/j.foodpol.2010.04.006

Richards, T. J., and Rickard, B. (2020). COVID-19 impact on fruit and vegetable markets. *Can. J. Agric. Econ.* 68, 189–194. doi: 10.1111/cjag.12231

Rohr, J. R., Barrett, C. B., Civitello, D. J., Craft, M. E., Delius, B., DeLeo, G. A., et al. (2019). Emerging human infectious diseases and the links to global food production. *Nat. Sustain.* 2, 445–456. doi: 10.1038/s41893-019-0293-3

Rosa-Schleich, J., Loos, J., Mußhoff, O., and Tscharntke, T. (2019). Ecological-economic trade-offs of diversified farming systems—a review. *Ecol. Econ.* 160, 251–263. doi: 10.1016/j.ecolecon.2019.03.002

Rosset, P. M., Machín Sosa, B., Roque Jaime, A. M., and Ávila Lozano, D. R. (2011). The Campesino-to-Campesino agroecology movement of ANAP in Cuba: social process methodology in the construction of sustainable peasant agriculture and food sovereignty. *J. Peasant Stud.* 38, 161–191. doi: 10.1080/03066150.2010.538584

Rotz, S., and Fraser, E. D. (2015). Resilience and the industrial food system: analyzing the impacts of agricultural industrialization on food system vulnerability. *J. Environ. Stud. Sci.* 5, 459–473. doi: 10.1007/s13412-015-0277-1

Saldaña, J. (2015). *The Coding Manual for Qualitative Researchers*. Newbury Park CA: Sage.

Santos-Díaz, S., Hensiek, S., Owings, T., and Towns, M. H. (2019). Survey of undergraduate students' goals and achievement strategies for laboratory coursework. *J. Chem. Educ.* 96, 850–856. doi: 10.1021/acs.jchemed.8b00984

Saqr, M., and Wasson, B. (2020). COVID-19: lost opportunities and lessons for the future. *Int. J. Health Sci.* 14, 4.

Sayre, N. F., Carlisle, L., Huntsinger, L., Fisher, G., and Shattuck, A. (2012). The role of rangelands in diversified farming systems: innovations, obstacles, and opportunities in the USA. *Ecol. Soc.* 17. doi: 10.5751/ES-04790-170443

Shahed, K. S., Azeem, A., Ali, S. M., and Moktadir, M. A. (2021). A supply chain disruption risk mitigation model to manage COVID-19 pandemic risk. *Environ. Sci. Pollut. Res*. 2021, 1–16. doi: 10.1007/s11356-020-12289-4

Siche, R. (2020). What is the impact of COVID-19 disease on agriculture? *Sci. Agropec.* 11, 3–6. doi: 10.17268/sci.agropecu.2020.01.00

South Dakota Department of Health (2020). *Novel Coronavirus (COVID-19) Updates*. State of South Dakota. Available online at: https://doh.sd.gov/news/coronavirus.aspx (accessed Sep 11, 2020).

State of Montana (2020a). *Directive Requiring Face Coverings in Certain Indoor Spaces and Outdoor Gatherings to Prevent the Spread of COVID-19.* Helena, MT: State of Montana. Available online at: https://dphhs.mt.gov/aboutus/news/2020/directiverequiringfacecoverings (accessed Sep 10, 2020).

State of Montana (2020b). *Executive order Amending Executive Order 2-2020 and Providing that the State of Emergency Runs Concurrent with the President's Emergency Declaration*. Helena, MT: State of Montana.

State of Montana (2020c). *Executive Order Declaring a State of Emergency to Exist within the State of Montana Related to the Communicable Disease COVID-19 Novel Coronavirus.* Helena, MT: State of Montana.

Stephens, E. C., Martin, G., van Wijk, M., Timsina, J., and Snow, V. (2020). Impacts of COVID-19 on agricultural and food systems worldwide and on progress to the sustainable development goals. *Agric. Syst.* 183, 102873. doi: 10.1016/j.agsy.2020.102873

Stoy, P. C., Ahmed, S., Jarchow, M., Rashford, B., Swanson, D., Albeke, S., et al. (2018). Opportunities and Trade-offs among BECCS and the Food, Water, Energy, Biodiversity, and Social Systems Nexus at Regional Scales. *BioScience* 68, 100–111. doi: 10.1093/biosci/bix145

Swinnen, J., and McDermott, J. (2020). COVID-19 and global food security. *EuroChoices* 19, 26–33. doi: 10.1111/1746-692X.12288

Sy, S. (2020, Apr 20). How the COVID-19 pandemic is sending American agriculture into chaos. PBR.

Taqi, H. M., Ahmed, H. N., Paul, S., Garshasbi, M., Ali, S. M., Kabir, G., et al. (2020). Strategies to manage the impacts of the COVID-19 pandemic in the supply chain: implications for improving economic and social sustainability. *Sustainability* 12, 9483. doi: 10.3390/su12229483

Taylor, D. B. (2020, April 7). A Timeline of the Coronavirus Pandemic. *The New York Times*.

Tendall, D., Joerin, J., Kopainsky, B., Edwards, P., Shreck, A., Le, Q. B., et al. (2015). Food system resilience: defining the concept. *Global Food Security* 6, 17–23. doi: 10.1016/j.gfs.2015.08.001

Thornton, P. K., Loboguerrero Rodriguez, A. M., Campbell, B. M., Mercado, L., Shackleton, S., and Kavikumar, K. (2019). *Rural Livelihoods, Food Security and Rural Transformation Under Climate Change*. Rotterdam, Netherlands and Washington DC: Global Commission on Adaptation.

Torales, J., O'Higgins, M., Castaldelli-Maia, J. M., and Ventriglio, A. (2020). The outbreak of COVID-19 coronavirus and its impact on global mental health. *Int. J. Social Psychiatry* 66, 317–320. doi: 10.1177/0020764020915212

Torero, M. (2020). Without food, there can be no exit from the pandemic. *Nature* 580, 588. doi: 10.1038/d41586-020-01181-3

UC Berkley (2020). *What Are Diversified Farming Systems?*. Berkley, CA: UC Berkley. Available online at: https://food.berkeley.edu/about-us/centers/dfs/what-are-diversified-farming-systems/ (accessed Aug 28, 2020).

Upton, G. J. (1992). Fisher's exact test. *J. R. Stat. Soc. Ser. A* 155, 395–402. doi: 10.2307/2982890

US Department of Agriculture (2018). *Wyoming Agricultural Facts*. Washington, DC: USDA. Available online at: https://www.nass.usda.gov/Statistics_by_State/Wyoming/Publications/Brochures/Wyoming%20AG%20Profile%20Brochure.pdf (accessed May, 15 2020).

US Department of Agriculture (2019). *USDA Economic Research Service State Fact Sheets*. Washington, DC: USDA. Available online at: https://www.ers.usda.gov/data-products.aspx (accessed Dec 16, 2019).

US Department of Agriculture (2020). *Farms, Land, and Value of Sales on Certified Organic Farms: 2019.* Washington, DC: Census of Agriculture.

Vaske, J. J., Beaman, J., and Sponarski, C. C. (2017). Rethinking internal consistency in Cronbach's alpha. *Leisure Sci.* 39, 163–173. doi: 10.1080/01490400.2015.1127189

Vaske, J. L. (2019). *Survey Research and Analysis*. Champaign, IL: Sagamore Publishing.

Walker, B., and Salt, D. (2012). *Resilience practice: Building capacity to absorb disturbance and maintain function*. Washington, DC: Island Press.

Warne, T., Ahmed, S., Byker Shanks, C., and Miller, P. (2019). Sustainability dimensions of a North American lentil system in a changing world. *Front. Sustain. Food Syst.* 3, 88. doi: 10.3389/fsufs.2019.00088

Westervelt, E. (2020). *As Food Supply Chain Breaks Down, Farm-To-Door CSAs Take Off*. Washington, DC: NPR. Available online at: https://www.npr.org/2020/05/10/852512047/as-food-supply-chain-breaks-down-farm-to-door-csas-take-off (accessed Oct 13, 2020).

Wolfson, J. A., and Leung, C. W. (2020). Food Insecurity and COVID-19: disparities in early effects for US adults. *Nutrients* 12, 1648. doi: 10.3390/nu12061648

Xiong, J., Lipsitz, O., Nasri, F., Lui, L. M., Gill, H., Phan, L., et al. (2020). Impact of COVID-19 pandemic on mental health in the general population: a systematic review. *J. Affective disorders*. doi: 10.1016/j.jad.2020.08.001

Youngberg, G., and DeMuth, S. P. (2013). Organic agriculture in the United States: A 30-year retrospective. *Renew. Agric. Food Syst.* 28, 294–328. doi: 10.1017/S1742170513000173

Yousafzai, A. K., Rasheed, M. A., and Bhutta, Z. A. (2013). Annual research review: improved nutrition–a pathway to resilience. *J. Child Psychol. Psychiatry* 54, 367–377. doi: 10.1111/jcpp.12019

Zimmerer, K. S., de Haan, S., Jones, A. D., Creed-Kanashiro, H., Tello, M., Carrasco, M., et al. (2019). The biodiversity of food and agriculture (Agrobiodiversity) in the anthropocene: Research advances and conceptual framework. *Anthropocene* 25, 100192. doi: 10.1016/j.ancene.2019.100192

Zurayk, R. (2020). Pandemic and food security. *J. Agric. Food Syst. Commun. Dev.* 9, 1–5. doi: 10.5304/jafscd.2020.093.014

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A Shock to the System: What the COVID-19 Pandemic Reveals About Australia's Food Systems and Their Resilience

Natalie A. Jones[1], Jennifer Bellamy[1], William Bellotti[1], Helen Ross[1], Severine van Bommel[1] and Yiyu Liu[2]*

[1] School of Agriculture and Food Sciences, The University of Queensland, Brisbane, QLD, Australia, [2] South China Normal University, Guangzhou, China

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*Patrick Meyfroidt,
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Bangladesh Agricultural
University, Bangladesh*

***Correspondence:**
*Natalie A. Jones
n.jones3@uq.edu.au*

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Australia has managed well through the COVID-19 pandemic, compared to many other developed nations. Through its first and second waves it was relatively successful in terms of control of outbreaks. Nevertheless, like everywhere, the shock to national systems has been profound, and adjustment remains complex and volatile. Food is a critical human need, and the food industry is recognised as a vital economic sector. We present an examination of some of the adaptive responses of Australia's food systems during the early stages of the COVID-19 pandemic, from January 2020 to October 2020, with a focus on three case studies (seafood exports, consumer behaviour and food sector employment). These case studies provide observations of specific stresses experienced, as well as insights into the adaptation strategies carried out by various actors within the nation's food systems. The shock was experienced differently in different parts of given food systems, and the opportunities for adaptation varied. Some supply chains lost business, others had to adapt to rapidly increased demands, and surges. Our analysis reveals features of Australia's food systems, and their relationships to other systems, that have facilitated resilience, and features that have impeded it. We found that international supply chains are highly vulnerable to global shocks, that insecure employment conditions throughout the food system reduce the resilience of the system overall, and that consumers are not fully confident in supply chains. We observed the importance of agency and adaptive behaviour throughout the food systems as actors worked to build their own resilience, with consequences for other parts of the system. Our findings suggest that food system resilience can be enhanced by ensuring that the goals and priorities of those most vulnerable in society are recognised and addressed within decision making processes throughout the system.

Keywords: COVID-19, resilience, food security, seafood, employment, consumer behaviour, food system

INTRODUCTION

The COVID-19 pandemic, and related policy responses, have revealed many previously under-recognised dependencies and vulnerabilities in Australia's society and economy, as elsewhere (Devereux et al., 2020; Dou et al., 2021; Love et al., 2021). The food and nutrition security of Australians is among the many aspects of society impacted by the sudden shock posed by the COVID-19 pandemic. While in general Australians are perceived to enjoy a high level of food security (Australian Bureau of Agricultural Resource Economics Sciences, 2020), the pandemic and associated government, industry and community responses have revealed both vulnerabilities and adaptations, and signs of resilience, in our food system. We have seen supermarket shelves emptied repeatedly due to panic buying (Sakzewski, 2020), shortage of farm labour (Sullivan, 2020b) due to restrictions on movement, and disruption of international trade (Pollard and McKenna, 2020), for example. These are to some extent associated with food production, but are most evident with food distribution and consumer behaviour. The important connections between production, distribution and consumption can be made transparent by applying a food systems approach (Ingram, 2011), going beyond a focus on agricultural production or agricultural systems, to the issue of food and nutrition security. Adding a resilience approach enlightens a focus on the ability of the food system to cope with a major disturbance and adapt while under duress.

The COVID-19 pandemic provides an extraordinary opportunity to "observe" while experiencing a set of complex adaptive systems – Australia's food systems – at a critical point when a major disturbance occurs. Sudden external shocks to food systems, like the COVID-19 global pandemic, are unanticipated or unforeseen disturbances that are complex and difficult to study and have the potential to trigger large unpredictable and synchronous impacts throughout whole food chains, across multiple sectors and at local and global scales (Béné, 2020; FAO, 2020; Love et al., 2021; White et al., 2021). Prior to COVID-19, these shocks have typically been events with more local impacts on production, due for example to extreme weather events or natural disasters (e.g. floods, droughts, cyclones, extreme fires), pest invasions and noxious diseases, or other environmental disasters (e.g. algal blooms or prolonged over-fishing causing a collapse of fisheries) (Cottrell et al., 2019; Stoll et al., 2021). As food systems become more globalised, increasingly geopolitical events are exposing countries to external shocks (including international trade disputes, global financial system collapses, violent conflicts) (Crona et al., 2015; Gephart et al., 2016), while often highlighting current injustices in food systems such as household food insecurity, and exacerbating existing poverty and inequalities (Sanderson et al., 2021). Complex adaptive systems theory (Gunderson and Holling, 2002; Chapin et al., 2009) explains how a major shock may cause a given system to adapt and reorganise (demonstrating resilience) or transform. It also explains how adaptation promotes learning in order to build robustness against future shocks of the same or different types (Love et al., 2021). This reorganisation process occurs through complex interactions at multiple levels within the system (Béné, 2020).

Emerging literature on food systems and their resilience under COVID-19 has offered international overviews conducted early in the pandemic by Devereux et al. (2020), Love et al. (2021) Bisoffi et al. (2021), and a special issue of Agricultural Systems (Stephens et al., 2020) that incorporates observations and perspectives from many countries in developed and developing regions including India, Nepal, Myanmar, Peru and other parts of Latin America, Africa, China, the Caribbean, USA and Canada. A study by Béné (2020) focused particularly on local food systems in the context of low and middle income countries. Meanwhile, Devereux et al. (2020) concentrated on household resilience in both developed and developing countries. A number of other country-specific studies include Amjath-Babu et al. (2020) on Bangladesh, Farrell et al. (2020) on the Pacific region, Bisoffi et al. (2021) for a global view, Davila et al. (2021) on the Pacific, and Fan et al. (2021) on Asia. These studies explore how and why consumer behaviour changed, and show how the supply chains adapted to the sudden changes in demand in a context of disrupted supply. Our analysis by contrast, focuses on a developed country, Australia, with relatively high food security prior to the pandemic (Snow et al., 2021; Whelan et al., 2021). Nevertheless in Australia there are vulnerabilities within its Indigenous populations and other low income sectors (Bowden, 2020; Foodbank, 2020; Fredericks and Bradfield, 2020a).

Our analysis treats the disruptions and adaptations caused by the pandemic as an opportunity to examine the resilience of Australia's food systems, and in so doing to add to the empirical literature on food systems and resilience (as called for by Choularton et al., 2015; and Tendall et al., 2015) in order to expand understanding of both food system behaviour, and resilience under an unusual type of disturbance (Berkes and Ross, 2016).

Beyond food systems, the pandemic is being seen worldwide as an opportunity for critical reflection on current economic systems and society, with a view to promoting resilience and environmental sustainability over narrowly conceived notions of economic efficiency (IPES-FOOD, 2020). Nevertheless some see the pandemic as a temporary disruption of "business as usual" and expect our economic systems and society to "bounce back" to normal after the pandemic has been resolved (Wells et al., 2020). By combining the food systems framework with a resilience perspective, we identify how actors within Australia's system exhibit agency to respond to shocks, and adapt, and so present insights into how food systems are reorganising.

The following section explains our conceptual framework, combining the concepts of food systems and resilience. This is followed in subsequent sections by our methods, background to the COVID-19 health shock in Australia, the set of case studies, and discussion of key outcomes and implications.

CONCEPTUALISING FOOD SYSTEMS AND RESILIENCE

In order to explore the disruptions imposed by COVID-19 on Australia's food systems, and consequent adaptive behaviour, our research joins two key framings. First, a food systems approach recognises drivers, activities and outcomes across the whole

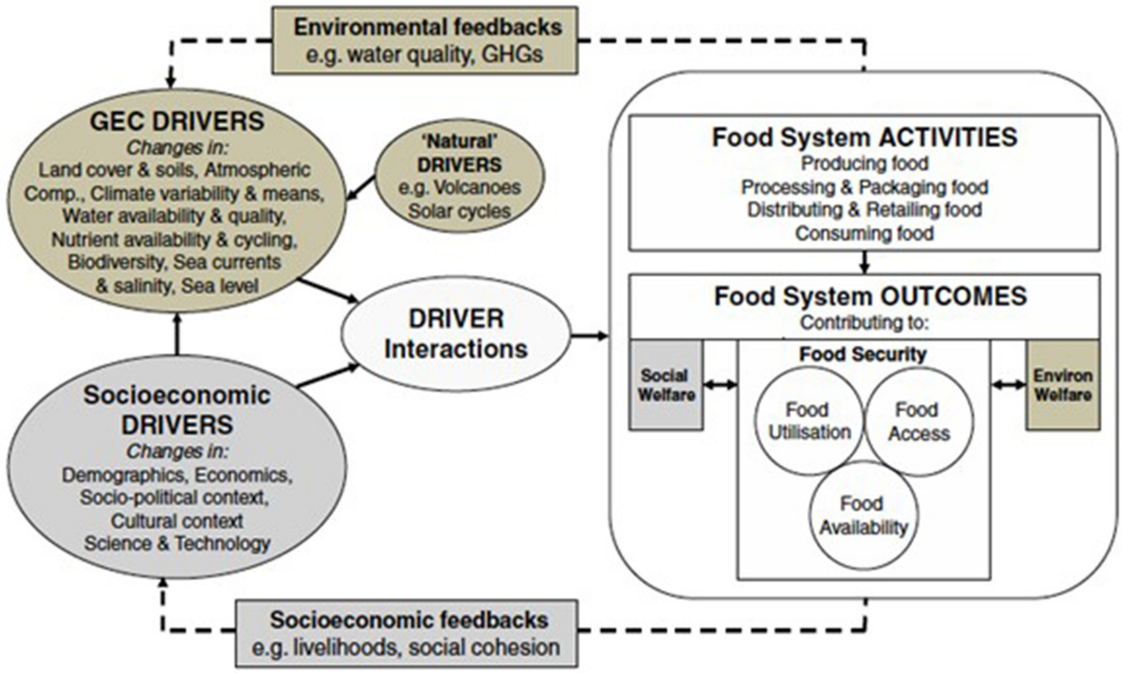

FIGURE 1 | A framework for food systems research emphasising Drivers, Activities, and Outcomes (Ingram, 2011, p. 421).

food system (e.g. from production to consumption), with a focus on the range of emerging interactions, feedbacks and their effects (Tendall et al., 2015; Béné, 2020) rather than on detailed characteristics of separate parts of the system. Second, a resilience framing is added to understand how food systems react and respond to shocks and stresses and to observe the enhanced dynamics of the impacts (Tendall et al., 2015).

Framing Food Systems

Our choice of a food systems framework is that developed by The Global Environmental Change and Food Systems (GECAFS) project (Ingram, 2011). A key innovation of this framework is the explicit distinction and integration of food system activities (what we do: producing, processing, distributing, retailing, and consuming food) with drivers of the food system, which can be biophysical or socioeconomic (Ingram, 2011; HLPE, 2020), and outcomes in terms of what we get: food security (determined by people's access, availability and use of food), environmental welfare and socioeconomic welfare (**Figure 1**). Recently, the FAO's High Level Panel of Experts (HLPE) on food security introduced "agency" as a further dimension of food security (HLPE, 2020). We recognise a fourth outcome category, "public health", to emphasise the importance of food systems in diet and nutrition including the fight against obesity. The HLPE (2020) variant of this framework places emphasis on policy and governance throughout the system.

The integrated GECAFS/HLPE framework thus positions food security as the key outcome of a complex adaptive system (Preiser et al., 2018), with other important outcomes including the jobs, livelihoods and businesses dependent on the food system (social welfare), and the environmental consequences of food systems (environmental welfare). The distinction between activities and outcomes assists in targeting interventions to specific activities in order to realise desired outcomes. The framework accommodates feedbacks, trade-offs, and interactions between activities, outcomes and drivers (Ericksen, 2008). For example, the "green revolution" in agriculture, an intervention designed to improve food security through increased crop production, has been detrimental in terms of impacts on ecosystems and health (John and Babu, 2021).

While the food systems framework emphasises multiple interactions, it requires an emphasis on how those interactions contribute to resilience, an important property of complex adaptive systems. The following section thus introduces a resilience framing to enhance the food system framing.

Framing Resilience

Our resilience framing is based on principles widely recognised in the social-ecological systems literature (Berkes et al., 2003; Béné et al., 2016; Béné, 2020), in which the paradigm of complex adaptive systems is paramount. We also draw on other fields contributing resilience theory relevant to our theme of food systems: people-environment relationships (social-ecological resilience), business and organisational resilience, and personal psychological coping (psycho-social resilience). Each of these fields identifies different features as contributing to resilience, including systemic interactions (Hertz et al., 2020), agility (Linnenluecke, 2017), and self-organisation and agency (Berkes and Ross, 2013).

The concept of resilience focuses on ability to contend with shocks (also referred to as disturbances or perturbations) and stressors. Resilience is seen as an unfolding emergent phenomenon and as a capacity and process as much as an outcome (Southwick et al., 2014).

Helfgott (2018, p.854) defines resilience as "a property of a system that describes the nature of the response of the system to a particular disturbance, of a particular magnitude, from the perspective of a particular observer over a specified timescale". She focuses attention on the resilience "of what" (in our case, outcomes of Australia's food system, i.e., food security), "to what" (in our case this is the pandemic and policy and practice changes involved in contending with it), "for whom" (whose interests are to be considered), and "over what timeframe". In considering "for whom", power relationships, and hence whose interests are considered important within a food system, are made apparent (Herrera, 2017). Resilience is partially subjective: people may be their own best judges about their own resilience and that of the systems they know well (Jones, 2019).

Much literature (such as Béné, 2020) differentiates the concept of "adaptive capacity", the capabilities that will position people or relevant parts of a system to adapt after a shock (such as after the COVID-19 outbreak occurs), from the process of responses and recovery outcomes involved in generating resilience.

Processes of building resilience are non-linear. Resilience status at any particular point in time may differ later, and the system or person is likely to have to address other, subsequent shocks over time. A person (Masten and Obradovic, 2006; Liu et al., 2017) or system (Berkes et al., 2003) may become more resilient after experiencing a few shocks, but then be set back or become more easily disturbed by subsequent shocks. Further, there is a relationship between resilience (which may or may not be desirable, in itself) and transformation to more desirable structures (Elmqvist et al., 2019).

Resilience is a multi-level and cross-scale phenomenon, in which interactions by individuals, households, communities, sectors, regions, nations may affect their own resilience and that at other levels in the same system (Berkes and Ross, 2016). Components in the food systems framework thus need to be considered as interacting at multiple levels whereby the many adaptations of actors to repeated changes in their part of the system affect one another. The relationships between levels within a system are not neat: they can be mutually supportive towards resilience or not (Leite et al., 2019). They can be indirect, for example where a pandemic jumps from the local to the global level, bypassing other levels (Berkes and Ross, 2016). Food supply chains are inherently multi-level phenomena, connecting producers to consumers through multiple activities performed by individuals, households and firms, which have local, regional and global effects.

Diversity within complex adaptive systems, including food systems, is a source of resilience since it offers multiple pathways for adaptation during and after shocks (Lade et al., 2020). While connectivity within a system is highly important (Ungar, 2018), it is necessary to beware of "path dependencies" that create rigidities within a food system which can limit adaptive capacity and hence resilience (Wilson, 2014).

The agency (Davidson, 2010; Berkes and Ross, 2013; Béné et al., 2016) of actors within a system also contributes to resilience, as they work proactively to adapt amidst their changing circumstances. New patterns and solutions to problems emerge as their initiatives interact. This is closely related to self-organisation, often a collaborative process. Supply chain governance (Boström et al., 2015), oriented to goals such as sustainability and potentially resilience, is a prime example of self-organising and agency in food systems. Agency is now recognised as an important dimension of food security, and thus to food system resilience (HLPE, 2020).

Food System Resilience

Advancing on these separate and generic framings of food systems, and of resilience, Tendall et al. (2015) have developed a conceptual framework specifically for food system resilience. Like us, they view food systems as a type of social-ecological system, involving the range of activities and outcomes identified in the food system framework reviewed above. They emphasise the need to move beyond particular components, or particular processes within food systems, to understand the complex cross-level interactions involved in any social-ecological system. Accordingly, they define food system resilience as "capacity over time of a food system and its units at multiple levels, to provide sufficient, appropriate and accessible food to all, in the face of various and even unforeseen disturbances" (p. 19). They emphasise behaviour over time, at multiple levels in a system, so that initial reactive action (to absorb, react and restore) translates towards preventive action, focused on learning and building robustness. Love et al. (2021, p. 2) elaborate on this idea to argue that this building of robustness should be towards generalised, rather than specified, resilience, to cater for multiple and cumulative other stressors such as climate change, natural disasters, political and economic instability, resource management issues, and shortcomings in governance. Where considerable literature in the field of social-ecological systems refers generically to "adaptive capacity", Tendall et al. differentiate resilience as involving different capacities over time after a disturbance, from initial robustness to withstand the stress, to capacities to absorb - in which redundancy is a useful characteristic – to resourcefulness and continuing adaptability. Flexibility supports the speed at which losses in food security can be overcome. Interventions in a food system under duress may have beneficial effects on system adjustment.

Tendall et al. (2015) identify three particular "entry points" for a whole system resilience-building process. National or regional food systems, involving multiple supply chains, are important to policy makers and governments, attentive to food security for their populations. Individual food supply chains, at any level from local to international (cf Love et al., 2021 on seafood) interest specific value chain actors, while individual perspectives include smallholder livelihoods, household food security (cf. Devereux et al., 2020), and the health of consumers.

Devereux et al. (2020) argue that the issues presented by COVID-19 are best addressed by joining several frameworks.

They combine the food systems frameworks we use (especially the latest elaboration, HLPE, 2020) with the FAO's "four pillars" approach to food security (availability, access, utilisation and stability), and a social justice perspective on "entitlement" based on Sen, which resonates with Helfgott's (2018) later focus on "for whom".

METHODS

This qualitative analysis has been conducted by a group of university colleagues engaged in the study of food systems, resilience, and people-food-environment relationships. We are interdisciplinary social and environmental scientists, some also having qualifications in agricultural sciences. The first few months of the COVID-19 pandemic, as experienced in Australia, provided an opportunity to observe the immediate impacts of the pandemic on the food system through media and other sources that were readily available online. Aligning with a participant observation approach, the research team was able to observe the pandemic while they participated in daily life (Denscombe, 2007) as the situation unfolded. As participant observers within a pandemic situation, our team observed food system disturbances that happened *in situ* (such as changes in the access, use and availability of certain food items). We thus identified key disturbances that took place within Australia's food systems that emerged through our lived experience of the pandemic by directly observing daily life.

These observations were complemented with an online ethnographic approach. Instead of a systematic literature review, we used an online ethnographic method (Underberg and Zorn, 2014; Varis, 2016) to treat online resources as information resources, or "vessels" (Coffey, 2014). These resources were used to analyse how the pandemic was affecting food system activities and outcomes that emerged through our participant observations as "promising lines of inquiry". We acquired data from diverse sources from across the food chain as impacts of the COVID-19 pandemic unfolded. These included news media reports, the grey literature (e.g. technical reports, quality newsletters, working papers, policy statements and other documents and databases published by governments (e.g. the Australian Bureau of Agricultural and Resource Economics and Sciences, ABARES), research organisations (academic reports, newsletters and magazines, including the Fish R&D Corporation) as well as other new academic literature. In terms of news media, we relied on reputable journalism sources that covered the COVID-19 pandemic on a national rather than a local scale, namely the Australian Broadcasting Corporation (online, radio and TV), *The Guardian* and *The Conversation*. This was to ensure that the issues we focused on were relevant to the broader Australian food system context, rather than being localised.

A real-time perspective was taken to build the process of the unfolding impact of COVID-19 on the Australian food system, in which we employed a multi-step analysis of important events. In this multi-step analysis we identified events, co-constructed emerging case studies, interpreted themes in these case studies and finally analysed these themes in relation to our original framework and research question. First, beginning in March 2020, information was collected daily from different sources (such as newspapers and social media) and notes were taken with regard to events that we thought would be able to give us insight with regard to the impact of COVID-19 on Australia's food systems. Events that were discussed as a team included – but were not limited to – panic buying, shortages of certain items in supermarkets, supply problems, agricultural produce going to waste due to labour shortages or transport issues, citizens buying seeds and chickens, and export issues. Second, these notes were discussed weekly and patterns started to emerge over time. We noticed patterns around export of fresh produce, most noticeably in the seafood sector, consumer behaviour and farm employment. Third, we developed each of these themes into mini-case studies that illustrated the patterns that we were observing and which represented different parts of the food systems analytical framework. We synthesised the diverse acquired data and information to address the following questions:

1. How and why has this part of the Australian food system and its related food chain been impacted by the COVID-19 shock, both in the short and longer term?
2. What types of response have occurred in reaction to COVID-19 impacts?
3. What actions if any are being taken to restore Australia's food system and food chain functions?

Fourth, we then reflected on the implications of these results in terms of what this could tell us about Australia's food system and adaptations, and to generate insights into ways of improving it for future resilience and equity. We reflected on how specific disruptions, impacts and responses to the pandemic across food system supply chains are altering food system dynamics and resilience.

A brief description of how the pandemic played out within Australia follows, as background to the case studies.

Background: Australia's Response to COVID-19

For at least the first year of the pandemic, Australia's response to the COVID-19 health crisis was considered to be among the most successful in the world (Duckett and Stobart, 2020a; Mercer, 2020; Patrick, 2020), compared to international standards. In a population of just over 25 million (Australian Bureau of Statistics, 2021), there were 27,590 confirmed cases and 907 deaths (Australian Government Department of Health, 2021). Following Duckett and Stobart (2020b,c) we provide a summary of events for the period January to early November 2020.

The first cases of COVID-19 in Australia were reported in late January 2020 among travellers arriving from China, prompting travel restrictions on those allowed to enter Australia (**Figure 2**). As the virus spread rapidly in other parts of the world, community transmission was first detected in early March. This led consumers to panic buy toilet paper and other groceries (Davey, 2020; Duckett and Stobart, 2020c; Smith and Klemm, 2020), as the population feared Australia might be facing a similar crisis to that experienced in other parts of the world.

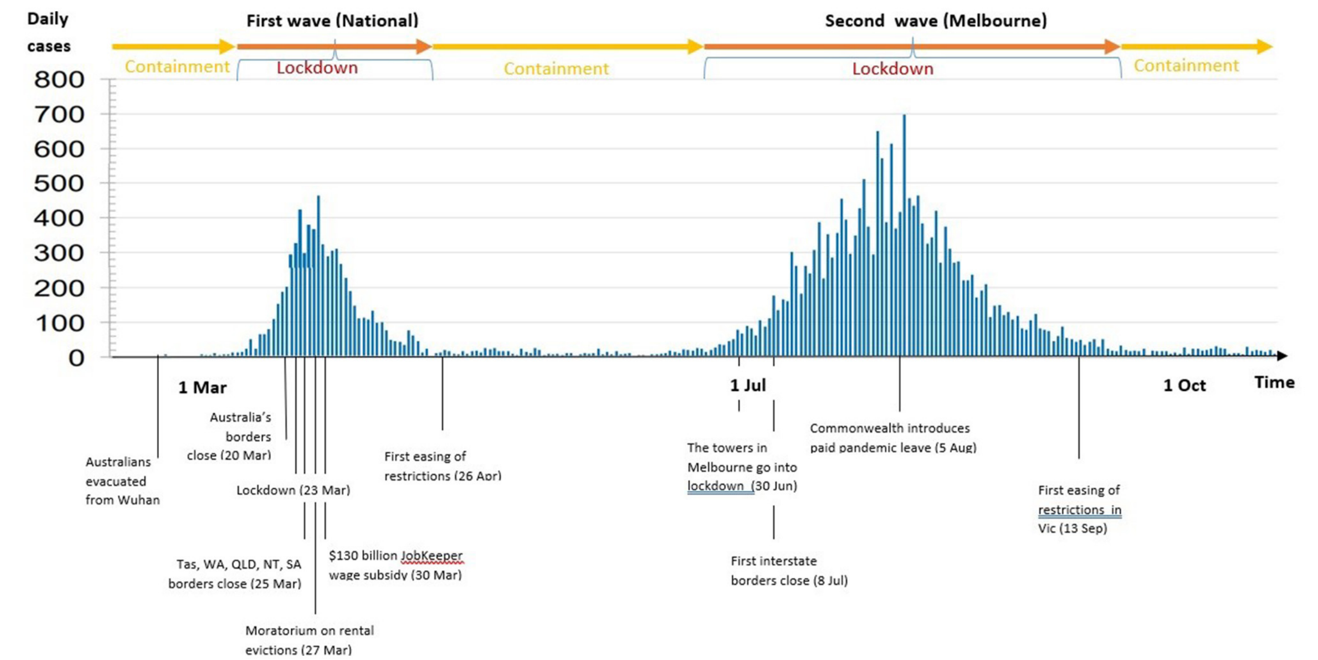

FIGURE 2 | Timeline of COVID-19 cases reported in Australia (Infogram, 2021). Adapted from Duckett and Stobart (2020c).

There were calls to introduce strict restrictions early to minimise harm later (Duckett and Stobart, 2020c). A set of measures restricting movement of people was introduced by the Australian government from mid-March onwards and two weeks later, the country moved into a total lockdown (Biddle et al., 2020b), closing its border to international travellers on 20 March 2020. Social gatherings were limited to two people, social distancing was introduced, non-essential travel was prohibited, people were urged to work from home if possible and schools were closed. Most states closed their interstate borders and lockdown restrictions were enforced with heavy fines. The Australian government introduced two large economic support packages: a doubling of the "JobSeeker" unemployment benefit payment (22nd of March, 2020) and a "JobKeeper" wage subsidy program to keep people connected to their employer while unable to work (30th of March, 2020). Free childcare was provided to support parents and centres, and the Australian government imposed a moratorium on rental evictions for tenants experiencing hardship (Duckett and Stobart, 2020c; Wahlquist, 2020).

By the beginning of May 2020, there were fewer than 20 new COVID-19 cases per day and in some states the rate had dropped to zero for several days (Ting and Palmer, 2020). When Australia had "flattened the curve" successfully, the federal government revealed a roadmap to lift COVID-19 restrictions, shifting the political discourse from "prevention of COVID-19 health risks" to "reopening of the economy" (Duckett and Stobart, 2020b).

A second wave of COVID-19 cases began in Melbourne in late June 2020, characterised by community transmission (Duckett and Stobart, 2020b). Contact tracing was not working as expected (Taylor, 2020), and people without entitlement to sick leave in lower paid, insecure jobs were unable to stay at home when unwell, thereby spreading the virus through workplaces (Duckett and Stobart, 2020b; Seneviratne, 2020). In the aged care sector, some carers worked across multiple nursing homes, exposing a highly vulnerable group of people to the virus (Judd and Taylor, 2020). In late July, paid pandemic leave was introduced but this was too late to stop the spread of the virus (Karp, 2020). By the beginning of August 2020, around 900 people in nursing homes had been infected with the virus, with a high mortality rate. The government of Victoria announced a six-week full lockdown for Melbourne and a partial lockdown for the rest of the state (Duckett and Stobart, 2020b). The restrictions were enforced by police and the army, including home checks. Fines for breaking the rules were very high (Cave, 2020). The other Australian states watched the crisis in Victoria unfold and kept their borders closed. This had the intended result and infection rates declined. By mid October 2020 the number of cases had dropped to single digit numbers and Melbourne had successfully controlled the second wave (Mercer, 2020).

The factors that contributed to Australia's successful control of COVID-19 under its first two waves are complex, but the lockdown, the strict border restrictions and public compliance with spatial distancing rules were important (Duckett and Stobart, 2020a). These authors also highlight how cross-sectoral and multi-level coordination also assisted, with a dedicated "National Cabinet" established comprising key federal, state and territory ministers, who worked closely with industry and the trade union movement. However, after JobKeeper, JobSeeker and the rental eviction moratorium expired near the end of March 2021, new hardships emerged for the small businesses, many of them food businesses, which were forced to close for varying periods, some permanently. Unifying public discourse, such as "we are all in it together", obscured the structural and systemic inequities differentially affecting Australian society

(Duckett, 2020). The end of the moratorium on rental evictions, for example, threw new people into financial and housing difficulty, while sporadic lockdown measures continued to have a significant economic and psychological impact (Foster and Hickey, 2020; Layard et al., 2020). As the pandemic continues to unfold social inequities persist.

RESULTS

In each case study below we provide a narrative about the impacts of the pandemic on supply chains and other components of the food systems framework and describe adaptation responses of supply chain actors, government and other actors. We present three contrasting situations: seafood exports (an activity involving entire supply chains), consumer behaviour (an activity at the "downstream" end of supply chains), and food sector employment (both a facet of activities throughout supply chains, and a social welfare outcome that interacts with the three aspects of food security).

Case Study 1: Seafood Exports

Globally seafood is well recognised as a key component of a safe, nutritious, and affordable diet, and an important source of food security and employment (Crona et al., 2015; Tlusty et al., 2019; Havice et al., 2020; HLPE, 2020). Extending beyond the practices of fishers and the narrow scope of economic production factors, "seafood systems" are highly diverse and complex food systems encompassing many different processes, activities, value chains, and complex interactions and outcomes (Tendall et al., 2015; Béné et al., 2019), as illustrated in **Figure 1**. The multiple drivers of change and cross-level and cross-scale interactions, trade-offs, and feedbacks fundamental to seafood systems are commonly country specific (Tendall et al., 2015; Béné et al., 2019; Bennett et al., 2021).

In Australia, measures undertaken to address the flow-on impacts of the COVID-19 shock have affected all aspects of seafood systems, exposing pre-existing vulnerabilities and risks, in ways that no other previous shocks have done. Australia is a developed country and an isolated continent surrounded by over 10 million sq. km of ocean with abundant fishery resources (Patterson et al., 2020). This case study examines the impact of COVID-19 on Australia's seafood exports from January 2020 until June 2021, and the implications for food security in a developed country context at a time of an unanticipated shock.

With a growing demand for seafood globally, seafood accounts for 38% of total fish production entering international trade (FAO, 2020). As a natural resource, seafood is recognised as enhancing ocean health and economic production globally, but "fish as food" and its role and contribution to both food security and nutrition is largely neglected (Béné et al., 2015; Tlusty et al., 2019; Bennett et al., 2021).

Since the 1990s, increased urbanisation and rising living standards in Asia have created a growing demand for premium seafood products (such as lobster, abalone and salmon), to service high-end restaurants, cafes, and other food-service outlets. Australian seafood export businesses have exploited this opportunity, with the support of both state and federal governments. Pre-COVID-19, seafood exports to growing Asian markets accounted for half of Australia's total annual fisheries and aquaculture production by value (Mobsby et al., 2020). The highest valued export product is live wild-caught rock lobster, with China the dominant export market. The perishable nature of seafood requires specialised capital-intensive cold storage, processing, packaging, and distribution strategies and rapid transportation by air freight to maintain freshness and extend seafood life (Stevens et al., 2020). The premium price received for Australian live rock lobster trade to China relates to: a high quality product with high environmental certifications and traceability credentials; proximity to seafood markets in Asia; and the capacity to rapidly transport live highly perishable seafood safely and nutritiously (Mobsby et al., 2020; Stevens et al., 2020).

In late January 2020, one of the first impacts in Australia of COVID-19 was this lucrative seafood export trade to Asia. At the peak demand period of Chinese New Year, many Asian seafood markets and retail outlets were closed due to restrictions imposed by their governments on human movements and other interactions to prevent the spread of COVID-19 (Cartizone, 2020; Hendry, 2020; Major, 2020; Meachim, 2020; Pollard and McKenna, 2020). Demand in China for live wild-caught rock lobster plummeted overnight (Greenville et al., 2020; Hynninen, 2020; Liveris, 2020) with immediate feedback effects reverberating across Australia's seafood export system (Cartizone, 2020; Mobsby et al., 2020; Plaganyi et al., 2020; Pollard and McKenna, 2020). Amidst orders being cancelled and fears that oversupply would lower prices, the substantial Western Australian Geraldton Fisherman's Cooperative (WAGFC) immediately called a halt on live rock lobster deliveries to its storage facilities in Geraldton and Perth, by imposing a landing price of zero dollars per kilogram to send a signal to fishers that all trading of rock lobsters must stop (Liveris, 2020; Meachim, 2020). Live premium rock lobster now sold direct from fishers on social media or off the "back of boats" for half the price received the previous week for the same product (Meachim, 2020; Murphy, 2020). The WAGFC was left holding valuable and perishable stocks in overloaded storage facilities at considerable expense, with no immediate market, at what would normally be a peak time for this profitable trade (Liveris, 2020; Major, 2020; Meachim, 2020; Norgrady, 2020b; Pollard and McKenna, 2020).

In mid-March 2020, a second major disruption emerged due to the closure of Australia's national borders by federal and state governments to stem the spread of COVID-19 into Australia. Initially stopping only international passenger flights into and out of Australia (but not freight flights), the closures inadvertently also stopped Australia's live seafood export trade, which used international passenger flights (Bagshaw, 2020; Hayes and Daly, 2020; Hendry, 2020; Mobsby et al., 2020). State government lockdown measures closed internal borders creating bottlenecks for the movement of food products within Australia, as well as havoc for returning overseas boat crews trying to re-connect with fishing fleets around Australia (Cartizone, 2020; Collis, 2020). The situation was compounded by a dramatic drop in the number of international tourists visiting Australia, adversely affecting domestic wholesale and retail demand (such as restaurants, cafes, hotels, caterers) servicing the tourist industry (FRDC, 2020; Hayes and Daly, 2020; Meachim, 2020).

Initial COVID-19 impacts in Australia were thus sudden, unanticipated, and severe, varying considerably across different sectors of the seafood export systems. The Western Australian live rock lobster export industry, valued at about $AUD750 million annually, and relying almost exclusively (94%) on Chinese markets was particularly exposed (Mobsby et al., 2020; Stevens et al., 2020). By mid-2020, the annual production value for live rock lobster fell by 25% to $AUD544 million (Mobsby et al., 2021). Fisheries suffered a reduction in activity, while live seafood exports declined in both price and volume, although not all sectors and products were affected equally. Sectors adversely impacted were those exporting live product, supplying dine-in food service, reliant on international air freight, or affected by border closures, lockdowns, and other mobility restrictions (Greenville et al., 2020; Ogier et al., 2021). While the value of live rock lobster and abalone exports declined by 45%, other seafood sectors including businesses supplying domestic retail and take-away food service markets (which normally compete with international imports) experienced a rise in demand and price (Mobsby et al., 2021; Ogier et al., 2021).

Efforts towards adaptation were diverse, and involved significant self-organising among actors at multiple levels. A critical feature of Australia's initial response to the COVID-19 pandemic was the federal and state governments working together to overcome transport and logistical challenges. A key mechanism was an emergency airfreight subsidy scheme (Greenville et al., 2020; Sullivan, 2020c). Through the scheme, 200 charter flights of live lobster and abalone were exported to key markets in China, Japan, Hong Kong, Singapore and the UAE (FRDC, 2020; Stevens et al., 2020). These flights involved freight sharing with other agricultural and mining industries or collaboration with carriers bringing cargo into Australia (such as medical supplies, respirators and other medical equipment to Australian authorities).

With contracts cancelled and a lack of export demand, many fishers were forced to dock their boats, shut down their businesses, and lay off staff (Hayes and Daly, 2020; Major, 2020; McKillop, 2020; Pollard and McKenna, 2020; Bagshaw, 2021). To stay in business, others adapted by exploring new export markets, diversifying their products, and attempting to pivot to the domestic market with new or alternative selling platforms, such as on-line consumer sales, internet selling, and home deliveries. Other examples include:

- When social distancing halved auction capacity, the Sydney Fish Market overhauled its wholesale auction system to provide remote on-line trading, proving a boon for exporters shifting to domestic sales by rapidly and efficiently connecting diversely located exporters to domestic markets (Boyer, 2020; Collis, 2020; Hynninen, 2020).
- A Torres Strait Island live rock lobster exporter to Asia shifted focus by repurposing its processing facility to export individually packed lobster tails to a new supermarket chain in Hong Kong (Plaganyi et al., 2020).
- Fresh packaged high-grade salmon and trout from Tasmania (usually destined for export to Japan), is now sold in large supermarket chains across Australia at much reduced prices (Nichols, 2020; Norgrady, 2020b).
- Mooloolaba Queensland seafood exporters adjusted their marketing strategies to more direct producer to consumer connections by setting up pop-up shop fronts or domestic retail outlets selling direct to local consumers (FRDC, 2020; Norgrady, 2020a).

Overall, slow demand in China, reduced air cargo capacity, and border closures led to a $AUD200 million drop in seafood export earnings in 2019-2020 (Mobsby et al., 2020). The immediate outcomes included: a reduction in fishing activity; loss of income in seafood export businesses; loss of employment throughout the seafood export chain; logistical transport and distributional bottlenecks; and ripple effects on supporting service industries throughout the economy (Pollard and McKenna, 2020; Prendergast, 2020). These impacts also affected other small businesses, rippling throughout the local community and all segments of the supply chain (Plaganyi et al., 2020).

While existing connections were disrupted, new connections also emerged to cope with changing demand and logistical issues. Digital technologies, for example, were key to establishing new marketing platforms providing rapid and efficient communication tools for managing the logistics of cancelled orders and border closures, connecting to new on-line wholesale auctions to ensure supply continuity, as well as facilitating the establishment of new markets and products.

COVID-19 severely impacted Australia's seafood export system by fuelling an economic slowdown of the national economy, disrupting food value chains and exposing underlying systemic vulnerabilities and risks. Paradoxically, it has also revealed emergent opportunities for adaptation and change (cf Stoll et al., 2021 for the United States of America and Canada). Three challenges for the future of seafood exports remain.

First is changing consumer preferences. Australia has ample supplies of safe healthy seafood (Australian Bureau of Agricultural Resource Economics Sciences, 2020) but despite producing substantially more seafood annually than Australians consume, over 65% of the seafood Australians consume domestically is imported from Asia, largely as low-valued processed products (Stevens et al., 2020). Over the last twenty years Australia has lost much of its seafood processing capacity because it does not compete well with the lower-cost offshore processing capacity of Asia (FRDC, 2020). Significant processing challenges emerged for the WAGFC in attempting to pivot away from the Chinese preferred live lobster export product to the Australian domestic market's preferred fresh cooked lobsters (Bagshaw, 2021). This has created a processing and marketing issue for the WAGFC as it does not currently have the right processing infrastructure to make the change (Seafood Industry Australia, 2021).

Second is the "creation of a gilded trap". Over the last 30 years, globally there has been a dominant focus on economic efficiency and high connectivity for international markets via private sector corporate-dominated supply chains (Havice et al., 2020). This has led to intensification and simplification of seafood systems, often at the expense of seafood system diversity (Österblom et al., 2015; Folke et al., 2016). These industrial seafood systems are organised around continuous flow of product through global supply chains (Havice et al., 2020). They are highly interconnected and characterised by weakened internal feedbacks that may mask the signals of loss of resilience and make them vulnerable in the face of sudden global disruptions like COVID-19 (Nyström et al., 2019; Clapp and Moseley, 2020). The WAGFC, Australia's largest rock lobster processor, is an example of a highly successful large vertically integrated and connected commercial corporation owned by private fishers and tied to international markets. With 230 vessels harvesting seafood along 1,000 km of the Western Australian coastline, it operates as a sustainable quota-managed fishery connecting the entire supply chain (from fishing to international markets) and across multiple levels (from local to global) (Geraldton Fishermen's Co-Operative, 2021). With parallels to the iconic USA and Canada case of the Gulf of Maine lobster fishery (see Steneck et al., 2011; Folke et al., 2016), WAGFC's long term success in maximising abundance and economic value of the wild rock lobster has created a "gilded trap" highly vulnerable to disturbances. Lacking diversity of product as well as markets able to pay such high prices for rock lobster as China, COVID-19 has revealed the fragility of WAGFC's high economic value rock lobster export trade.

The third challenge is political tension with China, which impact supply chain connectivity. In October 2020, deterioration in some highly politicised and sensitive bilateral agricultural trade relationships between Australia and China refuelled great uncertainty for Australian seafood exporters (Bonyhady et al., 2020; Dalzell et al., 2020; Srinivasan, 2020). Rock lobster exports to China in November 2020 fell by 80% compared with November 2019 (Mobsby et al., 2021). Although no official ban on seafood actually exists at the time of writing, there have been growing tensions over the delay in the import process for seafood into China. Consignments of rock lobsters were unexpectedly subjected to significant delays at several Chinese ports with the usual rate of inspection for import testing significantly increased. Twenty tonnes of live lobster worth $AUD20 million exported from Victoria, Australia, were destroyed on the tarmac in Shanghai due to unprecedented delays in custom clearances (Bagshaw and Gray, 2020; Bagshaw, 2021). More recently rock lobster exports to Hong Kong have risen sharply from negligible levels in October 2020 to 300 tonnes in March 2021 (Western Rock Lobster, 2021). It is highly likely that this rise is due to what is known as the "grey trade", where a Hong Kong middleman buys from Australia and then reroutes exports into China (Verrender, 2021; Western Rock Lobster, 2021). Although there have been some positive signs of recovery, "unofficial sanctions" by China on Australian live lobster export trade are continuing to accentuate supply chain disruptions that already existed prior to the COVID-19 shock, impacting livelihoods of those involved in the seafood industry.

Case Study 2: Consumer Behaviour

Consuming food represents one of four broad categories of food system activities. Key actors include consumers themselves, as well as the supply chains bringing food to market, and various organisations that influence food consuming behaviour such as market regulators, advertising, and consumer advocacy groups. COVID-19 has disrupted normal consumer behaviour in many ways (cf Dou et al., 2021). A few examples are described below.

In Australia, panic buying resulted in localised, short-term scarcity in certain foodstuffs and other groceries (Sakzewski, 2020). The first signs of panic buying in Australian supermarkets were reported in early March 2020, weeks before the country went into lockdown. There were temporary shortages of staple foods such as rice and potatoes in many stores, while basic necessities such as toilet paper sold out (Sakzewski, 2020). The government and the food retail sector responded quickly with a set of measures including (Hobday et al., 2020):

- Public reassurance that the food supply was secure and pleading with consumers not to panic.
- Local government easing of transport restrictions to facilitate 24-hour refurbishment of retail supply lines.
- Retailers imposing quotas on some high-demand products, extending opening hours, employing more casual staff and providing exclusive opening hours for vulnerable members of society.

At the height of panic-buying in 2020, the CEO of a large food retailer stated that consumer demand was equivalent to that of around 46 million people whereas Australia's population was under 26 million. Normal supply chains required modification to keep up with demand. Despite experience over the following year or more that food would always be available in the shops, and politicians' and stores' exhortations, panic buying surged at the start of each new lockdown, leading to considerable food waste (Elmas, 2021).

Loss of employment and income has driven vulnerable sectors of the population to rely on emergency food aid in record numbers (Warriner, 2020). Local emergency food aid organisations (e.g. FoodBank, SecondBite) reported a sharp increase in demand for emergency food aid, up from 15% of Australians in 2019, to 31% in 2020 (Foodbank, 2020). While the number of food insecure increased in those categories already insecure before the pandemic, a striking feature in 2020 was that COVID-19 resulted in many people becoming food insecure for the first time. Two groups were particularly impacted, the casual workforce and international students. Ironically, many of those newly food insecure were previously employed in the hospitality and food sector. The emergency food security of those people is met largely through services provided by voluntary organisations. Fredericks and Bradfield (2021) noted new levels of food insecurity among Indigenous students, with school students and their families deprived of food supports provided in some schools, and university students living away from their home communities unable to access family and community assistance for food. As the third wave rose rapidly from mid-2021, there were new reports of surges in demand at food banks.

While information is limited, there are some variants and complexities in food access among remote Indigenous communities. Fredericks and Bradfield (2021) note that movement restrictions have limited Indigenous people's opportunities to shop outside their communities, and purchase limits designed to limit panic buying have impeded Indigenous households who typically travel long distances, infrequently, to buy in bulk. Meanwhile, however, being confined to community areas has enabled more access to bush foods, at least for some; these are a common and valued supplement to bought foods (Fredericks and Bradfield, 2021).

While Australians in general enjoy a high level of food security, even before COVID-19 around 4 to 13% of the general population were estimated to be food insecure. For Indigenous Australians this increases to 22 to 32% of the Indigenous population, depending on location (Bowden, 2020). Fredericks and Bradfield (2020b) report that in Queensland, a state with a large Indigenous population, a third of Indigenous people had faced food insecurity at some time and 20% in the year prior to COVID-19. Follent et al. (2021) note that COVID-19 increased food prices in rural and remote areas of New South Wales, forcing purchase of cheaper and less nutritious foods. Other vulnerable groups include low-income earners, culturally and linguistically diverse groups, single-parents, the elderly, the homeless, and other socially and geographically isolated groups. This list highlights the primary causes of food insecurity in Australia as material hardship and inadequate financial resources, rather than lack of food production or food availability. For Indigenous people, especially those in remote areas, financial hardship can be compounded by additional factors including supply chain logistics leading to limited choices and high costs relative to the cities, and food storage issues which limit buying in bulk (Fredericks and Bradfield, 2021). Interestingly, many Indigenous communities closed their own borders at the start of the pandemic. Food supply issues that needed to be addressed in the first weeks of the pandemic. These were partly solved through self-organising, and through collaborations among a number of major food supply firms (Fredericks and Bradfield, 2021).

Restrictions on social gatherings and self-isolation requirements led to changes in food purchasing (Dawes, 2020), food preparation, and diets in the wider Australian population also (Sullivan, 2020a). These include increased online grocery shopping, home cooking, home gardening, new local food supply chains, increased home delivery of pre-cooked meals, and greater consumption of discretionary (junk) foods and alcohol (Biddle et al., 2020a; Davis and McCarthy, 2020; Dawes, 2020; Gaynor, 2020; Sullivan, 2020a; Zhou, 2020). While the long-term implications of COVID-19 inspired changes in food consumption behaviour remain unknown, what is clear is that these changes have been diverse and profound for many people.

Case Study 3: Food Sector Employment

The food sector is a significant source of employment in the Australian economy with jobs provided in a number of industries including agriculture, food processing, distribution and retail, as well as support industries such as agricultural services, food advertising, education and research. In this case study we focus on changes in employment observed at two ends of food system activities, agricultural and seafood production and the retail food service sector including restaurants and fast food outlets or "Quick Service Retail" (QSR).

As a developed economy with a high standard of living, Australia has high labour costs relative to many other countries. Driving down labour costs is a key management objective for many business owners, and has long-standing political support. This general background is magnified for food export businesses forced to compete on price in international markets. Inevitably, labour productivity innovations forged in export-orientated businesses flow into domestic-oriented businesses. A key labour cost-saving innovation has been casualisation of the workforce with consequent erosion of worker conditions such as pay rates and superannuation, and an increase in part-time and seasonal employment. In seasonal employment, such as planting and harvesting of horticultural crops, industry has become highly dependent on international backpackers and Pacific Island migrant workers, both relying on special category employment visas (Howe et al., 2017). Similarly, at the other end of the food supply chain, involving different types of food system activities, restaurants and QSR have also casualised their workforce to reduce labour costs and remain profitable in a highly competitive business environment. In Australian cities, international students supplement their income with casual employment, often in food sector businesses. While their student visas allow part-time employment, they remain vulnerable to sudden changes in economic conditions (Bogle, 2020), as highlighted by COVID-19.

One of the first government reactions to the global pandemic was to restrict movement of people across domestic and international borders. This policy immediately impacted the horticulture sector, jeopardising the supply of workers for time-critical work such as harvesting perishable crops. Not only were new workers restricted from arriving in Australia, international workers already in Australia were restricted from returning home. Horticultural producers warned of and later suffered crops being left unharvested (Bolton, 2020), and pleaded for policy exemptions to maintain labour in what was decreed an essential service. Public health standards for managing COVID-19 meant existing worker accommodation and conditions were in many cases no longer adequate. Furthermore, non-resident workers unable to reach employment locations were ineligible for government unemployment programs and other welfare programs, creating a high level of insecurity. Similarly, restaurant and QSR casual workers were made redundant as governments mandated social distancing and business closures. Overnight, many international students lost their casual work income and their non-residency status meant they were ineligible for government unemployment benefits and welfare programs. Emergency food organisations reported a sharp surge in demand for food aid from international students previously not experienced (Sallim, 2020).

The impacts described above continue to evolve, as farmers experience on-farm labour shortages (Sullivan, 2020d). As state (internal) borders continue to restrict transport of goods and services as well as people, farm businesses located along state borders continue to be severely disrupted, affecting crop management and livestock husbandry. In the early stages of the pandemic, abattoirs emerged as coronavirus hotspots, highlighting poor working conditions including a workforce employed in shifts on a casual basis. Many businesses have survived on emergency government support programs (wage subsidies, debt moratoriums, rent holidays, etc.) though many express fear now that those subsidies have ceased, and the country continues to experience outbreaks. On a more optimistic note, new businesses and employment have emerged out of the pandemic, including direct marketing of farm produce to consumers and home delivery of ready-to-eat meals from restaurant to consumer.

While restrictions on the movement of people have proved effective in reducing the spread of COVID-19, it continues to come at a cost to food sector employment. From a food systems perspective, the dominant impact to date has not been a direct deterioration in food security, but rather an impact on employment, livelihoods and businesses. In turn, loss of pre-COVID-19 livelihoods will impact on food security by reducing purchasing capacity. As discussed in case study 2, those workers in casual employment have been impacted more severely than workers with more secure employment. Especially vulnerable are non-resident, casual workers who not only lose employment but also are ineligible for government welfare. Under current Australian policy, these include international students.

Casualisation of the workforce has contributed to cheap food for consumers. But are consumers aware of their role in exploiting workers, and what price might they be willing to pay for a fairer distribution of their food purchasing dollar? Food businesses orientated to export markets are constrained by the need to be competitive on international markets. In contrast, domestic food producers and processors are driven by a powerful food retail duopoly to drive costs out of the supply chain. Casualisation of the food sector workforce has been the historical strategy of choice by employers to reduce costs in Australia, but the COVID-19 pandemic has exposed vulnerabilities associated with this strategy. If a majority of Australians desire fairer food systems, one where workers receive adequate working conditions and remuneration, the trade-off might be slightly higher food prices. Potential benefits include not only improved working conditions, but a more resilient food system.

DISCUSSION

Impacts of COVID-19 and Adaptations in Australia's Food Systems

We analysed three case studies through the combined lenses of food systems and resilience to understand the breadth and complexity of impacts of the COVID-19 pandemic on Australian food systems, and system responses. Measures to protect society from the pandemic disturbed parts of these systems and stimulated diverse adaptations, leading to "ripple effects" (Béné, 2020) as actors throughout the system and subsystems changed practices (cf Devereux et al., 2020; Love et al., 2021; Snow et al., 2021) in order to pursue their own resilience – rather than necessarily system resilience - in changed circumstances. Our case studies reveal points of vulnerability within Australia's food systems, as well as examples of adaptation which enable these systems to self-organise in response to the viral shock (cf Devereux et al., 2020).

Vulnerability of Supply Chains to International Export Markets

The seafood export case study reveals the vulnerability of an industry heavily reliant on a single dominant export market (cf Love et al., 2021), a structure which in complex adaptive systems terms stands out as lacking diversity. When COVID-19 struck, producers were largely dependent upon a specialist, lucrative, international food market and hence were vulnerable to changes in the global food system and markets. While producers benefitted from increased profit margins through participating in export markets, the trade-off is that they have a relatively low level of adaptive capacity with respect to changes (political, economic or otherwise) within these global trade systems as they have minimal ability to influence markets, laws and consumer behaviour in an international context. The resilience of the Australian food system is thus strongly linked to interactions with food system drivers, activities and outcomes occurring in other countries and regions of the world. i.e. Australia's food system is part of a multi-level system extending beyond its shores. However, while disruptions to international supply chains threatened the livelihoods of Australian producers and actors throughout their supply chains, the adaptation of turning to domestic markets offered some resilience, after a lag time, and increased food availability in the domestic market.

Employment Conditions Throughout the Food System Reduce the Resilience of the System Overall

COVID-19 highlights the importance of secure labour at every stage throughout food supply chains, from production through to retail activities. Our case study demonstrates that poor working conditions and over-reliance on a casualised workforce decrease the resilience of the system overall.

A lack of resilience was observed in terms of employment arrangements within the food sector that have inhibited the system in providing food availability, and food access to those left without incomes. National and state border closures left agricultural producers, normally reliant on low-paid, seasonal and temporary migrant and backpacker labour, without sufficient labour, thereby potentially decreasing the volume of food produced and supplied. Farmers reportedly had little influence over the policies implemented to deal with the pandemic, for example they were unable to secure the exemptions they sought in the early stages of the pandemic to allow migrant workers to fly in during the pandemic. Arguably, poor working conditions on farms (including low wages, and the nature and price of accommodation) fail to attract domestic workers. This is partly related to consumer expectations of having access to inexpensive produce, and large retailers' pressures on farmers to supply foods at low price. A lack of farm workers poses a risk to food availability within the Australian food system. This may ultimately drive greater investment in the use of robotics in the agricultural system to address the shortage in labour. More optimistically, future employment conditions and remuneration may need to be fairer and more attractive for on-farm workers.

The casualised nature of employment throughout the food sector has also reduced the food purchasing power of workers employed in businesses that closed (cafes and restaurants), especially those ineligible for government support owing to gaps in that system, then the cessation of the first and second wave supports. This highlights the economic vulnerability of these workers within Australia's food systems. A significant failure has been the creation of a large cohort of newly food-insecure international students and temporary visa holders. Fortunately, voluntary and not-for-profit organisations have largely met emergency demand for food aid, showing system resilience in their gearing up rapidly to serve this system failure.

The system thus exhibited a low level of resilience in terms of maintaining social welfare outcomes for certain types of employees, namely the casualised and temporary workforce. These workers, many of whom are youth and non-residents of Australia, had minimal capacity to influence their situations or pursue alternate work within a system under high pressure. The system showed some adaptive capacity thanks to the existence of food charities, which managed to expand rapidly, while new ones emerged. This case study highlights the important role of having alternate capacities, here food charities, in enhancing the resilience of the food system to ensure food security for all. The pandemic highlighted systemic inequities in food sector employment as a key driver of food system activities, i.e., how food is produced and distributed, and thus food system outcomes, i.e., accessibility of food.

Consumers Lack Confidence in Supply Chains

Ultimately consumers drive demand through food supply chains. COVID-19 has revealed features of our food supply chains normally hidden from view and has invited many to pause and reflect on our relationship with food and our consumption of it. There is a new awareness of the dominance of casual employment and reliance on international workers to carry out essential roles in our food supply chains and how these workers are highly vulnerable to shocks within the system. There is greater awareness of concentration of market power in food retailing and of worker conditions on farms and in food processing enterprises.

Sudden changes in consumer behaviour challenge supply chains, forcing very rapid action to maintain food availability. COVID-19 exposed a weakness in the food system in terms of the dominance of two large retail supermarket chains, highlighting low diversity in options for consumers to access food and other necessities. The large extent of panic buying at particular crisis points (each impending lockdown) suggests a sense of uncertainty among consumers about supplies of what they perceived as essentials (cf Whelan et al., 2021, in a local Australian case study).

While staple food items were scarce on shelves for a short time, the retail sector was able to adapt quickly to meet demand, through using their market power and multiple connections to step up production and supplies, and diversify supply lines where necessary. Meanwhile large retailers and various levels of government worked to build confidence through messaging, relaxation of urban transport restrictions, and working closely with supply chains to restore and expand supplies. In so doing these actors exhibited a high degree of adaptive capacity and cooperation in relation to the distribution and retailing of food. Meanwhile consumers discovered the diversity of outlets actually available to them, including small and specific ethnic suppliers, and provided greater support for localised food system actors. The system thus demonstrated resilience as consumers purchased products from alternative retailers, which strengthened diversity within the system. The system also demonstrated the power large retailers have in influencing the system, as exhibited by the consequences of a low-price business model (see above), and then by their adaptive capacity to bring about change in their operations quickly. This includes some benefits, such as the collective organising of large retailers, with Indigenous communities and others, to solve food supplies to communities that had closed their borders for health reasons.

For now, there is greater support for local food systems (buying local), and perhaps a greater willingness to support growers and fishers to realise a fair return on their efforts. Whether any of these result in lasting change in food consumer behaviour remains unknown.

Adaptive Behaviour and Resilience

All of the case studies show intensive and rapid efforts towards adaptation on the part of private sector actors, all levels of government, and consumers. It is too soon to attempt summary as to the extent to which parts of the system have, or have not, been resilient, as "driver" settings continue to change, and actor responses continue. It appears that many – or most - actors have been proactive, and often inventive, in solving pressure points in the rapidly changing system. In terms of the food systems framework we are using, food system activities occurring along supply chains - i.e., producing, processing and packaging, distributing, retailing and consuming - are not so much separate activities, as integrated activities that underpin livelihoods and provide food security. Diverse supply chains, and the ability of particular supply chains to diversify themselves rapidly, have been highly important in Australia's apparent resilience to the crisis. Some interesting constraints to adaptation were nevertheless shown. For instance, suppliers to restaurants could not make rapid switches to supply retail stores, because of different packaging requirements and machinery limitations.

Overall, the pandemic has affirmed diversity as a vital component in resilient systems. While Australia's distribution system is dominated by key supermarket chains, each should be recognised as providing diverse foods (and other goods) to consumers, and as using diverse supply chains for each food marketed. Meanwhile, a large number and variety of small, local outlets provided alternative sources of foods, and contributed to a trend towards greater support for local businesses. The existence of food charities enabled this latent resource to expand to serve those left unable to purchase food as they were excluded from the federal government's financial support policies.

Meanwhile connectedness, another characteristic noted of resilient systems (Sundstrom and Allen, 2019), complements diversity in supporting resilience, by enabling the diverse components available to be activated in new ways. However, as

Sundstrom and Allen (2019) note, high connectedness can also make a system vulnerable to disturbances.

Australia's food system is a multi-level system, linked by many short and longer food supply chains. Local, regional and national adaptations have influenced one another. Cooperation between private sector and government, among firms that would ordinarily be considered competitors, and along supply chains, has been evident and effective in supporting adaptation and resilience. This included easing (or tightening) border restrictions for people, goods and services; categorisation of the food sector as an essential service; easing restrictions for Pacific Island worker schemes; reducing transport restrictions to improve capacity for restocking supermarket shelves; and subsidising freight for food export businesses. This suggests high connectivity within the system as evidenced by relationships that facilitate communication and cooperation towards solving problems and so stimulating system changes. It also represents high agility (Ivanov, 2020) on the part of many supply chain actors.

Integrating Resilience Thinking Into Food Systems Theory and Practice

By observing how the shock of COVID-19 and associated policy measures have forced rapid changes in Australia's food systems, we can gain important insights for improving resilience of those systems. First, we need to understand a food system as a *complex adaptive system*. This is more than a matter of showing feedback loops in framework diagrams, as the GECAFS food systems framework does. We need to recognise that the constant interaction of many parts of the system, at many levels, produces emergent properties, i.e. new – often temporary - characteristics in the system that transcend specific observable causes.

The particularities of COVID-19 also create some opportunities to refine existing food system conceptual frameworks. The original food system framework (GECAFS) notion of "drivers", for instance, had not envisaged health crises, but the recent literature on food security (e.g. HLPE, 2020) highlights "political and institutional drivers" as a driver of other drivers and particularly in the context of food system resilience. As the HLPE framework acknowledges briefly, far greater attention needs to be paid to resilience, the characteristics of these multi-level systems that facilitate adaptability in the event of shocks, rather than focusing entirely on the sustainability of the system. Tendall et al. (2015) point out how sustainability, capacity to preserve a system long-term, and resilience, capacity to cope with disturbances, are complementary and both essential.

The frameworks may also require rethinking in terms of goals. The GECAFS framework we have used focuses on food security (in several dimensions) as primary goal, while also acknowledging social and environmental outcomes. Alternate, and multiple, goals can be considered to co-exist with the goals of supplying food, and these may drive behaviour in parts of the system. In government policy, international relations can play a role; the many businesses participating in food systems surely incorporate multiple goals such as viability, market share, and perhaps corporate social responsibility including environmental and social dimensions. Goals may shift in a crisis, hence what we have observed in terms of high levels of cooperation to maintain food supplies, transcending everyday competition. This recalls Helfgott's (2018) unpacking of resilience in terms of: of what, to what, for whom (and over what timeframes). In the parts of the national food system, one can envisage actors exercising high agency over their "for whom", to promote resilience in their particular parts of the system but inevitably with effects on other system parts, and system actors.

In our analysis, some key features have stood out as facilitating resilience. Australia's food system adaptations represent a high degree of self-organising, or more accurately re-organising to meet new circumstances. This has occurred at all stages of supply chains, including where consumers have become producers through increased home-gardening. We have noted features in the structure and organisation of Australia's food system and its many parts, which have, with some exceptions, supported that re-organising. Diversity, even within a highly concentrated retail system, appears to have been very important. It has apparently combined with connectedness, enabling new solutions to be found through activating and developing new relationships, in a spirit of increased cooperation during the sense of emergency. We have also observed a high degree of agency, pro-activeness and indeed agility among food system actors, private sector, government, not-for-profits and consumers. These are important features to retain. Next must come learning, to continue to build the system's performance and resilience (Fazey et al., 2020; HLPE, 2020).

CONCLUSION

COVID-19 and related responses represent a significant and complex shock to Australia's food systems. By and large, but with a few significant exceptions, these systems have proven adaptive and resilient, although individual businesses are likely to continue to collapse as the pandemic persists. Our case studies have highlighted the importance of "agency", expressed at different levels throughout the food system (from the individual to government institutions), in how food systems function.

Exploring and unpacking dimensions of agency and associated governance structures within a given food system can reveal different goals and priorities among actors who have varying levels of power and influence. In order to build resilient people-centred food systems that are equitable and inclusive, it is necessary to ensure that the goals and priorities of those that are most vulnerable are recognised and accounted for in decision making processes. For example, if we accept that the key outcome desired of food systems is food security, then the majority of Australians have continued to be able to afford and access food, without fundamental changes to diets. However, food security is not the only outcome of food systems. Social welfare in terms of secure livelihoods and employment, for example, is also important to ensure there is a labour force actively driving the system and that those people are being fairly compensated for their work, to ensure they can meet their own nutritional needs. It is these goals and priorities that also need to be reflected within a resilient food system.

Globally, there are calls for realising the pandemic as an opportunity for change to a healthier, more sustainable and socially just food system. Australia is likely to remain a food exporting country into the future, and hence make a significant contribution to other countries' food security. In doing so, we need to ensure that all Australians whose livelihoods depend on, or are employed in our food industries, from production through to retail, receive satisfactory working conditions and fair remuneration for their labour.

Building greater resilience into our food systems will thus require a long-term view to address the structural dimensions (Béné, 2020), for example government policy and legislation, which determine how the various dimensions of our food systems function, interact and become reinforced overtime. COVID-19 has presented a shock to the social patterns underpinning Australia's food systems to provide an opportunity to overcome vulnerabilities within the system to enhance food security for all.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

All authors conceived of the study, jointly, and discussed the development and interpretation, reviewed and commented on the manuscript throughout the information gathering and writing process, contributed to the article, and approved the submitted version. NJ, HR, and WB took editorial responsibility. WB, HR, SB, JB, and NJ each wrote substantial sections and which were edited by all other members.

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REFERENCES

Amjath-Babu, T. S., Krupnik, T. J., Thilsted, S. H., and McDonald, A. J. (2020). Key indicators for monitoring food system disruptions caused by the COVID-19 pandemic: insights from Bangladesh towards effective response. *Food Secur.* 12, 761–768. doi: 10.1007/s12571-020-01083-2

Australian Bureau of Agricultural and Resource Economics and Sciences (2020). *Australian Food Security and the Covid-19 Pandemic, Australian Bureau of Agricultural and Resource Economics and Sciences.* Canberra, ACT.

Australian Bureau of Statistics (2021). *Population Clock*. Australian Bureau of Statistics. Available online at: https://www.abs.gov.au/ausstats/abs@.nsf/0/1647509ef7e25faaca2568a900154b63?OpenDocument (accessed 06 July 2021).

Australian Government Department of Health (2021). *Coronavirus (COVID-19) at a glance.* Available online at: https://www.health.gov.au/resources/publications/coronavirus-covid-19-at-a-glance-31-october-2021 (accessed 31 October 2020).

Bagshaw, E. (2020). Emergency 'lobster flights' to save $800 million worth of seafood. Sydney Morning Herald. Available online at: https://www.smh.com.au/politics/federal/emergency-lobster-flights-to-save-800-million-worth-of-seafood-20200331-p54fqa.html (accessed March 31, 2020).

Bagshaw, E. (2021). #FreedomLobster, #FreedomPineapple: new food alliance driven by China's trade wars. Sydney Morning Herald. Available online at: https://www.smh.com.au/world/asia/freedomlobster-freedompineapple-new-food-alliance-driven-by-china-s-trade-wars-20210316-p57b3a.html?btis (accessed March 27, 2021).

Bagshaw, E., and Gray, D. (2020). China's $6 billion trade stoush: Fears wheat is next Australian target. Sydney Morning Herald. Available online at: https://www.smh.com.au/world/asia/china-s-6-billion-trade-stoush-fears-wheat-is-next-australian-target-20201104-p56bet.html (accessed Nov 04, 2020).

Béné, C. (2020). Resilience of local food systems and links to food security – a review of some important concepts in the context of COVID-19 and other shocks. *Food Secur.* 12, 805–822. doi: 10.1007/s12571-020-01076-1

Béné, C., Barange, M., Subasinghe, R., Pinstrup-Andersen, P., Merino, G., Hemre, G.-I., et al. (2015). Feeding 9 billion by 2050 – Putting fish back on the menu. *Food Secur.* 7, 261–274. doi: 10.1007/s12571-015-0427-z

Béné, C., Headey, D., Haddad, L., and Von Grebmer, K. (2016). Is resilience a useful concept in the context of food security and nutrition programmes? Some conceptual and practical considerations. *Food Secur.* 8, 123–138. doi: 10.1007/s12571-015-0526-x

Béné, C., Prager, S. D., Achicanoy, H., a,.E., Toro, P. A., Lamotte, L., et al. (2019). Understanding food systems drivers: A critical review of the literature. *Global Food Secur.* 23, 149–159. doi: 10.1016/j.gfs.2019.04.009

Bennett, A., Basurto, X., Virdin, J., Lin, X., Betances, S. J., Smith, M. D., et al. (2021). Recognize fish as food in policy discourse and development funding. *Ambio.* 50, 981–989. doi: 10.1007/s13280-020-01451-4

Berkes, F., Colding, J., and Folke, C. (2003). *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change.* Cambridge, New York: Cambridge University Press.

Berkes, F., and Ross, H. (2013). Community resilience: toward an integrated approach. *Soc. Nat. Resour.* 26, 5–20. doi: 10.1080/08941920.2012.736605

Berkes, F., and Ross, H. (2016). Panarchy and community resilience: Sustainability science and policy implications. *Environ. Sci. Policy.* 61, 185–193. doi: 10.1016/j.envsci.2016.04.004

Biddle, N., Edwards, B., Gray, M., and Sollis, K. (2020a). *Alcohol Consumption During the COVID19 Period: May 2020*. Australian National University, Canberra).

Biddle, N., Edwards, B., Gray, M., and Sollis, K. (2020b). Hardship, distress, and resilience: The initial impacts of COVID-19 in Australia. Australian National University. Available online at: https://openresearch-repository.anu.edu.au/handle/1885/213194

Bisoffi, S., Ahrné, L., Aschemann-Witzel, J., Báldi, A., Cuhls, K., Declerck, F., et al. (2021). COVID-19 and sustainable food systems: what should we learn before the next emergency. *Front. Sustain. Food Syst.* 5, 53. doi: 10.3389/fsufs.2021.650987

Bogle, A. (2020). Gig economy workers fear livelihoods, customers at risk during coronavirus outbreak. ABC News. Available online at: https://www.abc.net.au/news/science/2020-03-06/gig-economy-workers-uber-deliveroo-ola-coronavirus-outbreak/12022072 (accessed Mar 6, 2020).

Bolton, M. (2020). Farm worker shortage expected to worsen as industry body says 26,000 workers needed nationwide by March. In: *ABC News.* Available online at: https://www.abc.net.au/news/rural/2020-12-11/farm-worker-shortage-expected-to-worsen-as-industry-crops-rot/12974250 (accessed Dec 11, 2020).

Bonyhady, N., Bagshaw, E., and Preiss, B. (2020). Australian lobster exports feared latest victim of China tensions, Sydney Morning Herald. Available online at: https://www.smh.com.au/politics/federal/australian-lobster-exports-feared-latest-victim-of-china-tensions-20201101-p56ak0.html (accessed November 1, 2020).

Boström, M., Jönsson, A. M., Lockie, S., Mol, A. P. J., and Oosterveer, P. (2015). Sustainable and responsible supply chain governance: challenges and opportunities. *J. Cleaner Produc.* 107, 1–7. doi: 10.1016/j.jclepro.2014.11.050

Bowden, M. (2020). *Understanding Food Insecurity in Australia*. Victoria: Australian Institute of Family Studies.

Boyer, A. (2020). *Sales Strategies Adapt.* FISH COVID19 Special Issue 1. Fisheries Research and Development Corporation: Australia.

Cartizone, I. (2020). *Keeping seafood supplies flowing*. FISH COVID19 Special Issue 1. Fisheries Research and Development Corporation: Australia.

Cave, D. (2020). What lockdown 2.0 looks like: harsher rules, deeper confusion. In: *The New York Times.* Available online at: https://www.nytimes.com/2020/08/04/world/australia/coronavirus-melbourne-lockdown.html (accessed August 4, 2020).

Chapin, F. S., Folke, C., and Kofinas, G. P. (2009). A framework for understanding change. In: *Principles of Ecosystem Stewardship: Resilience-Based Natural Resource Management in a Changing World, eds*. Chapin, F.S., Kofinas, G.P., and Folke, C. ebook: Springer Science+Business Media. doi: 10.1007/978-0-387-73033-2_1

Choularton, R., Frankenberger, T., Kurtz, J., and Nelson, S. (2015). *Measuring shocks and stressors as part of resilience measurement. Resilience measurement technical working group.* Technical Series No. 5. Rome: Food Security Information Network).

Clapp, J., and Moseley, W. G. (2020). This food crisis is different: COVID-19 and the fragility of the neoliberal food security order. *J. Peasant Stud.* 47, 1393–1417. doi: 10.1080/03066150.2020.1823838

Coffey, A. (2014). Analysing documents. In: *The SAGE handbook of qualitative data analysis. SAGE Publications Ltd.* pp. 367–379. doi: 10.4135/9781446282243.n25

Collis, B. (2020). *Fleets race to prepare as restrictions tighten.* FISH COVID19 Special Issue 1. Fisheries Research and Development Corporation: Australia.

Cottrell, R. S., Nash, K. L., Halpern, B. S., Remenyi, T. A., Corney, S. P., Fleming, A., et al. (2019). Food production shocks across land and sea. *Nat. Sustain.* 2, 130–137. doi: 10.1038/s41893-018-0210-1

Crona, B. I., Van Holt, T., Petersson, M., Daw, T. M., and Buchary, E. (2015). Using social–ecological syndromes to understand impacts of international seafood trade on small-scale fisheries. *Global Environ. Change.* 35, 162–175. doi: 10.1016/j.gloenvcha.2015.07.006

Dalzell, S., Snape, J., and De Landgraff, T. (2020). Tonnes of Australian lobsters stuck in Chinese airports amid trade tensions. In: *ABC News,* Available online at: https://www.abc.net.au/news/2020-11-02/australian-lobster-exports-caught-in-china-trade-tensions/12837700 (accessed November 2, 2020).

Davey, M. (2020). Coronavirus: first cases of community transmission confirmed in Australia. The Guardian, 2 March 2020. In: *The Guardian.* Available online at: https://www.theguardian.com/world/2020/mar/02/coronavirus-first-cases-of-community-transmission-confirmed-in-australia (accessed Mar 2, 2020).

Davidson, D. J. (2010). The applicability of the concept of resilience to social systems: some sources of optimism and nagging doubts. *Soc. Nat. Resour.* 23, 1135–1149. doi: 10.1080/08941921003652940

Davila, F., Bourke, R. M., McWilliam, A., Crimp, S., Robins, L., Van Wensveen, M., et al. (2021). COVID-19 and food systems in pacific island countries, papua new guinea, and timor-leste: opportunities for actions towards the sustainable development goals. *Agric. Syst.* 191, 103137–103137. doi: 10.1016/j.agsy.2021.103137

Davis, J., and McCarthy, M. (2020). City farming on rise as COVID-19 makes people rethink how they source their food. In: *ABC News.* Available online at: https://www.abc.net.au/news/rural/2020-10-25/urban-farming-on-rise-due-to-covid-19-pandemic/12797672 (accessed Oct 25, 2020).

Dawes, S. (2020). Coronavirus panic buying triggers supermarket price hikes as retailers plead for calm. In: *ABC News.* Available online at: https://www.abc.net.au/news/2020-03-22/coronavirus-panic-buying-sees-fresh-produce-price-hikes/12078198 (accessed Mar 22, 2022).

Denscombe, M. (2007). *The Good Research Guide for Small-Scale Social Research Projects*. Suffolk, UK: Open University Press.

Devereux, S., Bén,é, C., and Hoddinott, J. (2020). Conceptualising COVID-19's impacts on household food security. *Food Secur.* 12, 769–772. doi: 10.1007/s12571-020-01085-0

Dou, Z., Stefanovski, D., Galligan, D., Lindem, M., Rozin, P., Chen, T., et al. (2021). Household food dynamics and food system resilience amid the COVID-19 pandemic: a cross-national comparison of China and the United States. *Front. Sustain. Food Syst.* 4, 212. doi: 10.3389/fsufs.2020.577153

Duckett, S. (2020). *Waves of Inequity in the Coronavirus Pandemic*. Available online at: https://grattan.edu.au/news/waves-of-inequity-in-the-coronavirus-pandemic/?:GrattanInstitute

Duckett, S., and Stobart, A. (2020a). 4 ways Australia's coronavirus response was a triumph, and 4 ways it fell short. In: *The Conversation*. Available online at: https://theconversation.com/4-ways-australias-coronavirus-response-was-a-triumph-and-4-ways-it-fell-short-139845 (accessed Jun 4, 2020).

Duckett, S., and Stobart, A. (2020b). Australia's COVID-19 journey takes a turn for the worse. Available online at: Available online at: https://grattan.edu.au/news/australias-covid-19-journey-takes-a-turn-for-the-worse/ Grattan Institute.

Duckett, S., and Stobart, A. (2020c). Australia's COVID-19 response: the story so far. Available online at: https://grattan.edu.au/news/australias-covid-19-response-the-story-so-far/ Grattan Institute.

Elmas, M. (2021). Lockdown food waste is costing households thousands of dollars. Here's how to cut down. In: *The New Daily.* Available online at: https://thenewdaily.com.au/finance/finance-news/2021/08/06/lockdown-food-waste-australia/?utm_source=Adestraandutm_medium=emailandutm_campaign=Saturday%20News%20-%2020210807 (accessed August 6, 2021).

Elmqvist, T., Andersson, E., Frantzeskaki, N., McPhearson, T., Olsson, P., Gaffney, O., et al. (2019). Sustainability and resilience for transformation in the urban century. *Nat. Sustain.* 2, 267–273. doi: 10.1038/s41893-019-0250-1

Ericksen, P. J. (2008). Conceptualizing food systems for global environmental change research. *Global Environ. Change.* 18, 234–245. doi: 10.1016/j.gloenvcha.2007.09.002

Fan, S., Teng, P., Chew, P., Smith, G., and Copeland, L. (2021). Food system resilience and COVID-19 – Lessons from the Asian experience. *Global Food Secur.* 28, 100501. doi: 10.1016/j.gfs.2021.100501

FAO (2020). *Summary of the Impacts of the COVID-19 Pandemic on the Fisheries and Aquaculture Sector: Addendum to the State of World Fisheries and Acquaculture 2020.* (Rome).

Farrell, P., Thow, A. M., Wate, J. T., Nonga, N., Vatucawaqa, P., Brewer, T., et al. (2020). COVID-19 and Pacific food system resilience: opportunities to build a robust response. *Food Secur.* 1–9. doi: 10.1007/s12571-020-01087-y

Fazey, I., Schäpke, N., Caniglia, G., Hodgson, A., Kendrick, I., Lyon, C., et al. (2020). Transforming knowledge systems for life on Earth: Visions of future systems and how to get there. *Energy Res. Soc Sci.* 70, 101724. doi: 10.1016/j.erss.2020.101724

Folke, C., Biggs, R., Norström, A. V., Reyers, B., and Rockström, J. (2016). Social-ecological resilience and biosphere-based sustainability science. *Ecol. Soc.* 21. doi: 10.5751/ES-08748-210341

Follent, D., Paulson, C., Orcher, P., O'Neill, B., Lee, D., Briscoe, K., et al. (2021). The indirect impacts of COVID-19 on Aboriginal communities across New South Wales. *Med. J. Austral.* 214, 199-200.e191. doi: 10.5694/mja2.50948

Foodbank (2020). *Foodbank Hunger Report: Food Security in the Time of Covid-19*. North Ryde, Australia.

Foster, G., and Hickey, M. (2020). COVID lockdowns have human costs as well as benefits. It's time to consider both. In: *The Conversation.* Available online at: https://theconversation.com/covid-lockdowns-have-human-costs-as-well-as-benefits-its-time-to-consider-both-137233 (accessed April 29, 2020).

FRDC (2020). 2018 Status of Australian Fish Stock Reports [Online]. Available online at: http://www.fish.gov.au/reports/key-results (accessed 6 July 2021).

Fredericks, B., and Bradfield, A. (2020a). Food insecurity in uncertain times: ways forward post–pandemic. *Griffith Rev.* 71, 115–23. doi: 10.3316/informit.675463859707460

Fredericks, B., and Bradfield, A. (2020b). We don't want to go back to 'normal when 'normal' wasn't good for everyone. *Axon: Creat. Explorat.* 10. Available online at: https://axonjournal.com.au/sites/default/files/article_pdf/Axon-10-2-Fredericks-Bradfield.pdf

Fredericks, B., and Bradfield, A. (2021). *Food insecurity in uncertain times: ways forward post-pandemic, Croakey Health Media: informed, engaged communities for health*. Croakey Health Media: informed, engaged communities for health. Available online at: https://www.croakey.org/food-insecurity-in-uncertain-timesways-forward-post-pandemic/

Gaynor, A. (2020). If you took to growing veggies in the coronavirus pandemic, then keep it up when lockdown ends. In: *The Conversation.* Available online at: https://theconversation.com/if-you-took-to-growing-veggies-in-the-coronavirus-pandemic-then-keep-it-up-when-lockdown-ends-135359 (accessed May 26, 2020).

Gephart, J. A., Rovenskaya, E., Dieckmann, U., Pace, M. L., and Brännström, Å. (2016). Vulnerability to shocks in the global seafood trade network. *Environ. Res. Lett.* 11, 035008. doi: 10.1088/1748-9326/11/3/035008

Geraldton Fishermen's Co-Operative (2021). *Our Story - Geraldton Fishermen's Co-Operative*. Available online at: https://brolos.com.au/ (accessed July 6, 2021).

Greenville, J., McGilvray, H., Cao, L. Y., and Fell, J. (2020). *Impacts of COVID-19 on Australian Agriculture, Forestry and Fisheries Trade.* Canberra, ACT: Australian Bureau of Agricultural and Resource Economics and Sciences.

Gunderson, L. H., and Holling, C. S. (2002). *Panarchy: Understanding Transformations in Human and Natural Systems.* Washington, D.C.: Island Press.

Havice, E., Marschke, M., and Vandergeest, P. (2020). Industrial seafood systems in the immobilizing COVID-19 moment. *Agric. Human Valu.* 37, 655–656. doi: 10.1007/s10460-020-10117-6

Hayes, J., and Daly, J. (2020). Coronavirus shutdown may have peaked in China but Australian exporters still struggling due to airfreight. In: *ABC News.* Available online at: https://www.abc.net.au/news/2020-03-26/seafood-exporters-feeling-airfreight-pinch-under-coronavirus/12090904 (accessed March 27, 2020).

Helfgott, A. (2018). Operationalising systemic resilience. *Eur. J. Operat. Res.* 268, 852–864. doi: 10.1016/j.ejor.2017.11.056

Hendry, M. (2020). Coronavirus cripples mud crabs as prices drop by two thirds amid transport nightmare. In: *ABC News.*. Available online at: https://www.abc.net.au/news/2020-03-27/coronavirus-sinking-mud-crab-prices-as-easter-approaches/12095562 (accessed March 27, 2020).

Herrera, H. (2017). Resilience for whom? The problem structuring process of the resilience analysis. *Sustainability* 9, 1196. doi: 10.3390/su9071196

Hertz, T., Mancilla Garcia, M., and Schlüter, M. (2020). From nouns to verbs: How process ontologies enhance our understanding of social-ecological systems understood as complex adaptive systems. *People Nat.* 2, 328–338. doi: 10.1002/pan3.10079

HLPE (2020). Food Security and Nutrition: Building a Global Narrative Towards 2030. In: *A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security*. (Rome).

Hobday, L., Khadem, N., and Sas, N. (2020). Supermarkets allowed to work together after coronavirus panic buying, but shoppers fear grocery price hikes. In: *ABC News.* Available online at: https://www.abc.net.au/news/2020-03-24/supermarket-coronavirus-panic-buying-price-gouging-coles-woolies/12084282 (accessed March 24, 2020).

Howe, J., Reilly, A., Van Den Broek, D., and Wright, C. F. (2017). *Sustainable Solutions: the future of labour supply in the Australian Vegetable Industry*. Adelaide: University of Adelaide.

Hynninen, E. (2020). Lobster fisherman hopes to survive impact of coronavirus, rising costs, with help from local fans. In: *ABC Rural.* Available online at: https://www.abc.net.au/news/rural/2020-02-19/scott-inkson-lobster-fisherman-tasmania/11977344 (accessed February 19, 2020).

Infogram (2021). *New daily confirmed COVID-19 cases in Australia (since first case).* Available online at: https://infogram.com/1p7ve7kjeld1pebz2nm0vpqv7nsnp92jn2x?live (accessed July 23, 2021)

Ingram, J. (2011). A food systems approach to researching food security and its interactions with global environmental change. *Food Secur.* 3, 417–431. doi: 10.1007/s12571-011-0149-9

IPES-FOOD (2020). "COVID-19 and the crisis in food systems: Symptoms, causes, and potential solutions," in *IPES - International Panel of Food Experts on Sustainable Food Systems*. (Brussels, Belgium).

Ivanov, D. (2020). Viable supply chain model: integrating agility, resilience and sustainability perspectives—lessons from and thinking beyond the COVID-19 pandemic. *Ann. Oper. Res.* 1–21. doi: 10.1007/s10479-020-03640-6

John, D. A., and Babu, G. R. (2021). Lessons from the aftermaths of green revolution on food system and health. *Front. Sustain. Food Syst.* 5. doi: 10.3389/fsufs.2021.644559

Jones, L. (2019). Resilience isn't the same for all: comparing subjective and objective approaches to resilience measurement. *WIREs Clim. Change.* 10, e552. doi: 10.1002/wcc.552

Judd, B., and Taylor, C. (2020). Melbourne aged care is facing a coronavirus catastrophe. This is how it happened. In: *ABC News.* Available online at: https://www.abc.net.au/news/2020-07-29/victoria-coronavirus-aged-care-outbreaks-timeline/12498532 (accessed July 29, 2020).

Karp, P. (2020). Victorian workers offered $1,500 pandemic leave payment, but unions and business call for more. In: *The Guardian.* Available online at: https://www.theguardian.com/australia-news/2020/aug/03/morrison-announces-1500-pandemic-leave-disaster-payment-for-workers-with-no-sick-leave (accessed Aug 3, 2020).

Lade, S. J., Walker, B. H., and Haider, L. J. (2020). Resilience as pathway diversity: linking systems, individual, and temporal perspectives on resilience. *Ecol. Soc.* 25. doi: 10.5751/ES-11760-250319

Layard, R., Clark, A., De Neve, J., Krekel, C., Fancourt, D., Hey, N., et al. (2020). When to release the lockdown: a wellbeing framework for analysing costs and benefits. In: *Occasional Paper 49, Centre for Economic Performance* (London School of Economics). doi: 10.2139/ssrn.3590884

Leite, M., Ross, H., and Berkes, F. (2019). Interactions between individual, household, and fishing community resilience in southeast Brazil. *Ecol. Soc.* 24. doi: 10.5751/ES-10910-240302

Linnenluecke, M. K. (2017). Resilience in business and management research: a review of influential publications and a research agenda. *Int. J. Manage. Rev.* 19, 4–30. doi: 10.1111/ijmr.12076

Liu, J. J. W., Reed, M., and Girard, T. A. (2017). Advancing resilience: an integrative, multi-system model of resilience. *Personal. Individ. Differ.* 111, 111–118. doi: 10.1016/j.paid.2017.02.007

Liveris, J. (2020). Coronavirus trade closure makes lobster cheaper for Australian shoppers. In: *ABC Rural News.* Available online at: https://www.abc.net.au/news/rural/2020-02-04/coronavirus-sees-cheap-lobster-on-domestic-menu/11924186 (accessed February 4, 2020).

Love, D. C., Allison, E. H., Asche, F., Belton, B., Cottrell, R. S., Froehlich, H. E., et al. (2021). Emerging COVID-19 impacts, responses, and lessons for building resilience in the seafood system. *Global Food Secur.* 28, 100494. doi: 10.1016/j.gfs.2021.100494

Major, T. (2020). Coronavirus devastates Bowen's fishing industry, farmers face uncertain winter. In: *ABC Rural News.* Available online at: https://www.abc.net.au/news/2020-03-23/coronavirus-downturn-wreaks-havoc-in-bowen-coral-trout-industry/12076550 (accessed March 23, 2020).

Masten, A. S., and Obradovic, J. (2006). Competence and resilience in development. *Ann. N.Y. Acad. Sci.* 1094, 13–27. doi: 10.1196/annals.1376.003

McKillop, C. (2020). Australian tropical rock lobster exports to China and US recovering but volumes, prices remain low. In: *ABC News.* Available online at: https://www.abc.net.au/news/2020-08-29/tropical-rock-lobster-exports-recovering-but-far-from-good/12601952 (accessed Aug 29, 2020).

Meachim, L. (2020). WA crayfish industry halts exports as coronavirus shuts down Lunar New Year celebrations. In: *ABC News.* Available online at: https://www.abc.net.au/news/2020-01-25/coronavirus-puts-wa-crayfishing-industry-on-hold/11900668 (accessed January 26, 2020).

Mercer, P. (2020). Covid: Melbourne's hard-won success after a marathon lockdown. In: *Covid: Melbourne's hard-won success after a marathon lockdown.* BBC News. Available online at: https://www.bbc.com/news/world-australia-54654646 (accessed October 26, 2020).

Mobsby, D., Stevens, A. H., and Curtotti, R. (2020). *Australian Fisheries and Aquaculture Outlook 2020.* Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra: ACT.

Mobsby, D., Stevens, A. H., Curtotti, R., and Dyleweski, M. (2021). *Australian Fisheries and Aquaculture: Outlook to 2025–26.* Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra: ACT.

Murphy, N. (2020). Australian fishermen brokering deal to fly lobsters to China, get coronavirus medical supplies in return, ABC News Landline. Available online at: https://www.abc.net.au/news/2020-04-01/china-lobster-market-back-freight-challenge-amid-coronavirus/12108212 (accessed April 1, 2020).

Nichols, J. (2020). *Coronavirus pressure sees exporter ink deal with Coles as fishers struggle to stay afloat*. Sydney Morning Herald. Available online at: https://www.abc.net.au/news/rural/2020-04-22/coronavirus-forces-seafood-exporters-into-domestic-market/12171784 (accessed April 22, 2020).

Norgrady, B. (2020a). Seafood rides new market waves. FISH COVID19 Special Issue 2. *Fisheries Research and Development Corporation, Australia* p. 17–18.

Norgrady, B. (2020b). Seafood rides new market waves'. FISH COVID19 Special Issue 2. *Fisheries Research and Development Corporation, Australia.* p. 17–18.

Nyström, M., Jouffray, J. B., Norström, A. V., Crona, B., Søgaard Jørgensen, P., Carpenter, S. R., et al. (2019). Anatomy and resilience of the global production ecosystem. *Nature.* 575, 98–108. doi: 10.1038/s41586-019-1712-3

Ogier, E., Sen, S., Jennings, S., Magnusson, A., Smith, D. C., Colquhoun, E., et al. (2021). Impacts of COVID-19 on the Australian Seafood Industry: January-June 2020. In: *Fisheries Research and Development Corporation (FRDC)* 2016.

Österblom, H., Jouffray, J.-B., Folke, C., Crona, B., Troell, M., Merrie, A., et al. (2015). Transnational corporations as 'Keystone Actors' in marine ecosystems. *PLoS ONE.* 10, e0127533. doi: 10.1371/journal.pone.0127533

Patrick, A. O. (2020). Australia has almost eliminated the coronavirus — by putting faith in science, The Washington Post. Available online at: https://www.washingtonpost.com/world/asia_pacific/australia-coronavirus-cases-melbourne-lockdown/2020/11/05/96c198b2-1cb7-11eb-ad53-4c1fda49907d_story.html (accessed November 5, 2020).

Patterson, H., Larcombe, J., Woodhams, J., and Curtotti, R. (2020). *Fishery status reports 2020.* Canberra, ACT: Australian Bureau of Agricultural and Resource Economics and Sciences.

Plaganyi, E., Murphy, N., Deng, R. A., Pascoe, S., and Hutton, T. (2020). Coronavirus is killing Australia's lobster export market. In: *The Conversation.* Available online at: https://theconversation.com/coronavirus-is-killing-australias-lobster-export-market-131750 (accessed February 19, 2020).

Pollard, E., and McKenna, K. (2020). Coronavirus devastates Australian export businesses as economic costs of emergency filter through. In: *ABC News.* Available online at: https://www.abc.net.au/news/2020-02-04/coronavirus-devastates-australian-export-businesses/11925536?utm_source=abc_newsandutm_medium=content_sharedandutm_content=mailandutm_campaign=abc_news (accessed February 4, 2020).

Preiser, R., Biggs, R., De Vos, A., and Folke, C. (2018). Social-ecological systems as complex adaptive systems: organizing principles for advancing research methods and approaches. *Ecol. Soc.* 23, 46. doi: 10.5751/ES-10558-230446

Prendergast, J. (2020). Coronavirus likely to wipe $389 million off Australian seafood industry's bottom line. In: *ABC News.* Available online at: https://www.abc.net.au/news/2020-03-05/australian-seafood-takes-massive-hit-as-coronavirus-spreads/12022136 (accessed March 5, 2020)

Sakzewski, E. (2020). Panic-buying, restrictions and the 'new normal': Documenting life in Australia during the coronavirus pandemic. In: *ABC News.* Available online at: https://www.abc.net.au/news/2020-06-07/australians-documenting-life-in-iso-coronavirus-national-musuem/12251758 (accessed June 7, 2020)

Sallim, N. (2020). COVID-19 pandemic sees international students unable to return home, surviving on free food. In: *ABC News.* Available online at: https://www.abc.net.au/news/2020-11-28/international-students-face-financial-difficulties-in-pandemic/12922142 (accessed November 28, 2020)

Sanderson, A., Furness, E., Nicol, P., Pitt, H., and Taherzadeh, A. (2021). Shaping more resilient and just food systems: Lessons from the COVID-19 Pandemic. *Ambio.* 50, 782–793. doi: 10.1007/s13280-021-01532-y

Seafood Industry Australia (2021). Seafood Industry Australia: the voice of Australian Seafood. Available online at: https://seafoodindustryaustralia.com.au/ (accessed July 6, 2021).

Seneviratne, K. (2020). Australia's COVID-19 Second Wave Blamed on Insecure Jobs. In: *IndepthNews.* Available online at: https://www.indepthnews.net/index.php/the-world/asia-pacific/3720-australia-s-covid-19-second-wave-blamed-on-insecure-jobs (accessed July 25, 2020).

Smith, L., and Klemm, M. (2020). Even as behavioural researchers we couldn't resist the urge to buy toilet paper. In: *The Guardian.* Available online at: https://www.theguardian.com/commentisfree/2020/mar/05/even-as-behavioural-researchers-we-couldnt-resist-the-urge-to-buy-toilet-paper (accessed March 5, 2020).

Snow, V., Rodriguez, D., Dynes, R., Kaye-Blake, W., Mallawaarachchi, T., Zydenbos, S., et al. (2021). Resilience achieved via multiple compensating subsystems: the immediate impacts of COVID-19 control measures on the agri-food systems of Australia and New Zealand. *Agric. Syst.* 187, 103025. doi: 10.1016/j.agsy.2020.103025

Southwick, S. M., Bonanno, G. A., Masten, A. S., Panter-Brick, C., and Yehuda, R. (2014). Resilience definitions, theory, and challenges: interdisciplinary perspectives. *Eur. J. Psychotraumatol.* 5, 25338. doi: 10.3402/ejpt.v5.25338

Srinivasan, P. (2020). China's trade war with Australia is affecting a growing number of industries. How did we get here? ABC News. Available online at: https://www.abc.net.au/news/2020-12-10/chinas-trade-war-with-australia-export-industry/12967190 (accessed December 10, 2020).

Steneck, R. S., Hughes, T. P., Cinner, J. E., Adger, W. N., Arnold, S. N., Berkes, F., et al. (2011). Creation of a gilded trap by the high economic value of the Maine lobster fishery. *Conserv. Biol.* 25, 904–912. doi: 10.1111/j.1523-1739.2011.01717.x

Stephens, E. C., Martin, G., Van Wijk, M., Timsina, J., and Snow, V. (2020). Editorial: Impacts of COVID-19 on agricultural and food systems worldwide and on progress to the sustainable development goals. *Agric. Syst.* 183, 102873. doi: 10.1016/j.agsy.2020.102873

Stevens, A. H., Mobsby, D., and Curtotti, R. (2020). Australian fisheries and aquaculture statistics 2018. In: *Fisheries Research and Development Corporation*. Project 2019-093, Australian Bureau of Agricultural and Resource Economics and Sciences. (Canberra, ACT).

Stoll, J. S., Harrison, H. L., De Sousa, E., Callaway, D., Collier, M., Harrell, K., et al. (2021). Alternative seafood networks during COVID-19: implications for resilience and sustainability. *Front. Sustain. Food Syst.* 5. doi: 10.3389/fsufs.2021.614368

Sullivan, K. (2020a). Farmers call for calm amid unprecedented coronavirus supermarket panic buying. In: *ABC News.* Available online at: https://www.abc.net.au/news/2020-03-21/farmers-call-for-calm-amid-coronavirus-panic-buying/12076764 (accessed Mar 21, 2020).

Sullivan, K. (2020b). Farmers fear worker shortage due to COVID-19 restrictions despite rising unemployment. In: *ABC News*. Available online at: https://www.abc.net.au/news/rural/2020-07-30/farm-labour-shortage-feared-due-to-coronavirus-controls/12504802 (accessed July 30, 2020).

Sullivan, K. (2020c). International Freight Assistance Mechanism extended to help food exporters during pandemic. In: *ABC News*. Available online at: https://www.abc.net.au/news/2020-07-03/ifam-funding-extended-for-fresh-food-exporters/12417328 (accessed July 3, 2020).

Sullivan, K. (2020d). Pressure grows for new 'ag visa' to ease farm labour shortages. In: *ABC News.* Available online at: https://www.abc.net.au/news/2020-12-15/coalition-mps-reignite-calls-for-agriculture-visa/12982562 (accessed December 15, 2020).

Sundstrom, S. M., and Allen, C. R. (2019). The adaptive cycle: more than a metaphor. *Ecol. Compl.* 39, 100767. doi: 10.1016/j.ecocom.2019.100767

Taylor, J. (2020). Victoria's poor contact tracing during second Covid wave 'cost lives', report finds. In: *The Guardian.* Available online at: https://www.theguardian.com/australia-news/2020/dec/14/victorias-poor-contact-tracing-during-second-covid-wave-cost-lives-report-finds (accessed December 14, 2020).

Tendall, D. M., Joerin, J., Kopainsky, B., Edwards, P., Shreck, A., Le, Q. B., et al. (2015). Food system resilience: defining the concept. *Global Food Secur.* 6, 17–23. doi: 10.1016/j.gfs.2015.08.001

Ting, I., and Palmer, A. (2020). One hundred days of the coronavirus crisis. In: *ABC News.* Available online at: https://www.abc.net.au/news/2020-05-04/charting-100-days-of-the-coronavirus-crisis-in-australia/12197884?nw=0 (accessed May 5, 2020)

Tlusty, M. F., Tyedmers, P., Bailey, M., Ziegler, F., Henriksson, P. J. G., Béné, C., et al. (2019). Reframing the sustainable seafood narrative. *Global Environ. Change.* 59, 101991. doi: 10.1016/j.gloenvcha.2019.101991

Underberg, N. M., and Zorn, E. (2014). *Digital Ethnography: Anthropology, Narrative, and New Media.* Austin: University of Texas Press. doi: 10.7560/744332

Ungar, M. (2018). Systemic resilience: principles and processes for a science of change in contexts of adversity. *Ecol. Soc.* 23. doi: 10.5751/ES-10385-230434

Varis, P. (2016). Digital ethnography. In: *The Routledge Handbook of Language and Digital Communication,* eds. Georgakopoulou, A., and Spilioti, T. *(London: Routledge)* p. 55–68.

Verrender, I. (2021). "How Beijing shot itself in the foot with its trade war with Australia," in *ABC News*. https://www.abc.net.au/news/2021-06-07/how-beijing-shot-itself-in-the-foot-with-its-trade-war/100194386 (accessed June 7, 2021).

Wahlquist, C. (2020). Australia's coronavirus lockdown – the first 50 days. In: *The Guardian.* Available online at: https://www.theguardian.com/world/2020/may/02/australias-coronavirus-lockdown-the-first-50-days (accessed May 2, 2020).

Warriner, J. (2020). New faces seeking charity help this Christmas as coronavirus pandemic sends families to the brink. In: *ABC News.* Available online at: https://www.abc.net.au/news/2020-12-10/new-faces-seek-christmas-charity-help-amid-warning-worse-to-come/12967914 (accessed December 10, 2020).

Wells, P., Abouarghoub, W., Pettit, S., and Beresford, A. (2020). A socio-technical transitions perspective for assessing future sustainability following the COVID-19 pandemic. *Sustain. Sci. Pract. Policy.* 16, 29–36. doi: 10.1080/15487733.2020.1763002

Western Rock Lobster (2021). Western Rock Lobster Market Report, October 2021. Available: https://westernrocklobster.org/knowledge-hub/western-rock-lobster-market-report-october-2021/ (accessed October 30, 2021).

Whelan, J., Brown, A. D., Coller, L., Strugnell, C., Allender, S., Alston, L., et al. (2021). The impact of COVID-19 on rural food supply and demand in Australia: utilising group model building to identify retailer and customer perspectives. *Nutrients.* 13, 417. doi: 10.3390/nu13020417

White, E. R., Froehlich, H. E., Gephart, J. A., Cottrell, R. S., Branch, T. A., Agrawal Bejarano, R., et al. (2021). Early effects of COVID-19 on US fisheries and seafood consumption. *Fish Fisher.* 22, 232–239. doi: 10.1111/faf.12525

Wilson, G. A. (2014). Community resilience: path dependency, lock-in effects and transitional ruptures. *J. Environ. Plann. Manage.* 57, 1–26. doi: 10.1080/09640568.2012.741519

Zhou, N. (2020). The pandemic purse: services suffer while Australians spend up on home-cooking and liquor. In: *The Guardian.* Available online at: https://www.theguardian.com/business/2020/sep/13/the-pandemic-purse-services-suffer-while-australians-spend-up-on-home-cooking-and-liquor (accessed Sep 13, 2020).

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Effect of COVID-19 Pandemic on Food Systems and Determinants of Resilience in Indigenous Communities of Jharkhand State, India: A Serial Cross-Sectional Study

Suparna Ghosh-Jerath*[1]*, *Ridhima Kapoor*[1], *Ayushi Dhasmana*[1], *Archna Singh*[2], *Shauna Downs*[3] and *Selena Ahmed*[4]

[1] Indian Institute of Public Health-Delhi, Public Health Foundation of India, Gurgaon, India, [2] Department of Biochemistry, All India Institute of Medical Sciences (AIIMS), New Delhi, India, [3] Department of Urban-Global Public Health, Rutgers School of Public Health, Newark, NJ, United States, [4] Department of Health and Human Development, Montana State University, Bozeman, MT, United States

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****Correspondence:***
Suparna Ghosh-Jerath
suparna.ghoshj@iiphd.org

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The COVID-19 pandemic has globally jeopardized food security, with heightened threats for the most vulnerable including smallholder farmers as well as rural, indigenous populations. A serial cross-sectional study was conducted to document effect of COVID-19 pandemic on food environment, agricultural practices, diets and food security, along with potential determinants of food systems resilience, among vulnerable smallholder farmer households in indigenous communities of Santhal, Munda, and Sauria Paharia of Jharkhand state, India. Telephonic household surveys were conducted in two phases i.e., lockdown and unlock phase to assess the impact of the pandemic on their food systems and agricultural practices. Market surveys were conducted during the unlock phase, to understand the impact on local informal markets. Secondary data on state and district level food production and Government food security programs were also reviewed. For data analysis purpose, a conceptual framework was developed which delineated possible pathways of impact of COVID-19 pandemic on food environment, food security and food consumption patterns along with factors that may offer resilience. Our findings revealed adverse effects on food production and access among all three communities, due to restrictions in movement of farm labor and supplies, along with disruptions in food supply chains and other food-related logistics and services associated with the pandemic and mitigation measures. The pandemic significantly impacted the livelihoods and incomes among all three indigenous communities during both lockdown and unlock phases, which were attributed to a reduction in sale of agricultural produce, distress selling at lower prices and reduced opportunity for daily wage laboring. A significant proportion of respondents also experienced changes in dietary intake patterns. Key determinants of resilience were identified; these included accessibility to agricultural inputs like indigenous seeds, labor available at household level due to back migration and access to diverse food environments, specifically the wild food environment. There is a need for programs and interventions to conserve and revitalize the bio-cultural resources available within these vulnerable indigenous communities and build resilient food systems that depend on shorter food supply chains and utilize indigenous knowledge systems and associated resources, thereby supporting healthy, equitable and sustainable food systems for all.

Keywords: tribal, COVID-19, food system, resilience, indigenous population, food production, diets, food environment

INTRODUCTION

Over 820 million people in the world suffer from hunger, while about two billion people experience moderate or severe food insecurity (The United Nations, 2019). The world is not on track to achieve Sustainable Development Goal (SDG) 2 of Zero Hunger by 2030 and if these trends continue, the number of people affected by hunger would surpass 840 million by 2030 (Kretchmer, 2020). Evidence suggests that manmade conflicts, climate change, and economic downturns can lead to acute hunger among 135 million people globally. The COVID-19 pandemic could double that number, putting millions of people at risk of suffering from acute hunger (Anthem, 2020). In fact, the pandemic has jeopardized food security in communities globally, with heightened threats for the most vulnerable including smallholder farmers as well as rural, and indigenous populations (FAO, 2020b). It is well recognized that sustainable food systems can play a critical role in creating a zero-hunger world (The Economist, 2021). However, the COVID-19 pandemic has put the global food supply system under the most vigorous pressure tests (Vos et al., 2020), calling for a need to strengthen the resilience of food systems to support food security for all (Bén, 2020; Zurayk, 2020).

In order to contain the impact of the COVID-19 pandemic, governments in all the countries, irrespective of their Gross National Income (GNI) per capita, imposed a range of measures (like bans on public gatherings, restrictions on mobility, temporary closure of academic institutions, markets, private, and government organizations and other measures) to prevent the spread of the virus. These collective measures are generally known as a "lockdown," which is a community containment strategy that helps to restrict the contact of unidentified or asymptomatic cases with the community (Manzar et al., 2020). This resulted in cross-cutting implications for all aspects of food systems from production, distribution, and storage to food environments, consumption, and waste, at all levels and scales (Zurayk, 2020). The lockdown measures and accompanying mobility restriction, though crucial to contain the pandemic and minimize loss of life, have created significant economic stresses with adverse consequences for food security and hunger, with populations who are already vulnerable to poverty and malnutrition being disproportionately impacted (Laborde et al., 2020). Among the worst affected are two-thirds of the world's poor comprising of smallholder farmers who depend on agriculture for income as well as for household food supply (Castaneda et al., 2016).

The agriculture sector has typically been exempted from lockdown restrictions in most of the countries to ensure continuity of food production. Although analysis at a macro-level (i.e., global and national) during the initial months of the pandemic indicated that the COVID-19 pandemic did not substantially compromise food availability (Bén, 2020; Devereux et al., 2020), later on, the negative impact on food availability was more evident in different parts of the world (FSIN Global Network Against Food Crises, 2021). Further, studies and data sets have also indicated disruptions of national and global supply chains with impacts of reduced food exports and imports on the global food market (Aday and Aday, 2020; FAO, 2020a). At the local level, multiple studies are emerging that demonstrate how food access was threatened due to supply chain disruptions coupled with other factors such as increased food prices relative to wages and income (Devereux et al., 2020). For example, the pandemic restricted the movement of people and goods as well as disrupted access to farm inputs, labor availability and schedules, transportation, safety, and management practices (Torero, 2020). This led to a cascade along agri-food supply chains, impacting markets, prices, income and livelihoods, food accessibility and security and, nutrition (Muscogiuri et al., 2020; TechnoServe, 2020). These supply chain disruptions linked to the COVID-19 lockdown have been notable among the vulnerable populations such as indigenous smallholder farmers, impacting their food environments and overall food systems (ILO, 2020). Further, the compromised diets consumed by these communities may impact their metabolic health and nutritional status, which may have important implications for the progression and pathology of COVID-19 (Muscogiuri et al., 2020), exacerbating existing health disparities.

The need for resilient and equitable food systems has been re-emphasized in response to the COVID-19 pandemic for supporting food security for all (Bén, 2020), including vulnerable populations with heightened health disparities. A food systems resilience framework addresses the complex relationships within food systems despite disturbances (Ericksen et al., 2009; Ingram et al., 2010; Tendall et al., 2015), such as climate change, habitat destruction, the current COVID-19 pandemic, as well as the interaction of these disturbances (Ahmed et al., 2020). While smallholder farmers including those in indigenous communities are vulnerable to global change including pandemics, they also variably demonstrate unique attributes of resilience concerning their food systems. Some of these smallholder farming communities are geographically positioned in the hard-to-reach and challenging terrains of low- and middle-income countries, (Rapsomanikis, 2015; Haga, 2020) where they are the crucial providers of food in areas with some of the most pressing needs for food access (Bén, 2020). Further, they contribute to national food security, especially at times when trade is compromised. They are wellpositioned to ensure continuity in food supplies amidst complex logistical and transport issues (Haga, 2020; Lopez-Ridaura et al., 2021). The use of family labor by smallholder farms may enable them to overcome possible labor shortages in the context of supply chain disruptions with regard to harvesting, getting food to market, and other farm-related activities (Haga, 2020; Tripathi et al., 2021). Based on the resilience theory, where diversity is a key socio-ecological determinant of resilience (Walker and Salt, 2012), the food systems of smallholder farmers may have more diverse types of food environments. Smallholder farmers in low and middle-income countries (LMICs) often manage wild and cultivated food environments while accessing formal and informal markets (Downs et al., 2020). It is hypothesized that access to a greater number of types of food environments in the context of global change may offer greater resilience toward supporting diets and food security (Ahmed et al., 2020).

India, a country in Southeast Asia, is home to about 120 million smallholder farmers who constitute over 80% of the agricultural sector in India (Ministry of Agriculture Farmers Welfare, 2016). The nationwide lockdown that was announced on 24th March 2020 in India, came at an unfortunate time for farmers, as it coincided with the harvest season for the *Rabi* (winter) crops in many parts of the country (GAIN, 2021). This lockdown led to the closure of multiple government and private establishments and restricted inter and intra-state movements (Hindustan Times, 2020; Kar, 2020; Times of India, 2020) which further added to the challenges around agricultural activities and the supply chain. This compounded the misery of the smallholder farmers who were already burdened by challenges around limited agrotechnology, climate change, price volatility, and rising debts (Ministry of Agriculture Farmers Welfare, 2016). All these changes worsened the living conditions of many smallholder farmers, who faced additional challenges due to loss of livelihoods and stagnant wages (Harris et al., 2020). Further, the closure of Anganwadi centres (maternal and child health centres) and schools, which are the main sites for delivery of government's supplementary feeding programs [like Integrated Child Development Services (ICDS) and Mid-day meal (MDM) programs], had exacerbated the nutritional vulnerability amongst the families of these smallholder farmer communities (Sinha, 2021).

Jharkhand, an eastern Indian state known for its rich biodiverse agroforestry (Kumar and Saikia, 2020), is home to several indigenous communities that constitute 26.2% of the state's population (Census of India, 2011). About 80% of the population in this state's rural areas derive their livelihoods from agriculture (Ministry of Environment Forests Climate Change, 2018). Most of the state population comprises smallholder farmers, with about 50% of them having land ownership of fewer than 0.4 hectares (ha). The indigenous communities of India, recognized by the government as "Scheduled tribes (STs)," are among the most food insecure and nutritionally vulnerable communities (MoHFW Ministry of Tribal Affairs, 2020; UNICEF India, 2020). A majority of these STs comprise marginal and smallholder farmers (Ministry of Tribal Affairs, 2002), who extensively rely on their indigenous local food systems for nutrition and livelihood (Bhattacharjee et al., 2009). During the countrywide lockdown imposed from 24th March to 7th June 2020, the lives of many indigenous communities in Jharkhand were affected, especially for those residing in the hard-to-reach geographies of the state (Indiaspend, 2020). Studies and surveys in Jharkhand have reported impacts on agricultural practices and livestock management as well as disruptions in supply chains and functioning of supplementary feeding programs (NABARD, 2020; State Food Commission Social Audit Unit Jharkhand, 2020; Nair et al., 2021). Estimates have suggested that disruption to nutrition programs could lead to additional cases of underweight and wasting respectively as well as an increase in deaths due to wasting in the state of Jharkhand (Rajpal et al., 2020; Roberton et al., 2020; Bahl et al., 2021).

Exploring the effect of COVID-19 pandemic and lockdown measures on the food environment of vulnerable indigenous communities of Jharkhand as well as identification of determinants of resilience is thus crucial. Hence, the present paper documents the effect of the COVID-19 pandemic on the food environment, agricultural practices, diets, and food security of vulnerable smallholder farmer households in indigenous communities of Santhal, Munda, and Sauria Paharia of Jharkhand, India. This study further explored the potential determinants of resilience with regards to the food systems of these indigenous communities during the COVID-19 pandemic. The findings from this study will provide valuable insights into the status of food systems, food security, and diets of these communities toward supporting future efforts to ensure food security in the context of global change.

METHODS

Study Area, Population, and Setting

Three indigenous communities in the Indian state of Jharkhand, namely, Sauria Paharia, Santhal, and Munda communities were included in this study. The Santhal and Munda communities were selected as these are amongst the most populous indigenous communities in Jharkhand (Census of India, 2011). In addition, the Sauria Paharia community was included in this study as it is a particularly vulnerable tribal group (PVTG) owing to its pre-agricultural level of technology, low level of literacy, economic vulnerability, and declining population (Press Information Bureau, 2019). The study population for the Household (HH) survey comprised adult members (18 years of age and above) of HHs residing in 44 study villages located in purposively selected geographically diverse blocks of Sunderpahari, Boarijor, Poreyahat, and Pathargama in Godda, and Murhu and Torpa in Khunti districts respectively (**Figure 1**). The Godda district is home to Sauria Paharia and Santhal communities, with regions surrounded by undulating uplands, long ridges, and depressions along with scattered hillocks covered with forests (Godda, 2021). The Khunti district, on the other hand, is predominantly populated by the Munda community, and 40% of the district is covered with forests, with both hilly terrain and plain lands, respectively (Singh and Kumar, 2016).

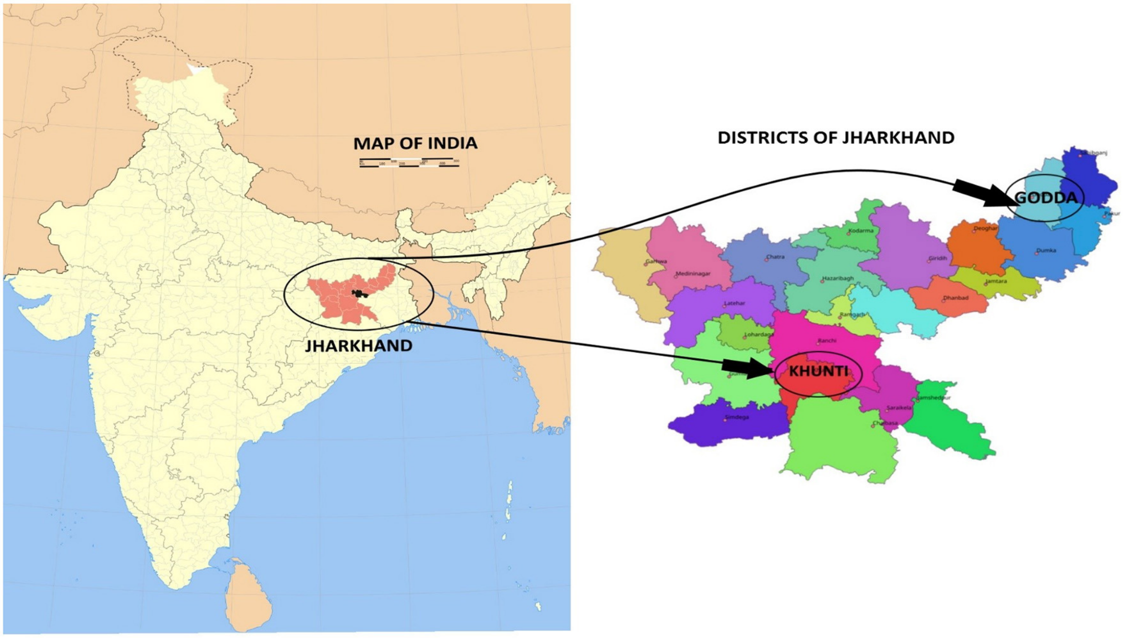

FIGURE 1 | Selection of study districts in Jharkhand.

Study Design and Duration

A serial (repeated) cross-sectional HH survey was conducted telephonically in two phases (**Figure 2**) to understand and differentiate the impact of the COVID-19 pandemic on food systems at variable levels of restrictions imposed by the national and state governments The first phase of data collection was between 25th May to 25th June 2020. This included both lockdown period and early week of post lockdown phase due to COVID-19 pandemic in the study area and is referred to as *"Lockdown phase."* During this period, most services, organizations, factories, and markets remained closed and no public gatherings and intra- or inter-state travel were allowed. The lockdown phase coincided with the sowing season of the agricultural calendar in the study area. The second phase of data collection was between 15th September to 7th October 2020 during the fourth phase of the countrywide unlock i.e., ease of lockdown restrictions in India, and is referred to as the "*Unlock phase.*" During this phase, most services, establishments, and factories were allowed to open and relaxations were announced for agricultural businesses, travel within cities, and states and selling of farm supplies in open markets. In addition, market surveys with food vendors were conducted during the third phase of countrywide unlock in August 2020 (**Figure 2**).

Study Tools

For assessing the effects of COVID-19 pandemic on food systems and agricultural practices of indigenous communities, HH surveys were conducted using a tool titled "*COVID-19 Surveillance Community Action Network* (C-SCAN)" for food systems, which was developed based on the food environment typology framework (Downs et al., 2020) and has been previously administered in China (Ahmed et al., 2020). The survey consisted of six parts and elicited information regarding the socio-demographic profiles, different types of food sources accessed, and perceptions about food security aspects including food availability, access and utilization, diets consumed, HH income, and farming and gardening systems. The survey aimed to examine how consumers (smallholder farmers) in indigenous communities interacted and utilized various types of food environments when food systems were disrupted due to shocks and stressors including the COVID-19 pandemic and associated lockdown measures. Since the hypotheses that were applied to develop the C-SCAN survey tool delineated factors that may offer resilience in different food systems, the responses were utilized to rapidly gain insights into the resiliency of indigenous food systems. Specifically, understanding the resilience of indigenous food systems in the context of COVID-19 pandemic was achieved in the C-SCAN survey tool through questions eliciting information regarding the traditional ecological knowledge of the communities, access to diverse food environments with predominant reliance on wild and cultivated food sources, access to informal built food environments that rely on locally produced foods, and farming practices that may utilize specific agroecological approaches. The questions in the C-SCAN survey tool were framed in the form of binary Yes/No responses which allowed for rapid assessment and analysis, while selected questions also had provision for further qualitative descriptions. For use in a local context, we translated the survey tool from English to Hindi to facilitate the communication of core team members with the indigenous communities, who mainly understood the Hindi language. In case of the Sauria Paharia community, where people were more comfortable with their

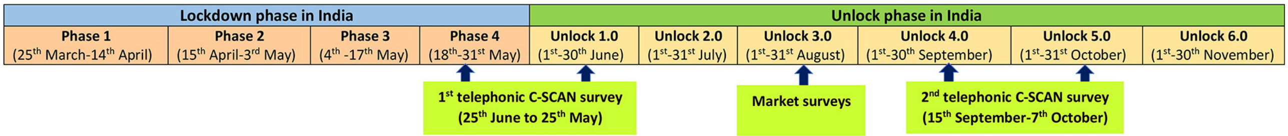

FIGURE 2 | Timeline of data collection period of C-SCAN and market survey.

native Paharia dialect, the survey was administered by local Sauria Paharia field investigators. For the market survey, a survey tool adapted from Downs et al. (2020) was administered to the food vendors by the local field investigators (who were trained by the core team on administering the survey). The market survey elicited information on the following parameters: (i) the main types of foods sold in the market in terms of food groups, (ii) food prices pre- and post-lockdown, along with perceived reasons for change, (iii) sources of food procurement and any change in procurement patterns with rationale for shifting behavior, and (iv) change in sales of specific food items (during and post lockdown) (along with perceived reasons). Additionally, a set of interview questions were also administered to the food vendors, which elicited their perceptions on post-lockdown changes in sales and income.

Sample Size Calculation

Using Epi-Info Software, Version 7.2, the sample size was calculated based on a preliminary study conducted by co-authors, which reported a 93% change in income among smallholder farmers in China, due to the COVID-19 pandemic (Ahmed et al., 2020). A sample size of 104 was estimated considering an absolute precision of 6%, a design effect of 1.5, and a 95% confidence interval. To compensate for the 50% non-response rate (considering that the survey was to be conducted telephonically in hard-to-reach rural areas of Jharkhand), a sample size of 150 was arrived at. Given the need for a rapid response to accomplish research in the context of the COVID-19 pandemic and lockdown measures, this sample size was also commensurate with the available resources required to conduct this rapid survey.

Sampling

The study villages were selected using probability proportional to size sampling as part of a larger study which is exploring the role of indigenous foods on food and nutrition security of indigenous communities of Jharkhand, details of which are reported elsewhere (Ghosh-Jerath et al., 2019). Given the extraordinary circumstances of the COVID-19 pandemic and the need to carry out rapid and continuous assessments of the effects of the pandemic and associated phases of lockdown measures on food environments and agricultural practices, we used a convenience sampling of HHs from the Sauria Paharia, Santhal and Munda communities in the selected villages that were surveyed as part of the larger study (Ghosh-Jerath et al., 2019). We further conveniently prepared a list of HHs that had access to either mobile phones or landline telephones. All HHs from this list ($n = 946$), were approached during the lockdown and unlock phase. Additional HHs in the study villages were also approached through the local field team using a snowball sampling technique (75 in the lockdown and 142 in the unlock phase). Out of all these approached HHs, 152 surveys (Sauria Paharia, $n = 49$; Santhals, $n = 35$, Munda, $n = 68$) in the lockdown phase (response rate: 14.9%) and 151 surveys (Sauria Paharia, $n = 72$; Santhals, $n = 20$, Munda, $n = 59$) in unlock phase (response rate: 13.8%) were telephonically completed (**Supplementary Table 1**).

For the market surveys, a total of eight local weekly markets (list provided as **Supplementary Table 2**) that are frequently accessed by Sauria Paharia, Santhal and Munda communities in the selected blocks of Godda and Khunti districts were purposively chosen. Additionally, a vendor survey was conducted with a convenience sample of 56 vendors (6 to 7 vendors per market) in a total of 8 markets. The criteria for the selection of the respondents (HH members and food vendors) was based upon their availability and consent for participation.

Data Collection and Data Entry

The field investigators administered C-SCAN survey tool telephonically using paper forms. The responses received were entered in the paper forms by the field investigators and shared with the core team. This ensured the necessity of social distancing in the unusual circumstances amidst the COVID-19 pandemic for safety and infection prevention while at the same time reaching out to geographically isolated communities in the state. Survey administration by local Sauria Paharia field investigators helped in efficient rapport building with the communities, thus making it easier for the community to discuss their situation openly without hesitation. For data entry purposes, the C-SCAN survey tool was incorporated in CS-Pro Software, Version 7.3, that provided in-built checks (range, context, and logic checks) for ensuring data quality. The market and vendor surveys were conducted as face-to-face interviews using paper forms by the local field investigators and the data was entered in an excel sheet.

Data Triangulation With Secondary Literature

In order to supplement our study findings, an online search was conducted to identify state and district level government reports that have documented the impact of COVID-19 pandemic on different aspects of food systems in Jharkhand. For this purpose, many ministry websites were searched. We were able to extract data on two main aspects:

(1) Food production in Jharkhand during the lockdown phase: This data was collected by the National Bank for Agriculture and Rural development (NABARD, 2020) from 29 April 2020 to 04 May 2020, through an online questionnaire that was administered to district development managers, based on their interactions with various stakeholders, viz. farmers, government officials, members of self-help groups, farmer clubs, and farmer producer organizations;

(2) District-level access to Public Distribution System (PDS) and other government food security programs during the lockdown and unlock phase. For information on this, the state website of PDS distribution (Department of Food, Public Distribution and Consumer Affairs, Government of Jharkhand, 2020) was reviewed to document the transaction status of different commodities under PDS during the pre-COVID-19 period, lockdown phase and unlock phase in Godda and Khunti districts. Additionally, a state audit report on the status of two supplementary feeding programs, namely, MDM and ICDS programs during the lockdown phase was also reviewed (State Food Commission Social Audit Unit Jharkhand, 2020).

Data Analysis

A conceptual framework (adapted from HLPE, 2020) was developed for the data analysis purpose, which delineated the possible pathways on how the COVID-19 pandemic and the resulting lockdown may have affected the food environment, food security, and food consumption patterns of the vulnerable populations. Further, based on the food environment typology framework (Ahmed et al., 2020; Downs et al., 2020), a set of factors were incorporated in this framework, that were likely to offer resilience to the COVID-19 pandemic's impact on food systems. These factors included access to diverse types of food environments, reliance on wild and cultivated food sources, possession of traditional ecological knowledge, use of the agroecological approach for food production, and access to informal built food environments that rely on local agricultural produce (**Figure 3**).

The raw data from the C-SCAN tool and market surveys were exported and cleaned in MS Excel, and the analysis was performed in Stata, version 15.1 (StataCorp, 2017). The quantitative variables were analyzed using descriptive statistics, which included computation of frequency counts and percentages for categorical variables, mean, standard deviation, median, and interquartile ranges (IQR) for continuous variables. Inferential statistical analyses were conducted using the chi-square test for comparison of categorical variables and t-test for continuous outcomes. Since we wanted to compare the characteristics of the HHs surveyed in lockdown and unlock phases, we used two-tailed tests of hypotheses and a p-value < 0.05 as the criteria for statistical significance. The qualitative responses were translated to English and cleaned by removing filler words (and, or, those, etc.) and categorized under specific additional variables (such as type of foods that were easy to access, difficult to access, reasons for change in income, etc.). Based on the conceptual framework (**Figure 3**), qualitative responses were manually coded according to key sub-theme categories and subsequently organized based on the broader concepts included in the conceptual framework. In order to substantiate the study findings, the responses from our telephonic and market surveys were further triangulated with the district level and state level secondary data.

Ethical Considerations

Necessary approvals were obtained from the Institutional Ethics Committee of Indian Institute of Public Health- Delhi Public Health Foundation of India to protect human subjects through ensuring the highest ethical standards and conduct in the present research study. Verbal informed consent was obtained from the HH survey respondents and market vendors while providing them with all necessary details regarding the study. Due permissions for recording the telephonic interviews were obtained from the respondents. All the collected data were kept confidential and safe.

RESULTS

Amongst the surveyed HHs, the majority of the respondents were males (76% in lockdown phase and 72% in unlock phase), with a mean age of 33 ± 11 and 32 ± 9 years, respectively. Most HHs practiced farming on agricultural lands, while some HHs grew food in home gardens (*Baris*). Among the PVTGs, i.e., the Sauria Paharia community, nearly three-fourths of the HHs (during the administration of both surveys) reported farming on burnt patches of forest land (known as *Kurwa* farming). Farming was the primary source of income in majority of the HHs (72% in lockdown phase and 74% in unlock phase), while some HHs (18% in lockdown phase and 17% in unlock phase) were also engaged in daily wage laboring (**Table 1**).

The following sections discuss the effect of COVID-19 pandemic and the resulting lockdown on various aspects of HH food security, i.e., food availability, access, and utilization in the three indigenous communities during the lockdown, and the unlock phases, supplemented with secondary data on food production and access to government programs. Further, findings from market and vendor surveys are presented to highlight the impact of the COVID-19 pandemic on the informal markets accessed by the three indigenous communities. Finally, findings from both C-SCAN and market surveys are dissected to explore the factors and mechanisms that offered resilience to these indigenous communities during the pandemic.

Perceived Impacts of COVID-19 Pandemic on Different Aspects of Household Food Security

Impact on Food Availability

COVID-19 Pandemic and the Food Environment

During both the lockdown and subsequent unlock phases of the COVID-19 pandemic examined here, the surveyed communities reported accessing foods mainly from their natural food environment. Specifically, they procured food from wild food environments including forests, local water bodies, and surrounding natural vegetation as well as from cultivated food environments including fields, and gardens (**Figure 4**). The Sauria Paharia HHs reported the highest availability of food from the wild food environment, while the Santhals and Mundas

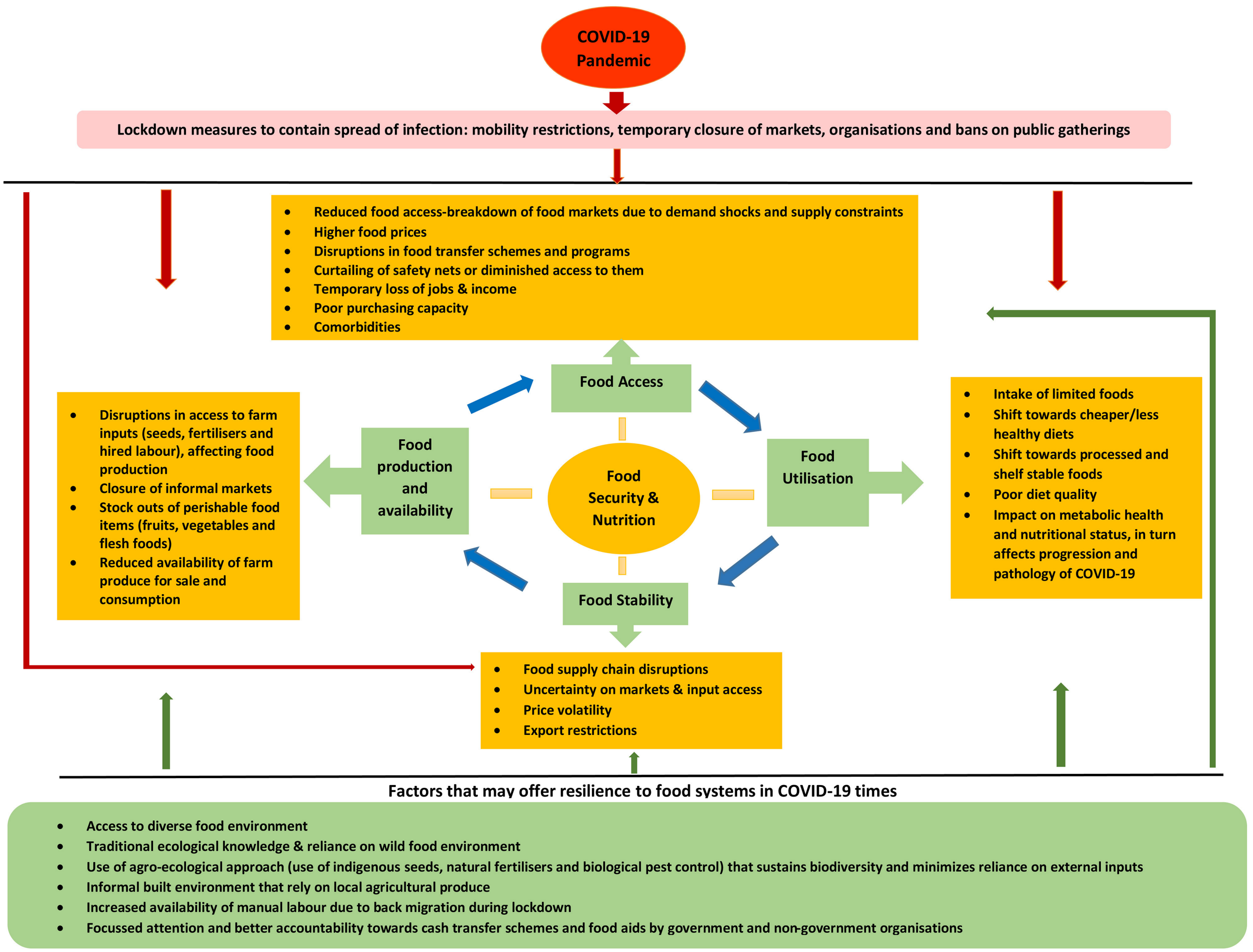

FIGURE 3 | Conceptual framework: Impact of COVID-19 pandemic on food security among vulnerable populations and factors offering resilience.

mainly reported food availability from the cultivated food environment. During the lockdown phase, a higher number of Sauria Paharia HHs reported food availability from farms, as most of the community members practiced settled agriculture on plain farmlands (done primarily once a year), at the time of the survey. On the other hand, as the community mainly sourced *Kurwa* lands during the unlock phase, a higher food availability was reported from that source. Nearly all HHs reported food availability in the built food environment including weekly informal markets, mobile vendors, and corner shops within the villages. In addition, a large majority (85.5%) of HHs from all three communities reported availability of subsidized foods in the form of grains, sugar, salt, etc., in the formal markets, which included fair price shops under PDS, a federal food security program in India. Only about one-fifth of the HHs in Santhal and Munda communities reported the availability of supplementary food in the form of take-home ration that was delivered to their door-steps from Anganwadi centers under ICDS. Among Sauria Paharias, only 2% of HHs reported availability of supplementary food from Anganwadi centers. A significant difference ($p<0.001$) was also observed in the availability of dry ration from MDM program during the two phases: due to the closure of schools, a few Santhal (14%) and Munda (3%) HHs reported receiving additional food in the form of dry rations (like cereals and pulses) through MDM, however the distribution was reportedly discontinued during the unlock phase, even though the schools remained closed.

Food Production During the COVID-19 Pandemic

The majority of the HHs (74% in lockdown and 54% in unlock phases) did not report any changes in their crop production and yields. However, disruptions in regular access to farm inputs were reported, notably in Santhal and Munda communities. A substantial number of HHs in both these communities (60–69% in lockdown and 35–47% in unlock phases) reported hardships in procuring farm inputs (seeds and fertilizers), as markets were open for limited durations (even during the unlock phase) and prices were higher owing to shortage of supplies. A few Santhal and Munda HHs also reported hardships in arranging manual labor for agricultural work owing to concerns around the spread of COVID-19 infection. During both the phases, Sauria Paharia HHs were relatively less impacted as they chiefly relied on

TABLE 1 | General profile of telephonically surveyed households belonging to indigenous communities of Jharkhand, India.

Characteristics	Lockdown phase (May-June, 2020) ($N = 152$)	Unlock phase (Sept-Oct, 2020) ($N = 151$)	p value[†]
Age of the respondent [Mean (SD)]	33.2 (±11.2)	31.52 (±8.8)	0.148
Gender of the respondent, n (%)			0.764
Male	116 (76.3)	113 (74.8)	
Female	36 (23.7)	38 (25.2)	
Households, n (%)			0.011**
Sauria Paharia	49 (32.2)	72 (47.7)	
Santhal	35 (23.0)	20 (13.3)	
Munda	68 (44.8)	59 (39.0)	
Type of farming*, n (%)			0.000**
Only Farm	18 (11.9)	30 (19.9)	
Only Kurwa	24 (15.8)	47 (31.2)	
Only Bari	3 (2.0)	1 (0.7)	
Any two sources	97 (63.9)	71 (47.0)	
All three sources	95 (62.5)	–	
None	3 (2.0)	2 (1.4)	
Primary source of income, n (%)			0.939
Agriculture	110 (72.4)	112 (74.2)	
Daily wage labor	28 (18.4)	26 (17.2)	
Others (own business, remittances, etc)	14 (9.2)	13 (8.6)	

**Multiple responses were captured as households practiced multiple types of farming.*
***$p < 0.05$.*
[†]Continuous variable (age of the respondent) following a normal distribution between the indigenous communities were compared using independent t-test and the remaining categorical variables were compared using Chi-square test.

indigenous seeds and organic manure for agriculture. In addition, about 12% of HHs ($n = 6/49$) in the Sauria Paharia community also reported greater access to foods sourced from wild food environment such as forests, local water bodies, and natural habitats. Due to a marked decline in the procurement of various agronomic inputs during the lockdown phase, a small proportion of HHs ($n = 5/103$) in Santhal and Munda communities reported a delay in the usual sowing time, while no such changes were reported during the unlock phase. In contrast, nearly three-quarters of HHs (72%) in the Sauria Paharia community reported sowing their crops earlier (as compared to pre-COVID-19 times) during the lockdown, as many migrant HH members had returned to their villages, leading to surplus manual labor for the sowing process. Surveyed HHs in Sauria Paharia community reported no changes in farming schedule during the unlock phase (**Table 2**).

The secondary data on state-level impact of COVID-19 pandemic on agriculture production in Jharkhand (NABARD, 2020) (**Figure 5**) reported similar trends. The majority of the districts (16 out of 20 surveyed districts) in Jharkhand experienced a reduction in overall agricultural production, with an average production decrease of 6.7%. However, the farm production was relatively less impacted, as compared to other allied sectors like horticulture, animal husbandry, and fisheries (a production decrease between 9 to 30%). A possible reason could be the completion of crop production and harvesting in many districts before the lockdown announcement. The farm gate prices (i.e., prices of farm produce) were adversely impacted in almost all districts, although the average % decrease (0.8%) was nominal. The main reasons cited were reduced consumer demand due to lack of transport and shutting down of local weekly markets. The lockdown restrictions further resulted in a reduced supply of farm inputs (like seeds, fertilizers, pesticides, machinery, and fodder) in many districts, which contributed to their high prices (% price hike ranging between 9 to 16%). Impact on labor supply for agricultural activities was uneven across the state: reduced labor supply was reported in 10 districts, while increased availability was reported in 8 districts. This was attributed to the return of migrant labor in their native villages. The demand for farm labor, however, reduced in many districts during the pandemic.

Concerns Regarding Future Crop Sales and Farming Patterns

The findings from telephonic survey revealed varying challenges in the three communities regarding their perception of future impact of COVID-19 pandemic on their farming patterns. During the lockdown phase, more than half the HHs in Munda and Santhal communities were concerned that the continued closure of markets might affect their future ability to purchase seeds, fertilizers, and other equipment necessary for crop production (**Table 2**). However, during the unlock phase, relatively fewer HHs in both communities were concerned regarding the purchase of external inputs for farming. Further, during the lockdown phase, HHs in all Santhal and Munda communities were concerned about the future availability of manual labor for assistance in farming due to the fear of COVID-19 virus spread and the consequent higher labor charges. HHs in all three communities reported concerns about their future crop sales, owing to the continued closure of local markets and movement restrictions across districts and states, which they perceived as likely to impact their ability to sell their farm and forest produce. A male respondent from Sauria Paharia community commented, "*As the markets are closed, fewer people from the villages will buy the (farm) produce, so it will be difficult to sell*," while another male respondent from the Santhal community opined "*Because of reduced access to labor and seeds, our crop yield might get affected, which may lead to reduced crop sales.*" This concern over future selling ability continued in unlock phase as well, with a higher number of HHs (particularly in Sauria Paharia and Munda communities) anticipating a reduction in their future crop sales, which was attributed to an increase in the number of market vendors selling their farm produce (**Table 2**).

Impact on Food Access

Direct Impact on Food Access Due to COVID-19 Pandemic and the Resulting Lockdown

Impact on Informal Weekly Markets

During the lockdown phase, a substantial number of HHs (63%) in all three indigenous communities observed changes in their access to different food environments and sources, with the highest impacts reported by the Munda community, followed by Santhals and Sauria Paharias (**Table 2**). Among these communities, about one-third of the HHs (highest in the Santhals) reported hardships in procuring food items from the local informal markets (**Figure 6**). Common reasons cited for reduced access included reduced opening hours (early mornings or late evenings) of the markets amidst the lockdown, limited diversity in available food commodities, increased food prices, and lack of transportation facilities to reach the local markets. When enquired about the impact of COVID-19 pandemic on the food prices, most HHs (87%) in all three communities observed differences in the usual pricing of the food items (**Table 2**). The respondents attributed this change to the sudden announcement of the lockdown, which led to restricted movement and hampered the timely reach of food supplies to the local market, thus leading to price fluctuations. More than half of the HHs in Santhal and Munda communities reported an increase in the prices of vegetables. In contrast, the majority of Sauria Paharia HHs reported a decrease in the prices of vegetables, owing to an improved availability through the cultivated food environment and distress selling of these commodities by the local vendors. Apart from vegetables, other food commodities like meat, poultry and fish, pulses, and cooking oils were also reportedly being sold at inflated prices, as compared to the pre-COVID-19 period

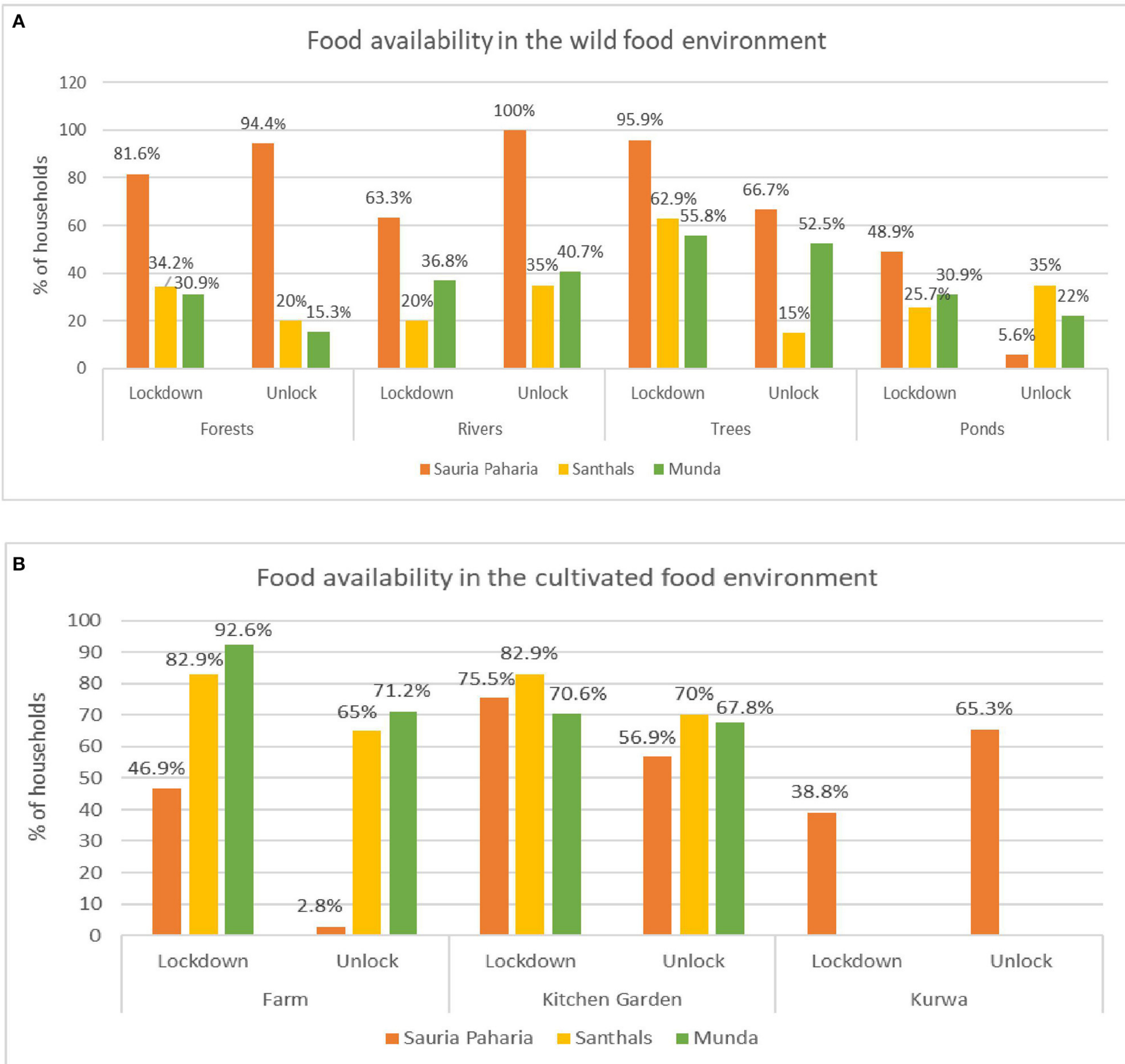

FIGURE 4 | Continued

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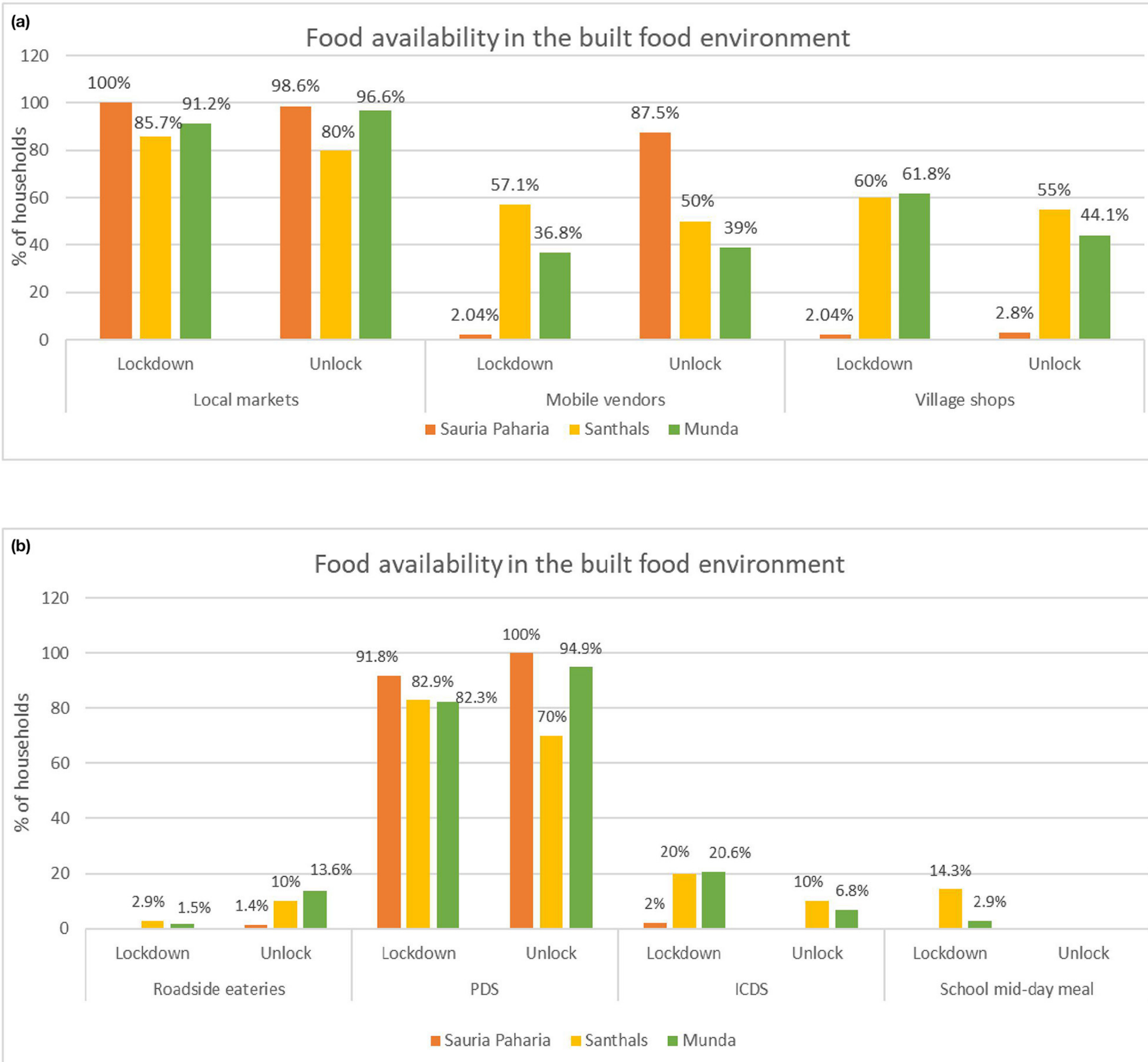


***Note: Kurwa** is a traditional farming performed by the Sauria Paharia community on the burnt patches of forest land.*

***PDS**, Public Distribution System is an Indian food security system under Ministry of Consumer Affairs, Food and Public Distribution. In this, major food commodities including staple food grains, such as wheat and/or rice, sugar and kerosene oil (a fuel used for cooking) are distributed through a network of public distribution shops (also known as ration shops) at subsidized prices. Possession of a PDS ration card (an official document entitling the holder to a ration of food) under various categories of poverty, that is, APL, BPL, and AAY, a category based on degrees of poverty, entitles the holder to access the food product at highly subsidized process.*

***ICDS**, Integrated Child Development Services Scheme is one of the flagship programmes launched by the Ministry of Women and Child Development, Government of India which adopts a multisectoral approach for the health and nutritional welfare of children (0-6 years), pregnant and lactating mothers, and women (15-45 years). It offers a package of six services i.e., supplementary nutrition, preschool non-formal education, nutrition and health education, immunization, health checkups, and referral services which are implemented through a network of anganwadi centres.*

FIGURE 4 | Food environment of the indigenous communities during the COVID-19 pandemic. **(A)** Food availability in the wild food environment during the lockdown phase (May–June, 2020) and the unlock phase (September-October, 2020). **(B)** Food availability in the cultivated food environment during the lockdown phase (May-June, 2020) and the unlock phase (September-October, 2020). **(C)** (a,b) Food availability in the built food environment during the lockdown phase (May-June, 2020) and the unlock phase (September-October, 2020).

(**Figure 7**). As a consequence, HHs, during the lockdown phase, reported decreased access to specific food items, particularly specific vegetables (20%), pulses (12%), and cooking oil (12%), from the nearby local markets. On the other hand, improved access to cereals (mainly rice) was reported in some HHs of Munda (27%) and Sauria Paharia (22%) communities (**Figure 8**).

During the unlock phase, despite easing of lockdown restrictions and resumption of the flow of food through supply networks, a large proportion of HHs (90%) in all three communities reported an increase in prices of food items, which mainly comprised of perishable foods like green leafy vegetables, meat, poultry and fish and other vegetables (**Figure 7**). However, despite the inflation in food prices, the food access during this period was reportedly similar to pre-COVID-19 period in majority of the HHs (**Figure 8**).

Impact on PDS and Other Government Food Security Programs

During the lockdown phase, improved access to formal markets (especially the PDS) was reported in one-third of the total HHs, especially among Santhal and Munda communities (**Figure 6**). Nearly, 50% of the HHs reported receiving additional amounts of food grains (rice and pulses) through PDS during the lockdown. As one male respondent from Sauria Paharia community commented "*Rice and pulses are now more easily available as government is providing ration at home and for free.*" Among Santhal HHs about 15% also reported access to hot-cooked meals for the entire family *via* the school feeding program (MDM). An additional one-fourth of the HHs in Santhal and Munda communities reported availing take-home ration from ICDS. During the unlock phase, the overall access to the formal markets was better for PDS, with 95% of surveyed HHs in all three communities reporting accessing the fair price shops and also receiving additional rations. However, fewer HHs from all three communities reported receiving additional amounts and/or varieties of food grains from PDS during the unlock phase (25%) as compared to the lockdown period (50%) (**Figure 6**). Additionally, a relatively lower proportion of surveyed HHs from Santhal (10%) and Munda (6.8%) communities reported receiving take home ration from ICDS (**Figure 6**).

The secondary data on access to government food security programs in selected study districts of Jharkhand, revealed similar outcomes during the lockdown and unlock phases. Higher amounts of rice were distributed through PDS during both lockdown and unlock phases in both Godda and Khunti districts, with additional amounts of rice and pulses distributed by Pradhan Mantri Garib Kalyan Anna Yojana (**Figure 9**). However, in the case of other commodities like wheat, kerosene oil, salt, and sugar, comparatively lower amounts were distributed during the lockdown phase in both districts, while higher amounts of wheat, salt, and sugar were distributed during the unlock phase in Khunti district. According to the State audit data for Godda district (State Food Commission Social Audit Unit Jharkhand, 2020), (conducted between 6th-17th May, 2020), utilization of MDM and ICDS programs was reportedly better than the data collected from indigenous communities of Godda district in the present study during the lockdown phase. According to the secondary data, only about 29% HHs did not receive food grains via MDM and 46% HHs did not receive food grains through ICDS. Secondary data on the audit of MDM and ICDS utilization was not available for the Khunti district.

Indirect Impact of COVID-19 Pandemic and Resulting Lockdown

Apart from directly affecting the food supply chains during the lockdown, survey findings indicate that the COVID-19 pandemic also influenced people's access to food through loss of livelihoods and income (**Table 2**). During the lockdown phase, more than three-fourths of the surveyed HHs reported a decrease in HH income, among which about 25% of the HHs lost their livelihood source altogether. Surveyed HHs from the PVTGs observed the highest impact on income i.e., the Sauria Paharias (86%), followed by the Santhal (80%) and the Munda (69%) communities (**Table 2**). Reduction in crop sales was the main concern among the communities, with significant changes experienced by the Sauria Paharias (67%). Closed markets, movement restrictions, and lack of transport facilities during the lockdown were cited as the common reasons for reduced crop sales in all three communities. One male respondent from Santhal community stated "*I cannot sell crops now as the local markets are closed and I have no other source of income*," while another male respondent from Munda community was worried about not being able to travel for work. He shared "*I cannot sell my farm produce due to the closed markets and neither can I migrate for work because of travel restrictions*." A female respondent from Sauria Paharia community mirrored similar views and stated "*We have no work now, so there is no money. We can't earn money from farming (sale of crops) also. Everything is closed due to coronavirus pandemic. Earlier we used to sell Barbatti (cowpea) and use the money to buy food, but due to lockdown, we are unable to sell, hence there is no earning*." Consequently, more than half the HHs (57%) among Sauria Paharias and one-fifth HHs in Santhal and Munda communities resorted to selling their crops at lower prices (as compared to previous years) as limited people were accessing the local weekly markets. Further, to improve their HH income, a large majority of the HHs from the Sauria Paharia community (76%) reported selling wild products (sourced from surrounding forests and wild habitats) in the weekly markets. One of the male respondents shared: *"Due to coronavirus pandemic (lockdown), we have started selling fruits-Mahua (Indian butter tree) and Aam (Mango) in the local markets. We have also started collecting leaves from the forests, which are woven and sold as leaf plates. We use the money earned from selling these items to buy food for household consumption."* A small proportion of HHs (14%, $n = 5/35$) from the Santhal community also reported this practice. The Munda community did not report this practice.

During the unlock phase, some HHs reported improvements in financial conditions as compared to the lockdown phase. However, about 40% of HHs reported a reduction in HH income, out of which around 6% HHs completely lost their livelihood source. This impact was faced uniformly across the three communities (**Table 2**). As the mobility restrictions were eased during the unlock period, half the HHs (50%, $n = 36/72$)

TABLE 2 | Perceived impacts of COVID-19 pandemic on food production and access among indigenous communities of Jharkhand, India.

Components	Lockdown phase (May-June, 2020), *n* (%)				Unlock phase (Sept-Oct, 2020), *n* (%)				*p* value†
	All indigenous communities (N = 152)	Sauria Paharia (N = 49)	Santhal (N = 35)	Munda (N = 68)	All indigenous communities (N = 151)	Sauria Paharia (N = 72)	Santhal (N = 20)	Munda (N = 59)	
Change in overall food production	12 (7.9)	3 (6.1)	5 (14.3)	4 (5.9)	4 (2.7)	–	1 (5)	3 (5.1)	0.394
Type of change									
1. Negative impact$	11 (7.2)	3 (6.1)	5 (14.3)	3 (4.4)	2 (1.4)	–	–	2 (3.4)	
2. Positive impact$	1 (0.7)	–	–	1 (1.5)	2 (1.4)	–	1 (5)	1 (1.7)	
Changes in sale of farm produce	66 (43.5)	33 (67.4)	12 (34.3)	21 (30.9)	60 (39.8)	39 (54.2)	7 (35)	14 (23.8)	0.550
Type of change*									
1. Distress selling	50 (32.9)	28 (57.1)	8 (22.9)	14 (20.6)	–	–	–	–	
2. Selling at higher prices	–	–	–	–	47 (31.2)	36 (50)	5 (25)	6 (10.2)	
3. Reduced sales	38 (23.9)	10 (20.4)	11 (31.4)	17 (25.0)	11 (7.3)	2 (2.8)	2 (10)	7 (11.9)	
4. Increased sales	–	–	–	–	3 (2)	1 (1.4)	–	2 (3.4)	
Change in farming schedule	47 (30.9)	39 (79.6)	5 (14.3)	3 (4.4)	35 (23.2)	32 (44.4)	2 (10)	1 (1.7)	0.111
Type of change									
1. Early sowing	38 (25)	35 (71.5)	3 (8.6)	–	3 (2)	1 (1.4)	2 (10)	–	
2. Delayed sowing	8 (5.3)	3 (6.2)	2 (5.8)	3 (4.4)	1 (0.7)	–	–	1 (1.7)	
3. Not sowing	1 (0.7)	1 (2.1)	–	–	31 (20.6)	31 (43.1)	–	–	
Reduced access to farm inputs	74 (48.7)	6 (12.2)	21 (60)	47 (69.1)	35 (23.2)	–	7 (35)	28 (47.5)	0.223
Reasons*									
1. Inability to purchase seeds	60 (39.5)	6 (12.2)	19 (54.3)	35 (51.5)	21 (14)	–	5 (25)	16 (27.2)	
2. Inability to purchase fertilizer	51 (33.6)	–	12 (34.3)	39 (57.4)	32 (21.2)	–	6(30)	26 (44.1)	
3. Inability to purchase seeds and fertilizers	43 (28.3)	–	10 (28.6)	33 (48.6)	19 (12.6)	–	4 (20)	15 (25.5)	
4. Reduced access to labor	22 (14.5)	–	6 (17.2)	16 (23.6)	7 (4.7)	–	1 (5)	6 (10.2)	
Concern over future impact of COVID-19 on farming									0.192
Ability to purchase seeds	72 (47.4)	7 (14.3)	20 (57.1)	45 (66.2)	33 (22.2)	–	6 (30)	27 (47.4)	
Ability to procure farm inputs	37 (24.3)	2 (4.1)	13 (37.1)	22 (32.3)	17 (11.5)	–	7 (35)	10 (17.6)	
Ability to sell crops	82 (53.9)	18 (36.7)	15 (42.9)	49 (72.1)	98 (65.8)	64 (88.9)	8 (40)	26(45.7)	
Availability of manual labor	35 (23)	2 (4.1)	13 (37.1)	20 (29.4)	6 (4.1)	–	2 (10)	4 (7.1)	
Changes in food access									0.951
1. Easier	37 (24.4)	11 (22.4)	7 (20)	19 (27.9)	27 (17.9)	7 (9.7)	3 (15)	17 (28.8)	
2. Harder	54 (35.5)	12 (24.5)	13 (37.1)	29 (42.7)	22 (14.6)	(5.6)	6 (30)	12 (20.3)	
3. Same as before	61 (40.1)	26 (53.1)	15 (42.9)	20 (29.4)	102(67.5)	61 (84.7)	11 (55)	30 (50.9)	
Change in food prices	136 (23.7)	45 (91.8)	28 (80)	63 (92.7)	137(90.7)	68 (94.4)	12 (60)	57 (96.6)	0.659
Change in sources of food access	95 (62.5)	19 (38.8)	28 (80)	48 (70.6)	37 (24.5)	–	7 (35)	30 (50.8)	0.199
Changes in diet	66 (43.4)	37 (75.5)	17 (48.6)	12 (17.6)	33 (21.9)	17 (23.6)	4 (20)	12 (20.3)	0.866
Reduced HH income	117 (77)	42 (85.7)	28 (80)	47 (69.1)	64 (42.4)	31 (43.1)	7 (35)	26 (44.1)	0.307
Reason for change*									
1. Less opportunities for daily wage laboring	68 (44.7)	21 (42.9)	14 (40)	33 (48.5)	37 (24.6)	26 (36.2)	4 (20)	7 (11.9)	
2. Reduced sale of farm produce in local markets	54 (35.5)	27 (55.1)	15 (42.9)	12 (17.6)	25 (16.6)	8 (11.2)	4 (20)	13 (22.1)	
3. Others (reduced business, lack of transport, fear of infection, migration)	2 (1.3)	1 (2)	–	1 (1.5)	9 (6)	–	2 (10)	7 (11.9)	

†Chi-square test was used to determine the differences between lockdown (N = 152) and unlock (N = 151) phases.
**Multiple reasons were reported.*
$Negative impact of COVID-19 on food production include delayed/early cultivation, high prices of seeds and farm equipment, shortage of labor and manure, etc. whereas positive impact includes more production.
HH, household.

FIGURE 5 | Impact assessment of COVID-19 pandemic on agricultural production in Jharkhand. Source: NABARD (2020).

in the Sauria Paharia community, and a few HHs in Santhal ($n = 4/20$) and Munda ($n = 6/59$) communities reported that they resumed selling their farm produce at usual market prices or even higher than usual prices (as compared to pre-COVID-19 period). However, the practice of accessing the wild environment to sustain HH income declined during this phase. During the countrywide unlock phase, as the employment opportunities improved, only a couple of HHs (two HHs in Sauria Paharia and one HH in Munda community) reported selling the forest produce in the local markets.

Community Perceptions on Their Future Food Security Status

During the lockdown phase, the majority (59%) of the HHs from the three indigenous communities expressed concerns regarding different aspects of food security in the future (**Table 2**). Sauria Paharia, the most vulnerable community among the three communities surveyed, did not report any concern regarding food availability; the main concerns among a majority of the HHs (51%) in this community were related to food affordability owing to the increased food prices. HHs in Santhal and Munda communities reported concerns related to both food availability (44%) and affordability (45%), while some HHs also stated concerns regarding safety (18%) and quality (6%) of food during the pandemic, as they were worried about contracting COVID-19 infections through the foods available in the local markets (**Table 2**). During the unlock phase, relatively fewer HHs (35%) were worried about aspects related to food security. However, in the Munda community, the majority of HHs (75%) were worried about their future HH food security status, with major concerns around the future availability and affordability of foods. Among Santhals, a limited number of HHs expressed concerns on the future status of HH food availability, while none of the HHs in the Sauria Paharia community reported any concern on either of the food security aspects.

Impact on Utilization of Food

In all three indigenous communities, the changes in food access (albeit, in relatively lower magnitude) were further reflected in the consumption patterns of the HHs. During the lockdown phase, almost half (43.4%) of the HHs reported a change in food consumption patterns, with major changes experienced by the HHs in Sauria Paharia (76%) and Santhal (49%) communities. A substantial number of HHs in Sauria Paharia and Santhal communities reported reduced consumption of meat, poultry and fish and market procured freshly prepared sweets and savories (**Figure 10**). According to the respondents, before the onset of the COVID-19 pandemic, meat, poultry and fish were consumed once every week which was restricted to only once a month during lockdown restrictions. The change was mainly attributed to high food prices and diminished food affordability of the HHs. A couple of Sauria Paharia HHs ($n = 2/49$) also perceived that meat, fish, and poultry consumption may lead to COVID-19 infection. The Santhal HHs further reported consuming a less diverse diet consisting of mainly plain rice to save and stock up the other food items for future consumption. One Santhal respondent commented, "*Before we used to eat rice, pulses, and vegetables, but now we are consuming only plain rice with rice water*," while another respondent shared, "*We cannot eat pulses now. We only eat plain rice with mango chutney (paste) nowadays*." Although no major variations were observed among Munda HHs, some HHs ($n = 5/59$) reported consuming all food items in reduced quantities, due to their poor purchasing capacity during the lockdown.

The surveyed HHs in all three indigenous communities also reported a higher intake of certain food items during the lockdown phase. A small proportion of HHs (in Sauria Paharia and Santhal communities) reported stocking up on the fresh farm and kitchen garden produce, to meet their overall food requirements. These activities were undertaken to mitigate the effect of reduced HH earnings and food price inflation in the local markets. For instance, more than one-third of the HHs in Sauria Paharia community reported higher consumption of farm-produced grains (rice and maize), home-grown indigenous pulses (like Horse gram, Cowpea, Rice bean, and Red gram), and wild leafy vegetables collected from the forests. During the unlock phase, only a fifth of the total HHs reported changed consumption patterns. A relatively lower number of Sauria Paharia and Munda HHs reported reduced consumption of

***Note:** Wild food environment refers to forests, rivers, and streams; cultivated food environment includes agricultural fields, kitchen gardens and pastures; informal market refers to local markets, mobile vendors, street vendors, village corner shops and roadside hotels; and formal markets refers to government nutrition programmes like Public Distribution System, Integrated Child Development Services and School Mid-day meals.*

FIGURE 6 | Impact of COVID-19 pandemic on household food access in indigenous communities of Jharkhand, India. **(A)** Number of HHs citing places that were easier to access for food during the lockdown phase (May-June, 2020) and the unlock phase (September-October, 2020). **(B)** Number of HHs citing places that were difficult to access for food during the lockdown phase (May-June, 2020) and the unlock phase (September-October, 2020).

Tribal Group	Phase		Cereals (n)	Pulses (n)	Green leafy vegetables (n)	Other Vegetables (n)	Roots and Tubers (n)	Fruits (n)	Milk (n)	Meat, poultry and fish (n)	Cooking oil (n)	Sugar (n)	Condiments and spices (n)	Market procured freshly prepared-RTE food products (n)
Sauria Paharia (n= 49)	Lockdown	Foods that were higher in price	2	7	0	7	3	0	0	37	11	1	7	5
		Foods that were lower in price	0	0	0	33	0	0	0	0	0	0	0	0
Sauria Paharia (n= 72)	Unlock	Foods that were higher in price	0	0	22	47	44	0	0	36	1	0	0	0
		Foods that were lower in price	0	0	0	0	0	0	0	0	0	0	0	0
Santhal (n=35)	Lockdown	Foods that were higher in price	8	14	0	20	6	2	1	0	17	0	1	0
		Foods that were lower in price	0	0	0	5	0	0	0	0	0	0	0	0
Santhal (n=20)	Unlock	Foods that were higher in price	1	0	0	11	5	0	0	0	5	0	0	0
		Foods that were lower in price	0	0	0	0	0	0	0	0	0	0	0	0
Munda (n=68)	Lockdown	Foods that were higher in price	11	21	4	45	3	0	0	3	40	0	2	0
		Foods that were lower in price	0	0	0	5	0	0	0	0	0	0	0	0
Munda (n=59)	Unlock	Foods that were higher in price	14	16	4	47	7	0	0	4	22	0	3	0
		Foods that were lower in price	0	0	0	1	0	0	0	0	0	0	0	0

RTE, Ready to eat

***Note:** Green shading represents the foods that respondents indicated were lower in price during the lockdown and unlock phases. Darker green colors reflect higher number of respondents indicating that these foods were lower in price. Red shading represents the foods that respondents indicated were higher in price during the lockdown and unlock phases. Darker red colors reflect a higher number of respondents indicating that these foods were higher in price.*

FIGURE 7 | Impact of COVID-19 pandemic on food prices in tribal regions of Jharkhand, India.

Tribal Group	Phase		Cereals (n)	Pulses (n)	Vegetables (n)	Cooking oil (n)	Meat, poultry and fish (n)	Condiments and spices (n)
Sauria Paharia (n= 49)	Lockdown	Foods that were easier to access	11	1	0	0	0	0
		Foods that were difficult to access	7	3	7	3	0	2
Sauria Paharia (n= 72)	Unlock	Foods that were easier to access	6	0	0	0	0	0
		Foods that were difficult to access	0	0	0	0	0	0
Santhal (n=35)	Lockdown	Foods that were easier to access	4	3	0	0	0	0
		Foods that were difficult to access	4	7	10	2	0	1
Santhal (n=20)	Unlock	Foods that were easier to access	0	0	0	0	0	0
		Foods that were difficult to access	1	0	0	0	0	0
Munda (n=68)	Lockdown	Foods that were easier to access	18	13	7	0	0	0
		Foods that were difficult to access	3	8	13	13	1	2
Munda (n=59)	Unlock	Foods that were easier to access	11	3	3	1	0	0
		Foods that were difficult to access	1	2	1	0	0	0

Note: *Green shading represents the foods that respondents indicated were easier to access during the lockdown and unlock phases. Darker green colors reflect a higher number of respondents indicating that these foods were easier to access. Red shading represents the foods that respondents indicated were difficult to access during the lockdown and unlock phases. Darker red colors reflect a higher number of respondents indicating that these foods were difficult to access.*

FIGURE 8 | Impact of COVID-19 pandemic on food access in different indigenous communities of Jharkhand, India.

meat, poultry and fish and a couple of Munda HHs ($n = 6/59$) demonstrated reliance on their farm and kitchen garden produce to meet their day-to-day consumption needs (**Figure 10**).

Impact of COVID-19 on Informal Markets of Jharkhand, India

Impact on Food Prices and Retail

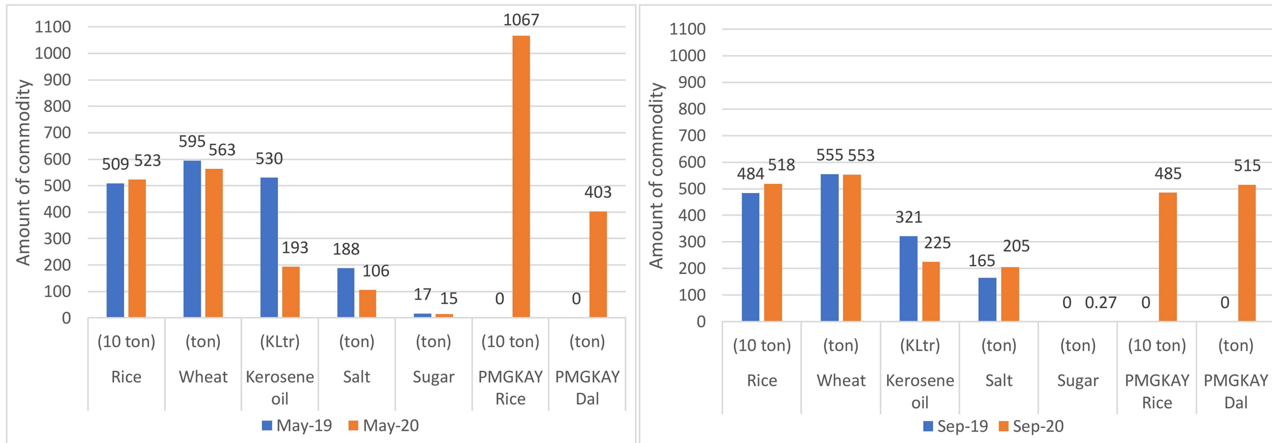
Based on the market surveys conducted (in August 2020) during the third unlock phase in India, notable impacts of the COVID-19 pandemic, and mitigation measures were observed on the prices and sales of food items available in the informal markets of Godda and Khunti districts in Jharkhand. In the local informal markets of Godda district ($n = 6$) that cater to Sauria Paharia and Santhal communities, decreased prices of indigenous cereals (rice, maize, and pearl millet) were reported (**Figure 11A**), due to better food distribution through PDS during the pandemic, resulting in lower consumer demand for the food grains. As a result, vendors in 2 out of the 6 surveyed markets reported reduced sales of cereals. Some varieties of indigenous pulses (including horse gram and cowpea) and vegetables (including kovai and bittergourd) were reportedly being sold at lower prices in all the six markets surveyed, due to their better availability via the local cultivated food environment. Owing to continued restrictions on wage laboring and allied jobs during the unlock phase, many HHs had resorted to distress selling, which, in turn, contributed to surplus availability of indigenous vegetables and pulses. However, despite the reduction in their prices, reduced sales of pulses and vegetables were reported (in 4 out of 6 markets), owing to market restrictions that continued even during the unlock phase of 2020. Concurrently, a retail price hike was reported for market-based pulses (including lentils, red gram, green gram, and chana dal) in Imru market, and for meat, poultry, and fish in all the markets due to an impact on the food supply chains during the pandemic (**Figure 11A**), which led to reduced sale of these foods. Among the roots and tubers food category, potatoes were being sold at higher prices than usual in 3 out of 6 markets, however, onions were being sold at lower prices in 5 out of 6 markets, while prices of ginger and garlic remained the same. The sale of very limited fruit varieties was reported in all the six markets, with a slight reduction in their prices. An increase in the prices of cooking oil (3 out of 6 markets), sugar (all the 6 markets), and a slight increase in the prices of condiments and spices (2 out of 6 markets) were observed. The prices of some of the freshly prepared ready-to-eat sweets and savories (*jalebi, rasgulla, aloo chop*) increased in the range of 18.5 to 21.3% (**Figure 11A**), however, no changes were observed in their sales.

In the local markets of Khunti district ($n = 2$) (catering to Munda community), only hybrid rice varieties were available, which were being sold at higher prices (percentage increase by 13.4%) (**Figure 11B**) due to the disrupted supply chains. Similar to informal markets of Godda district, the market vendors in Khunti district reported a price hike for market-based pulses (in Tapkara market) and reduced prices of indigenous pulses (in Torpa market) and other vegetables, In the case of roots and tubers, variable changes were observed in the prices of potato and colocasia across the two markets; however, garlic and ginger became cheaper. Price inflation was observed for meat, poultry and fish across all markets (percentage increase of 12% to 25%) (**Figure 11B**) due to supply chain disruptions and reduced consumer demands. Prices of packaged foods and freshly prepared foods remained the same (except for *samosa*), yet their sales were significantly reduced, due to the low consumer demand during the pandemic.

Perceived Impacts on Market Vendors and Their Earnings

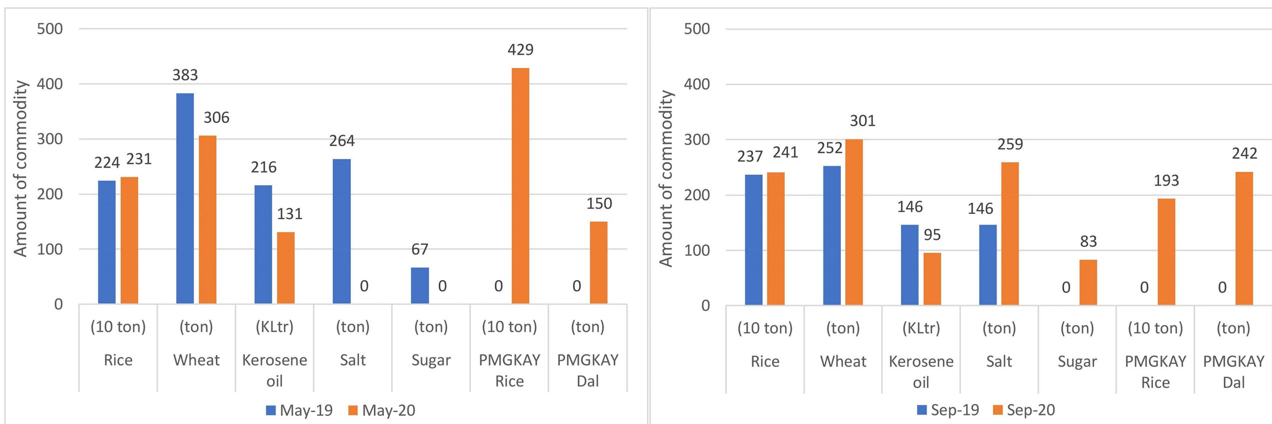
We further observed impacts on the income and livelihoods of the local vendors in the local markets of the Godda and Khunti districts of Jharkhand. Due to fear of the COVID-19 virus, shutting down of markets, and reduced sales, a relatively small number of vendors were selling cereals, vegetables, and meat, poultry and fish in the markets catering to the Sauria Paharia and Santhal communities ($n = 6$). In almost all of the surveyed markets (5 out of 6 markets), fewer vendors were selling freshly prepared sweets and savories than usual as they couldn't afford the raw materials for preparation (owing to a hike in their prices). In markets catering to Munda community ($n = 2$), a large number of people were selling vegetables due to their surplus

A



Source: Department of Food, Public Distribution & Consumer Affairs, Government of Jharkhand 2021

B



Source: Department of Food, Public Distribution &Consumer Affairs, Government of Jharkhand 2021

Note: *PMGKAY refers to Pradhan Mantri Garib Kalyan Anna Yojana launched by the Government of India, Ministry of Consumer Affairs, Food & Public Distribution on 26 March 2020 which provides an additional quota of free-of-cost 5 kg of food grains (Rice/Wheat) and 1 Kg of dal per person per month, to all the priority households (ration card holders and those identified by the Antyodaya Ann Yojana scheme) over and above their regular monthly entitlements.*

FIGURE 9 | Distribution status of communities under PDS in study districts of Jharkhand. **(A)** Transaction status of various commodities under PDS during pre-covid time (May 2019) v/s lockdown time (May 2020) and pre-covid time (September 2019) v/s unlock time (September 2020) in Godda, Jharkhand. **(B)** Transaction status of various commodities under PDS during pre-covid time (May 2019) v/s lockdown time (May 2020) and pre-covid time (September 2019) v/s unlock time (September 2020) in Khunti, Jharkhand. Source: Department of Food, Public Distribution and Consumer Affairs, Government of Jharkhand, 2020.

stocks from local produce, while on the other hand, a smaller number of vendors were selling meat, poultry and fish, packaged foods, and freshly prepared savories and snacks owing to their higher retail prices and reduced demand.

When inquired about the impact of COVID-19 pandemic on their income, the Godda and Khunti districts' market vendors reported similar changes. The vendors selling cereals, pulses, and vegetables in both districts reported reduced incomes, and cited factors like improved access to PDS and closed markets as the main reasons for income loss. On the other hand, vendors selling meat, poultry and fish, packaged foods, and freshly prepared foods in markets of Godda district reported an increase in their overall income owing to increased prices of the food items, in comparison to the pre-COVID-19 period. However, in Khunti district, these vendors experienced relatively lower incomes (in comparison to the pre-COVID-19 period) owing to the reduced consumer demand for these foods.

Factors Offering Resilience During the COVID-19 Pandemic

Based on the responses from the HHs, certain practices of the indigenous communities were found to demonstrate resilience in response to the impact of COVID-19 pandemic on their food consumption patterns, income generation, and farming systems. Among Sauria Paharias HHs, access to the wild and cultivated food environment was the primary factor that offered resilience in the face of the COVID-19 pandemic. Through our C-SCAN

Tribal Group	Phase		Cereals (n)	Pulses (n)	Green leafy vegetables (n)	Other vegetables (n)	Fruits (n)	Roots and Tubers (n)	Milk & milk products (n)	Meat, poultry and fish (n)	Cooking oil (n)	Sugar (n)	Condiments and spices (n)	Market procured freshly prepared-RTE food products (n)
Sauria Paharia (n= 49)	Lockdown	Foods that were consumed more	2	13	0	5	0	0	0	0	0	0	0	0
		Foods that were consumed less	0	1	0	2	1	0	6	32	4	7	4	5
Sauria Paharia (n= 72)	Unlock	Foods that were consumed more	1	11	2	1	0	0	0	0	0	0	0	0
		Foods that were consumed less	0	0	5	3	0	0	0	12	0	0	0	0
Santhal (n=35)	Lockdown	Foods that were consumed more	2	2	0	3	0	0	0	0	0	0	0	0
		Foods that were consumed less	0	0	1	5	0	0	0	1	0	0	0	0
Santhal (n=20)	Unlock	Foods that were consumed more	1	0	2	2	0	1	0	0	0	0	0	0
		Foods that were consumed less	0	3	0	1	0	0	0	9	0	0	0	0
Munda (n=68)	Lockdown	Foods that were consumed more	1	0	0	1	0	0	0	0	0	0	0	0
		Foods that were consumed less	0	0	1	3	0	0	0	1	0	0	0	0
Munda (n=59)	Unlock	Foods that were consumed more	4	5	3	4	0	0	0	0	0	0	0	0
		Foods that were consumed less	0	0	0	2	0	0	0	8	0	0	0	0

RTE, Ready-to-eat

Note: Green shading represents the foods that respondents indicated were consumed more during the lockdown and unlock phases. Darker green colors reflect a higher number of respondents indicating that these foods were consumed more. Red shading represents the foods that respondents indicated were consumed less during the lockdown and unlock phases. Darker red colors reflect a higher number of respondents indicating that these foods were consumed less.

FIGURE 10 | Impact of COVID-19 pandemic on food consumption pattern in tribal regions of Jharkhand, India.

survey findings, it was observed that several Sauria Paharia HHs relied on wild edible plants from their local wild habitats as well as produce from the *Kurwa* lands and kitchen gardens for fulfilling their day-to-day food consumption needs. They also utilized the wild food environment for additional income generation by selling the wild produce in the local markets. Another notable factor bolstering the resilience of HH in response to COVID-19 pandemic in our study was the improved supply chain for formal food markets, especially the government-supported program of PDS.

The transport disruption and market closures associated with the COVID-19 pandemic led to hardships among Santhal and Munda HHs in procuring farm inputs. However, the Sauria Paharia HHs, a large proportion of whom still relied on indigenous seeds (Ghosh-Jerath et al., 2020, 2021), were relatively less impacted during the lockdown and post lockdown phase compared to the other surveyed communities. The community utilized local inputs i.e., their indigenous seeds and compost, during the sowing season. Further, HHs in the community reported better access to labor during the sowing season, owing to the back migration of individuals returning to the community from their place of work in urban areas. One respondent stated, "*Earlier, we used to hire manual labor but since everyone is at home due to the lockdown, the entire family is working on the farms because we don't have the money to hire labor during this period*." In addition to this, a better access and dependence on diverse food sources (i.e., access to wild and cultivated food environment) among all three indigenous communities, offered them resilience and facilitated better food security with reference to food production, availability, and access during the lockdown phase of the pandemic. These findings concurred with the factors highlighted in the conceptual framework that may offer resilience in the context of shocks to the food system (**Figure 3**).

DISCUSSION

Administration of a rapid tool (C-SCAN) based on a food environment typology framework along with a market survey in Jharkhand state of eastern India highlighted how the COVID-19 pandemic adversely impacted the ability of the indigenous communities to procure sufficient, affordable, and nutritious foods while highlighting resilience attributes of indigenous food systems for supporting food security. Findings from the market surveys revealed variability in prices of commodities: reduced supplies led to a price hike while lower consumer demand resulted in reduced prices. Better outreach of PDS, access to diverse food environments and locally produced food resources were identified as critical factors for enhancing the food security of the surveyed communities in the context of the COVID-19 pandemic. However, some of the supplementary feeding programs were sub-optimally utilized due to the closure of the distribution platforms.

Impact on Agricultural Practices, Food Production and Supply Chains

During both the lockdown and unlock phases of the COVID-19 pandemic control measures, the majority of the study respondents did not report any effects on agricultural yields. Similar findings were observed in our secondary review, which highlighted minimal impacts on farm production in Jharkhand, although the allied sectors (e.g., horticulture) were adversely affected. The Munda and Santhal communities reported facing challenges in the procurement of farm input supplies during the lockdown phase, while a few respondents from the Sauria Paharia community reported the practice of early sowing due to availability of family members, owing to reverse migration. Similar disruptions in food production and availability of farm inputs due to transport restrictions have been reported in other studies across India (Harris et al., 2020; Nandi et al., 2021). The concerns regarding lack of manual labor during harvesting and sale of produce (especially perishable commodities) have also been reflected in data from the Indian states of Bihar, Rajasthan and Maharashtra (Kapil, 2020). This could be due to the absence of public procurement institutions for agricultural inputs as well as the labor-intensive cultivation among the smallholder farmers. The experiences of the indigenous smallholder farmer

A

Food groups \ Market name	Percentage change in the prices of foods (%)					
	Imru haat	Agiamore haat	Sindrimore haat	Rampur haat	Gariyal chowk haat	Chandna haat
Cereals	-10.5	-14.6	-10.1	-15.7	-6.8	-15.7
Pulses & Legumes	26.8	-8.4	-2.8	-2.8	-3.4	-7.0
Green leafy vegetables	NA	NA	NA	NA	NA	NA
Other vegetables	-33	-38	-28.6	-28.6	-32.3	-36.7
Roots &Tubers	10	-9.4	-8.6	-8.0	-7.5	8.1
Fruits	16.7	-5.0	-4.4	-3.3	0.0	NA
Meat, poultry and fish	27.6	10.2	28.8	23.4	19.3	16.8
Sugar	4.8	10.0	10.0	10.0	10.0	10.0
Condiments and Spices	0	0.0	0.0	0.0	5.0	5.0
Cooking oil	0	NA	10.0	0.0	20.0	20.0
Freshly prepared RTE foods	21.3	19.8	18.6	18.6	18.5	18.5
Packaged foods	0	0.0	0.0	0.0	0.0	0.0

B

Food groups \ Market name	Percentage change in food prices (%)	
	Tapkara Market	Torpa Market
Cereals	13.3	13.3
Pulses & Legumes	19	-35.7
Green leafy vegetables	0	0
Other vegetables	3.7	-13.8
Roots &Tubers	-8.3	-33.3
Fruits	16.7	NA
Meat, poultry and fish	25	12
Sugar	0	0
Condiments and Spices	0	0
Cooking oil	8.3	9.1
Freshly prepared RTE foods	-13.6	0

NA, Not available
RTE, Ready-to-eat
***Note:** Haat refers to the local weekly market*
Green shading represents the food groups that market vendors indicated were sold at lower prices during the unlock phase as compared to the pre-covid times. Darker green colors reflect a higher percentage decrease in the food prices. Red shading represents the food groups that market vendors indicated were sold at higher prices during the unlock phase as compared to the pre-covid times. Darker red colors reflect a higher percentage increase in the food prices. Yellow shading represents no change in the food prices.

FIGURE 11 | Impact of COVID-19 pandemic on the retail prices of the food groups in the informal markets in indigenous communities of Jharkhand, India. **(A)** Impact of COVID-19 pandemic on retail prices of food groups in the informal markets of Godda district, Jharkhand, India, catering to Santhal and Sauria Paharia communities. **(B)** Impact of COVID-19 pandemic on retail prices of food groups in the informal markets of Khunti district, Jharkhand, India, catering to Munda community.

communities in India could hence be useful for designing future relief packages, responsive to the cropping patterns, local availability of farm inputs, labor and access to markets. This could be a crucial step toward building of resilient farming systems in the face of similar future shocks (Ceballos et al., 2020).

Impact of Supply Chain Disruptions on Built Food Environment

A distinct variability was reported by all the three communities as well as the market vendors regarding the availability of food commodities from the built food environment, especially the informal markets with price inflation for specific food commodities (including pulses, meat, poultry and fish, oils, some vegetables) due to supply chain disruptions on one hand, and higher availability of local perishable produce (especially vegetables) leading to distress selling, lower demand and resulting lower prices. Disrupted access to informal markets has been reported in other studies, as is supply chain disruption leading to a decrease in the availability of vegetables and fruits in these informal markets (Harris et al., 2020; Mahajan and Tomar, 2020). Further, adverse impacts on weekly informal markets were reported in almost all surveyed districts in Jharkhand, during the lockdown phase (NABARD, 2020). Studies have documented both distress selling for income generation (The New Indian

Express, 2020; Cariappa et al., 2021; Rao, 2021), and price hikes in food commodities ascribed to movement restrictions that also limited arbitrage possibilities across cities after the lockdown (Narayanan and Saha, 2020; Sukhwani et al., 2020; Varshaney et al., 2020). The variable changes in commodity prices during the lockdown phase were likely driven by the nature of the commodity e.g., vegetables/fruits in terms of their availability from nearby regions or being a market-based commodity (like non-indigenous pulses and meat, poultry and fish) dependent on transportation networks and *mandi* inventories. Shorter supply chains can not only provide a buffer during such global crises, due to their rooted presence in the region, and proximity to the consumers but may provide a boost to the local micro-economy as well (Cappelli and Cini, 2020). This is particularly pertinent in the Indian scenario where there is a huge dependence on the agrarian economy (50% of India's total workforce) making the localized food chain, food processing, and allied sectors the bulwark for an uninterrupted food supply (Thulasiraman et al., 2021).

Improved Access to Formal Markets and Government Food Security Programs

In contrast to variations in access to food in informal markets, improved access to formal markets was reported for government-supported programs like the PDS (Kaur, 2020), and in some cases from the school meal program i.e., MDM. This improved access was reflected in almost all HHs accessing the fair price shops and other COVID-19 welfare schemes like Pradhan Mantri Garib Kalyan Yojana. Similar trends were reported for access to formal markets under government programs especially the PDS in many other states, reflecting an improved outreach (Lahoti et al., 2020; Pande et al., 2020) and was of immense importance in providing relief during the various lockdown phases (Sinha, 2021), despite the challenge of reaching all segments of the population consistently. While the additional provision of cereals and pulses through PDS was important for ensuring food security, it was not a sufficient measure to address the widespread prevalence of micronutrient malnutrition among the indigenous communities, that may have worsened during the pandemic (Gupta et al., 2021). Further, provision of non-perishables like rice, wheat and pulses, instead of diverse nutritious foods, may have further reinforced the consumption of cereal-based monotonous diets lacking in essential nutrients (Headey and Ruel, 2020). It is thus important to include nutrient-dense foods like millets (finger millet, sorghum) in the distribution basket of PDS, which may prove beneficial in improving the diet quality and nutritional status of these vulnerable populations, especially in situations when market access and income flow is severely affected (Gupta et al., 2021).

Though our study communities reported reduced access to supplementary feeding programs like ICDS, the district level data indicated a better utilization. This discrepancy could be attributed to the poor access to hard-to-reach villages, thus resulting in poor uptake of the specific schemes and interventions during the pandemic owing to center closures, supply chain disrruptions, and in some cases, repurposing of the local frontline workers for COVID-19 pandemic mitigation efforts like awareness generation, mask distribution and production, etc (KMPG, 2020). The disruption in the ICDS and MDM program as reported in our study and other reports may have a long-term impact on the nutritional status of vulnerable children who depend on these feeding programs to meet their nutritional needs (Bahl et al., 2021). Hence, it is important to keep these programs operational and continue the distribution of additional food and micronutrient supplements for pregnant women, adolescents and children, by strengthening the delivery systems while adhering to the social distancing norms (Haque et al., 2020).

Disruption in Livelihoods

The lockdown and the staggered unlock phases resulted in significant impacts on the livelihoods and incomes of the majority of respondents, with Sauria Paharias reporting the largest impact. These losses were attributed to a reduction in the sale of agricultural produce, or distress selling at lower prices. Similar findings were highlighted in a nationwide survey on informal workers that reported a high level of unemployment in Jharkhand during lockdown (95%) and unlock phases (62%), which resulted in indebtedness in nearly one-fourth of the population during both phases (Action Aid, 2020). Other studies have documented a loss of daily wage jobs in the range of 45–65% among rural migrants from Bihar and Jharkhand (Imbert et al., 2020; Save the Children, 2020), during the lockdown and post-lockdown period. The role of MGNREGA (Mahatma Gandhi National Rural Employment Guarantee Act) was found to be limited in this context; only 30% of the registered ST HHs in Godda and Khunti districts of Jharkhand, received employment during the entire period of 2020 (Mahatma Gandhi National Rural Employment Guarantee Act Jharkhand, 2020). In our study, most HHs in Santhal and Munda communities who suffered a loss of income during the lockdown phase were able to return to their usual ways of livelihood, but a considerable share of Sauria Paharia HHs continued facing difficulties in improving their income flow during the unlock phase. Studies suggest that prolonged income losses in such vulnerable communities may further lead to negative coping strategies, like distress sale of assets, predatory loans or child labor (WHO, 2020; ILO and FAO, 2021). It is thus essential to safeguard the vulnerable populations with stable cash flow through strategies like direct cash transfer programs and strengthening of existing employment guarantee schemes (like MGNREGA) (Dev, 2020).

Impact on Dietary Intake

A significant proportion of the respondents from all communities in our study reported a change in their dietary intake patterns with a decrease in dietary diversity. An increase in consumption of certain foods, especially locally grown indigenous produce, was also reported. Similar to our study findings, other studies from India and elsewhere have reported an impact on overall diets and a decrease in diet diversity scores of the communities (Harris et al., 2020; Bauza et al., 2021; Kansiime et al., 2021; Kusuma et al., 2021). Some reports suggest similar patterns of increased consumption of vegetables but a decrease in consumption of meats and dairy; others report dietary changes linked to food security status (Cicero et al., 2021; Litton and Beavers, 2021). It is worth highlighting here that the ability to consume one's own produce can be somewhat protective toward ensuring dietary diversity when other food access options are compromised.

Factors That May Offer Resilience to Food Systems Shocks Such as the COVID-19 Pandemic

Our telephonic survey provided a snapshot of various dimensions of food security that were affected in the study communities. While the COVID-19 pandemic situation posed many challenges both during and after the lockdown, we have identified several attributes in the survey responses that could offer resilience and inform preparedness for such unprecedented calamities in the future. One of the attributes that decreased the negative impact of the COVID-19 pandemic and associated mitigation measures on agricultural productivity among the Sauria Paharias was the availability of family members for sowing and farming practices. The increased use of family labor may incidentally provide some relief to smallholder farmers to overcome possible labor shortages around harvesting, getting food to market, and other farm-related activities (Haga, 2020). Recently, the Food and Agriculture Organization (FAO) has recognized family farmers as the custodians of multi-cropping systems, who may have the potential to enhance HH nutritional security, improve resilience to crop failures and price shocks, reduce migration and eradicate poverty. However, to turn this potential into reality, family farming needs an enabling policy environment, that promotes their access to natural resources and provides them with employment and social protection. With FAO's involvement in different family farming projects across the globe, this opportunity could be leveraged to raise awareness, scale-up support and enhance the capacities of local institutions and organizations for implementation of integrated family farming and rural developmental strategies (FAO, UN, 2018).

The Sauria Paharia's traditional practice of sowing indigenous varieties of seeds also offered resilience in the context of seed shortages since they were not exclusively dependent on the market availability of these farm inputs. The improved access to government-supported programs like PDS through formal food markets also proved to be a critical support measure. Our findings highlight that the traditional attributes of food systems need to be strengthened further and activities such as providing THR at the doorsteps of HHs during catastrophes need to be enhanced. In addition, the mitigating factors that addressed lower dietary intakes identified in the present study could serve as leverage points for the future. For certain food items in the local markets e.g., vegetables, the shorter supply chains were demonstrated to be beneficial in maintaining their availability. In fact, there were issues around the decrease in the availability of specific food items like oils and meat, poultry and fish as they were either cultivated or processed farther from the final point of sale (Mahajan and Tomar, 2020). It is important to recognize that while indigenous smallholder farmers are vulnerable with respect to their geographical location, they can also demonstrate resilience with respect to their food systems. Thus, these smallholder farmers can potentially be the most important providers of food in contexts where the need to enhance food security is greatest. Further, they can also effectively serve domestic markets, especially at times when trade is compromised. Smallholder farmers are wellplaced to continue the supply of food in situations where the COVID-19 crisis has created complex logistical and transport issues (Haga, 2020). An increase in foraging of wild foods also supplemented the diets of our study communities and provided an additional source of income. Although studies from Africa and Latin America (Blaney et al., 2009; Powell et al., 2011; Termote et al., 2012) have documented the role of agroforestry systems in enhancing the dietary diversity, evidence on contribution of wild foods and tree-based agriculture systems toward nutrition and livelihood security among smallholder farm communities, remains largely under-researched. In our study findings, we observed a clear dependence of the communities on the natural environment for food and livelihood at the time of crisis. Hence, a greater focus on sustainable use of wild produce will be crucial in initiating global efforts toward a more food secure and nutritionally sensitive future among vulnerable populations (Sunderland et al., 2013).

Study Limitations

Since the present study was based on a telephonic mode of data collection, there were a few limitations that may have impacted our study findings. First, as our study sample resided in hard-to-reach areas, most of the HHs could not be contacted due to poor network and call failures. Nonetheless, the possibility of a high non-response rate was considered while calculating the study sample size. Second, the telephonic nature of the survey often resulted in respondent fatigue, which may have influenced their responses. Third, although the study team had field staff speaking the local language, language and cultural barriers may have influenced some responses. Fourth, in the case of HHs where women were principally involved in food production and/or collection and preparation, telephonic interviews with male respondents may have influenced our study findings to some extent. Fifth, the purposive selection of study samples for both telephonic and market surveys may have induced some researcher bias, that could have an impact on the generalization of our study findings. However, we have tried to address this limitation by triangulating our study findings with secondary data from state and district level reports. Lastly, as the present study was a serial cross-sectional study, our findings cannot be used for establishing causality, drawing inferences at the individual level and effects of HH-level attributes toward the study results and resilience. However, the findings have provided some crucial information on how the COVID-19 pandemic has variably affected the food systems of the three indigenous communities. The mixed-methods approach has further been able to capture the community-level factors that may offer resilience in the context of food availability, access, and utilization.

CONCLUSION

This study highlights how the COVID-19 pandemic affected the ability of indigenous communities in Jharkhand state of India to procure sufficient, affordable, and nutritious foods while aspects of the indigenous food systems of the surveyed communities displayed crucial features of resilience to support the key pillars of food security, especially access and stability. Key drivers of the adverse impacts of food access for the surveyed communities were restrictions in the movement of farm labor and supplies, along with disruptions in food supply chains and other food-related logistics and services associated with the COVID-19 pandemic and mitigation measures. Key determinants of resilience for the surveyed communities were the ability to access diverse food environments, particularly wild and cultivated food environments, indigenous farm inputs and the improved access to fair price shops when local informal markets experienced shocks to food supply and shifts in prices. Findings highlight the critical need to support biocultural diversity in indigenous communities. These would include conservation of biodiversity of forests and other wild habitats as well as indigenous knowledge systems and associated practices and resources such as indigenous seed cultivars to propagate and sustain a rich diversified sustainable ecosystem of foods. Strengthening of food security and employment welfare schemes is further imperative to minimize the impacts on food and livelihood insecurity in vulnerable populations. Building food systems that are resilient to shocks such as the COVID-19 pandemic, requires shorter agri-food supply chains dependent on local and regional food sources, with collective action among all the stakeholders, including the agricultural extension services, food retailers, policymakers, governments, as well as the consumers. Findings on how indigenous communities tapped into their traditional foods systems in the context of the COVID-19 pandemic provide an opportunity to better understand the consequences of a global pandemic on the food and livelihood security of the vulnerable populations. Programs and interventions are called for to conserve and revitalize the biocultural resources available within these vulnerable communities thereby supporting healthy, equitable, and sustainable food systems for all. We should aspire to grow back more harmoniously with our environment as we endeavor to build back our world after the pandemic.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

All procedures involving humans in this study were approved by the Institutional Ethics Committee at Indian Institute of Public Health-Delhi, Public Health Foundation of India. Written informed consent for participation was not required for this study. Verbal informed consent was obtained from the HH survey respondents and market vendors in accordance with the Institutional Ethical Committee requirements.

AUTHOR CONTRIBUTIONS

SG-J, SD, and SA conceived and designed the study. SG-J and RK supervised the entire data collection process. SG-J, RK, and AD did the data analysis. SG-J, RK, AD, and AS prepared the first draft of the manuscript. SD and SA critiqued and modified the draft. SG-J had final responsibility for the decision to submit for publication. All authors read and approved the final version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2022.724321/full#supplementary-material

REFERENCES

Action Aid (2020). *Workers in the time of COVID-19: Round 2 of the National Study on Informal workers*. New Delhi: Action Aid Association Available online at: https://www.actionaidindia.org/wp-content/uploads/2020/11/Workers-in-the-time-of-COVID-19-Round-II-of-the-National-Study-on-Informal-Workers.pdf (accessed August 10, 2021).

Aday, S., and Aday, M. S. (2020). Impact of COVID-19 on the food supply chain. *Food Qual. Saf.* 4, 167–180. doi: 10.1093/fqsafe/fyaa024

Ahmed, S., Downs, S. M., Yang, C., Chunlin, L., Ten Broek, N., and Ghosh-Jerath, S. (2020). Rapid tool based on a food environment typology framework for evaluating effects of the COVID-19 pandemic on food system resilience. *Food Secur.* 20, 1–6. doi: 10.1007/s12571-020-01086-z

Anthem, P. (2020). *Risk of Hunger Pandemic as Coronavirus Set to Almost Double Acute Hunger by End Of 2020. World Food Programme*. Available online at: https://www.wfp.org/stories/risk-hunger-pandemic-coronavirus-set-almost-double-acute-hunger-end-2020 (accessed January 31, 2021).

Bahl, D., Bassi, S., and Arora, M. (2021). *The Impact of COVID-19 on Children and Adolescents: Early Evidence in India*. *ORF* Available online at: https://www.orfonline.org/research/the-impact-of-COVID-19-on-children-and-adolescents-early-evidence-in-india/ (accessed May *3,* 2021).

Bauza, V., Sclar, G. D., Bisoyi, A., Owens, A., Ghugey, A., and Clasen, T. (2021). Experience of the COVID-19 pandemic in rural odisha, India: knowledge, preventative actions, and impacts on daily life. *Int. J. Environ. Res. Public. Health* 18, 2863. doi: 10.3390/ijerph18062863

Bén,é, C. (2020). Resilience of local food systems and links to food security—a review of some important concepts in the context of COVID-19 and other shocks. *Food Secur.* 12, 805–822. doi: 10.1007/s12571-020-01076-1

Bhattacharjee, L., Kothari, G., Priya, V., and Nandi, B. K. (2009). "The bhil food system: links to food security, nutrition and health," in Indigenous Peoples' Food Systems: The Many Dimensions of Culture, Diversity and Environment for Nutrition and Health, eds H. V. Kuhnlein, B. Erasmus, and D. Spigelski (Rome: Food and Agriculture Organization of the United Nations Centre for Indigenous Peoples' Nutrition and Environment), 209–229.

Blaney, S., Beaudry, M., and Latham, M. (2009). Contribution of natural resources to nutritional status in a protected area of Gabon. *Food Nutr. Bull.* 30, 49–62. doi: 10.1177/156482650903000105

Cappelli, A., and Cini, E. (2020). Will the COVID-19 pandemic make us reconsider the relevance of short food supply chains and local productions? *Trends Food Sci. Technol.* 99, 566–567. doi: 10.1016/j.tifs.2020.03.041

Cariappa, A. A., Acharya, K. K., Adhav, C. A., Sendhil, R., and Ramasundaram, P. (2021). Impact of COVID-19 on the Indian agricultural system: A 10-point strategy for post-pandemic recovery. *Outlook Agric.* 50, 26–33. doi: 10.1177/0030727021989060

Castaneda, R., Doan, D., Newhouse, D. L., Nguyen, M., Uematsu, H., and Azevedo, J. P. (2016). Who are the poor in the developing world? *World Bank Policy Res. Work. Pap.* 7844, 1–39. doi: 10.1596/1813-9450-7844

Ceballos, F., Kannan, S., and Kramer, B. (2020). Impacts of a national lockdown on smallholder farmers' income and food security: empirical evidence from two states in India. *World Dev.* 136, 105069. doi: 10.1016/j.worlddev.2020.105069

Census of India (2011). *Census India Website Off. Regist. Gen. Census Comm. India*. Available online at: https://censusindia.gov.in/ (accessed February 1, 2021).

Cicero, A. F. G., Fogacci, F., Giovannini, M., Mezzadri, M., Grandi, E., Borghi, C., et al. (2021). COVID-19-related quarantine effect on dietary habits in a Northern Italian rural population: data from the brisighella heart study. *Nutrients* 13:309. doi: 10.3390/nu13020309

Department of Food, Public Distribution and Consumer Affairs, Government of Jharkhand (2020). *District wise Transaction Status (NFSA)*. Available online at: https://aahar.jharkhand.gov.in/district-monthly-reports (accessed August 11, 2021).

Dev, S. M. (2020). Income support through cash transfers and employment guarantee schemes during the pandemic times in India. *Indian J. Labour Econ.* 63, 133–138. doi: 10.1007/s41027-020-00268-9

Devereux, S., Bén,é, C., and Hoddinott, J. (2020). Conceptualising COVID-19's impacts on household food security. *Food Secur.* 12, 769–772. doi: 10.1007/s12571-020-01085-0

Downs, S. M., Ahmed, S., Fanzo, J., and Herforth, A. (2020). Food environment typology: advancing an expanded definition, framework, and methodological approach for improved characterization of wild, cultivated, and built food environments toward sustainable diets. *Foods Basel Switz.* 9, 32. doi: 10.3390/foods9040532

Ericksen, P. J., Ingram, J. S. I., and Liverman, D. M. (2009). Food security and global environmental change: emerging challenges. *Environ. Sci. Policy* 12, 373–377. doi: 10.1016/j.envsci.2009.04.007

FAO (2020a). *Impacts of Coronavirus on Food Security and Nutrition in Asia and the Pacific: Building More Resilient Food Systems*. Available online at: http://www.fao.org/3/ca9473en/CA9473EN.pdf (accessed December 10, 2020).

FAO (2020b). *The State of Food Security and Nutrition in the World 2020: Transforming food systems for affordable healthy diets*. Rome, Italy: FAO, IFAD, UNICEF, WFP and, W. H. O.

FAO, UN (2018). *FAO'S Work on Family Farming. Preparing for the Decade of Family Farming (2019–2028) to achieve the SDGs*. Rome, Italy: FAO, UN Available online at: https://www.fao.org/3/CA1465EN/ca1465en.pdf (accessed December 3, 2022).

FSIN and Global Network Against Food Crises (2021). *Global Report on Food Crises—2021. World Food Programme*. Available online at: https://www.wfp.org/publications/global-report-food-crises-2021 (accessed December 4, 2021).

GAIN (2021). *Impact of COVID-19 on Food Systems: A Situation Report*. *Global Alliance for Improved Nutrition*. Available online at: https://www.gainhealth.org/sites/default/files/publications/documents/impact-of-COVID-19-on-food-systems-global-situation-report-e6.pdf (accessed August 11, 2021).

Ghosh-Jerath, S., Downs, S., Singh, A., Paramanik, S., Goldberg, G., and Fanzo, J. (2019). Innovative matrix for applying a food systems approach for developing interventions to address nutrient deficiencies in indigenous communities in India: a study protocol. *BMC Public Health* 19:944. doi: 10.1186/s12889-019-6963-2

Ghosh-Jerath, S., Kapoor, R., Barman, S., Singh, G., Singh, A., Downs, S., et al. (2021). Traditional food environment and factors affecting indigenous food consumption in munda tribal community of Jharkhand, India. *Front. Nutr.* 7, 600470. doi: 10.3389/fnut.2020.600470

Ghosh-Jerath, S., Kapoor, R., Singh, A., Downs, S., Barman, S., and Fanzo, J. (2020). Leveraging traditional ecological knowledge and access to nutrient-rich indigenous foods to help achieve sdg 2: an analysis of the indigenous foods of sauria paharias, a vulnerable tribal community in Jharkhand, India. *Front. Nutr.* 7, 61. doi: 10.3389/fnut.2020.00061

Godda (2021). *Godda Dist. Adm. Jharkhand India*. Available online at: https://godda.nic.in/ (accessed January 4, 2022).

Gupta, S., Seth, P., Abraham, M., and Pingali, P. (2021). COVID-19 and women's nutrition security: panel data evidence from rural India. *Econ. Polit.* 23, 9. doi: 10.1007/s40888-021-00233-9

Haga, M. (2020). *Small-scale Farmers Can Help Build Resilient Food Systems in a post–COVID-19 world. IFAD*. Available online at: https://www.ifad.org/en/web/latest/blog/asset/41903536 (accessed January 19, 2021).

Haque, Y. A., Parajuli, B., Payden, and Shichiri, T. (2020). *Nutrition in the context of the COVID-19 pandemic in India. Outlook Poshan*. https://poshan.outlookindia.com/. Available online at: https://poshan.outlookindia.com/story/poshan-news-nutrition-in-the-context-of-the-COVID-19-pandemic-in-india/354455 (accessed December 31, 2021).

Harris, J., Depenbusch, L., Pal, A. A., Nair, R. M., and Ramasamy, S. (2020). Food system disruption: initial livelihood and dietary effects of COVID-19 on vegetable producers in India. *Food Secur.* 12, 841–851. doi: 10.1007/s12571-020-01064-5

Headey, D. D., and Ruel, M. T. (2020). "The COVID-19 nutrition crisis: What to expect and how to protect," in *COVID-19 and global food security Part Two: Diets and Nutrition*. Washington, DC: International Food Policy Research Institute (IFPRI). Available online at: doi: 10.2499/p15738coll2.133762_08

Hindustan Times (2020). *Jharkhand Extends Lockdown till July 31 Due to Rising Covid-19 Cases. Hindustan Times*. Available online at: https://www.hindustantimes.com/ranchi/jharkhand-extends-lockdown-till-july-31-due-to-rising-COVID-19-cases/story-OCFD3IssVVQu4jtcFgms6O.html (accessed January 19, 2021).

HLPE (2020). Impacts of Covid-19 On Food Security And Nutrition: Developing Effective Policy Responses to Address the Hunger and Malnutrition Pandemic. Available online at: https://www.fao.org/3/cb1000en/cb1000en.pdf.

ILO (2020). *Impact of COVID-19 on people's livelihoods, their health and our food systems. Int. Labour Organ. ILO.* Available online at: http://www.ilo.org/global/about-the-ilo/newsroom/statements-and-speeches/WCMS_757974/lang--en/index.htm (accessed May 20, 2021).

ILO and FAO (2021). *Extending Social Protection to Rural Populations: Perspectives for a Common FAO and ILO Approach.* Available online at: https://www.fao.org/3/cb2332en/cb2332en.pdf (accessed December 3, 2022).

Imbert, C., Chakravorty, B., Lohnert, M., and Panda, P. (2020). *Short- and Long-term Effects of the Lockdown on Young Rural Migrants from Bihar and Jharkhand. Abdul Latif Jameel Poverty Action Lab J-PAL.* Available online at: https://www.povertyactionlab.org/project/short-and-long-term-effects-lockdown-young-rural-migrants-bihar-and-jharkhand (accessed August 10, 2021).

Indiaspend (2020). PM's Atma-Nirbhar Bharat Finds no Mention of Adivasis Despite Persistent Appeals By Tribal Groups, Experts and Opposition Leaders. Available online at: https://www.indiaspend.com/wp-content/uploads/2020/05/Press-release-Covid-lockdown-impact-on-tribals-13-May.pdf (accessed August 8, 2021).

Ingram, J., Ericksen, P. J., and Liverman, D. (2010). *Food Security and Global Environmental Change.* 1st ed. London: Earthscan

Kansiime, M. K., Tambo, J. A., Mugambi, I., Bundi, M., Kara, A., and Owuor, C. (2021). COVID-19 implications on household income and food security in Kenya and Uganda: Findings from a rapid assessment. *World Dev.* 137, 105199. doi: 10.1016/j.worlddev.2020.105199

Kapil, S. (2020). *COVID-19: 60% farmers suffered yield loss on their harvest, shows survey. DownToEarth.* Available online at: https://www.downtoearth.org.in/news/agriculture/COVID-19-60-farmers-suffered-yield-loss-on-their-harvest-shows-survey-71270 (accessed May 2, 2021).

Kar, S. (2020). *Jharkhand Lockdown Extended till September 31; Bus Services to Resume in View of Exams. Indiacom News Desk.* Available online at: https://www.india.com/news/india/jharkhand-lockdown-extended-till-september-31-with-relaxations-bus-services-to-resume-in-view-of-exams-4124976/ (accessed February 1, 2021).

Kaur, G. (2020). *India Launches the Biggest Food Ration Subsidy Scheme in the World Amid Coronavirus Lockdown. Grainmart News.* Available online at: https://www.grainmart.in/news/india-launches-the-biggest-food-ration-subsidy-scheme-in-the-world-amid-coronavirus-lockdown/ (accessed May 3, 2021).

KMPG (2020). *Response to COVID-19 by the Anganwadi ecosystem in India. India: KMPG.* Available online at: https://assets.kpmg/content/dam/kpmg/in/pdf/2020/06/anganwadi-report-2020.pdf (accessed May 3, 2021).

Kretchmer, H. (2020). *Global Hunger Fell for Decades, but it's Rising Again.* Available online at: https://www.weforum.org/agenda/2020/07/global-hunger-rising-food-agriculture-organization-report/ (accessed August 10 2021).

Kumar, R., and Saikia, P. (2020). "Forest Resources of Jharkhand, Eastern India: Socio-economic and Bio-ecological Perspectives," in *Socio-economic and Eco-biological Dimensions in Resource use and Conservation: Strategies for Sustainability Environmental Science and Engineering*, eds. N. Roy, S. Roychoudhury, S. Nautiyal, S. K. Agarwal, and S. Baksi (Cham: Springer International Publishing), 61–101

Kusuma, D., Pradeepa, R., Khawaja, K. I., Hasan, M., Siddiqui, S., Mahmood, S., et al. (2021). Low uptake of COVID-19 prevention behaviours and high socioeconomic impact of lockdown measures in South Asia: Evidence from a large-scale multi-country surveillance programme. *SSM—Populat Health* 13, 100751. doi: 10.1016/j.ssmph.2021.100751

Laborde, D., Martin, W., and Vos, R. (2020). *Poverty and food insecurity could grow dramatically as COVID-19 spreads, IFPRI: International Food Policy Research Institute.* Available online at: https://www.ifpri.org/blog/poverty-and-food-insecurity-could-grow-dramatically-COVID-19-spreads (accessed January 19, 2021).

Lahoti, R., Basole, A., Abraham, R., Kesar, S., and Nath, P. (2020). *Hunger Grows as India's Lockdown Kills Jobs. India Forum.* Available online at: https://www.theindiaforum.in/article/hunger-grows-india-s-lockdown-kills-jobs (accessed May 3, 2021).

Litton, M. M., and Beavers, A. W. (2021). The Relationship between Food Security Status and Fruit and Vegetable Intake during the COVID-19 Pandemic. *Nutrients* 13, 712–724. doi: 10.3390/nu13030712

Lopez-Ridaura, S., Sanders, A., Barba-Escoto, L., Wiegel, J., Mayorga-Cortes, M., Gonzalez-Esquivel, C., et al. (2021). Immediate impact of COVID-19 pandemic on farming systems in Central America and Mexico. *Agric. Syst.* 192, 103178. doi: 10.1016/j.agsy.2021.103178

Mahajan, K., and Tomar, S. (2020). COVID-19 and Supply Chain Disruption: Evidence from Food Markets in India. *Am. J. Agric. Econ.* 00, 1–18. doi: 10.2139/ssrn.3596720

Mahatma Gandhi National Rural Employment Guarantee Act Jharkhand (2020). MGNREGA 2005. Available online at: https://mnregaweb2.nic.in/netnrega/homestciti.aspx?state_code=34&state_name=JHARKHAND (accessed January 4, 2022).

Manzar, D., Pandi-Perumal, S. R., and Bahammam, A. (2020). Lockdowns for community containment of COVID-19: Present challenges in the absence of interim guidelines. *J. Nat. Sci. Med.* 3, 318–321. doi: 10.2147/NSS.S313373

Ministry of Agriculture and Farmers Welfare (2016). State of Indian Agriculture 2015-16. *New Delhi: Department of Agriculture, Cooperation and Farmers Welfare Available online at: https://eands.dacnet.nic.in/PDF/State_of_Indian_Agriculture,2015-16.pdf (accessed August* 11, 2021).

Ministry of Environment Forests and Climate Change (2018). *Agriculture in Jharkhand. ENVIS Hub Jharkhand.* Available online at: http://www.jharenvis.nic.in/Database/AGRICULTUREINJHARKHAND_2327.aspx (accessed February 1 2021).

Ministry of Tribal Affairs (2002). *Annual Report 2019-20. Ministry of Tribal Affairs, Government of India.* Available online at: https://tribal.nic.in/downloads/Statistics/AnnualReport/AREnglish1920.pdf (accessed August 4, 2021).

MoHFW and Ministry of Tribal Affairs (2020). *Report on Expert Committee on Tribal Health, Tribal Health in India, Bridging the Gap and a Roadmap for the Future. Government of India.* Available online at: http://nhm.gov.in/nhm_components/tribal_report/Executive_Summary.pdf (accessed August 4, 2021).

Muscogiuri, G., Barrea, L., Savastano, S., and Colao, A. (2020). Nutritional recommendations for CoVID-19 quarantine. *Eur. J. Clin. Nutr.* 74, 850–851. doi: 10.1038/s41430-020-0635-2

NABARD (2020). *NABARD—National Bank for Agriculture and Rural Development.* Available online at: https://www.nabard.org/ (accessed January *4*, 2022).

Nair, D., Gupta, A., Stroming, S., Raj, R., Shukla, K., and Nag, D. (2021). *Improving the implementation of the Take Home Ration Programme Under ICDS.* New Delhi: IDinsight Available online at: https://www.idinsight.org/publication/improving-the-implementation-of-the-take-home-ration-programme-under-icds/ (accessed August 4, 2021).

Nandi, R., Nedumaran, S., Selvaraj, A., Mazumdar, S. D., and Kumar, S. (2021). The COVID-19 Induced Disruptions across Groundnut Value Chain: Empirical Evidence from South India. *Sustainability* 13, 1–21. Available online at: https://ideas.repec.org/a/gam/jsusta/v13y2021i4p1707-d493802.html (accessed May 2, 2021).

Narayanan, S., and Saha, S. (2020). Urban food markets and the lockdown in India. *Indira Gandhi Institute of Development Research, Mumbai, India.* Available online at: https://ideas.repec.org/p/ind/igiwpp/2020-017.html (accessed May 3, 2021).

Pande, R., Schaner, S., and Moore Troyer, C. (2020). *In Times of Pandemic, PDS Shops Should Provide Rations to all. Indian Express.* Available online at: https://indianexpress.com/article/opinion/columns/coronavirus-impact-free-rations-fair-price-shops-govt-pds-scheme-6518866/ (accessed May 3, 2021).

Powell, B., Hall, J., and Johns, T. (2011). Forest cover, use and dietary intake in the East Usambara Mountains, Tanzania. *Int. For. Rev.* 13, 305–317. doi: 10.1505/146554811798293944

Press Information Bureau, Government of India (2019). *Welfare of particularly vulnerable Tribal groups.* Available online at: https://pib.gov.in/Pressreleaseshare.aspx?PRID=1577166 (accessed April 6, 2021).

Rajpal, S., Joe, W., and Subramanian, S. V. (2020). Living on the edge? Sensitivity of child undernutrition prevalence to bodyweight shocks in the context of the 2020 national lockdown strategy in India. *J Glob Health Sci.* 2:e19. doi: 10.35500/jghs.2020.2.e19

Rao, G. V. R. S. (2021). *Farmers resort to distress sale owing to COVID-19-induced conditions. The Hindu.* Available online at: https://www.thehindu.com/news/national/andhra-pradesh/unsold-and-underpriced/article34678076.ece (accessed August 10, 2021).

Rapsomanikis, G. (2015). *The Economic Lives of Smallholder Farmers: An Analysis Based on Household Data From Nine Countries*. Rome: Food and Agriculture Organization of the United Nations Available online at: https://www.fao.org/3/i5251e/i5251e.pdf (accessed December 21, 2021).

Roberton, T., Carter, E. D., Chou, V. B., Stegmuller, A. R., Jackson, B. D., Tam, Y., et al. (2020). Early estimates of the indirect effects of the COVID-19 pandemic on maternal and child mortality in low-income and middle-income countries: a modelling study. *Lancet Glob. Health* 8, e901–e908. doi: 10.1016/S2214-109X(20)30229-1

Save the Children (2020). Rights of Vulnerable Families and Children of India under COVID-19: Implications for effective response and mitigation strategies. Available online at: https://resourcecentre.savethechildren.net/node/18102/pdf/rights_of_vulnerable_families_and_children_of_india_under_covid_240720f.pdf (accessed August 11, 2021).

Singh, G., and Kumar, J. (2016). Diversity and traditional knowledge on some less known edible wild herbaceous plant resource from district Khunti, Jharkhand, *India. Int. J. Bioassays* 5, 4557. doi: 10.21746/ijbio.2016.05.005

Sinha, D. (2021). Hunger and food security in the times of Covid-19. *J. Soc. Econ. Dev*. 23, 320–331. doi: 10.1007/s40847-020-00124-y

StataCorp. (2017). *Stata Statistical Software: Release 15*. College Station, TX: StataCorp LLC Available online at: https://www.stata.com/support/faqs/resources/citing-software-documentation-faqs/ (accessed January 23, 2021).

State Food Commission and Social Audit Unit Jharkhand (2020). *Concurrent Audit of Schemes Operated Under National Food Security Act*. Available online at: https://jharkhandsfc.in/pdf/2021/concurr_audit__rprt_schms_nsa_phs_i_ii.pdf (accessed January 4, 2022).

Sukhwani, V., Deshkar, S., and Shaw, R. (2020). COVID-19 Lockdown, Food Systems and Urban–Rural Partnership: Case of Nagpur, India. *Int. J. Environ. Res. Public. Health* 17, 5710. doi: 10.3390/ijerph17165710

Sunderland, T., Powell, B., Ickowitz, A., Foli, S., Pinedo-Vasquez, M., Nasi, R., et al. (2013). *Food security and nutrition: The role of forests. Discussion Paper. Bogor, Indonesia: Center for International Forestry Research.* Available online at: https://www.cifor.org/publications/pdf_files/WPapers/DPSunderland1301.pdf?andutm_source$=$CIFOR$+$blogandutm_medium$=$Further$+$readingandutm_campaign=Blog+featureand_ga=1.108105414.578506060.1384270572

TechnoServe (2020). 5 Ways COVID-19 is Affecting Smallholder Farmers Around the World. TechnoServe. Available online at: https://www.technoserve.org/blog/5-ways-COVID-19-is-affecting-smallholder-farmers/ (accessed February 8, 2021).

Tendall, D. M., Joerin, J., Kopainsky, B., Edwards, P., Shreck, A., Le, Q. B., et al. (2015). Food system resilience: Defining the concept. *Glob. Food Secur*. 6, 17–23. doi: 10.1016/j.gfs.2015.08.001

Termote, C., Bwama Meyi, M., Dhed'a Djailo, B., Huybregts, L., Lachat, C., Kolsteren, P., et al. (2012). A biodiverse rich environment does not contribute to a better diet: a case study from DR Congo. *PloS One* 7, e30533. doi: 10.1371/journal.pone.0030533

The Economist (2021). *Sustainable food systems are critical to a zero-hunger world. Barilla Cent. Food Nutr.* Available online at: https://foodsustainability.eiu.com/blogs/sustainable-food-systems-critical-zero-hunger-world/ (accessed August 10, 2021).

The New Indian Express (2020). *Across India, a massive agricultural crisis in the making due to coronavirus shutdown. New Indian Express.* Available online at:https://www.newindianexpress.com/thesundaystandard/2020/apr/12/across-india-a-massive-agricultural-crisis-in-the-making-due-to-coronavirus-shutdown-2128892.html (accessed August 10, 2021).

The United Nations (2019). *Over 820 Million People Suffering From Hunger; New UN Report Reveals Stubborn Realities of 'Immense' Global Challenge. UN News*. Available online at: https://news.un.org/en/story/2019/07/1042411 (accessed January 31, 2021).

Thulasiraman, V., Nandagopal, M. S. G., and Kothakota, A. (2021). Need for a balance between short food supply chains and integrated food processing sectors: COVID-19 takeaways from India. *J. Food Sci. Technol.* 58, 3667–3675. doi: 10.1007/s13197-020-04942-0

Times of India (2020). *Jharkhand Lockdown: Jharkhand announces immediate lockdown till March 31, Ranchi News*. Available online at: https://timesofindia.indiatimes.com/city/ranchi/jharkhand-announces-immediate-lockdown-till-march-31/articleshow/74775180.cms (accessed January 19, 2021).

Torero, M. (2020). Without food, there can be no exit from the pandemic. *Nature* 580, 588–589. doi: 10.1038/d41586-020-01181-3

Tripathi, H. G., Smith, H. E., Sait, S. M., Sallu, S. M., Whitfield, S., Jankielsohn, A., et al. (2021). Impacts of COVID-19 on Diverse Farm Systems in Tanzania and South Africa. *Sustainability* 13, 9863. doi: 10.3390/su13179863

UNICEF India (2020). *Tribal nutrition*. Available online at: https://www.unicef.org/india/what-we-do/tribal-nutrition (accessed May 20, 2021).

Varshaney, D., Roy, D., and Jv, M. (2020). Impact of COVID-19 on agricultural markets: assessing the roles of commodity characteristics, disease caseload and market reforms. *Indian Econ. Rev*. 1, 1–21. doi: 10.1007/s41775-020-00095-1

Vos, R., Martin, W., and Laborde, D. (2020). *How much will global poverty increase because of COVID-19? IFPRI: International Food Policy Research Institute*. Available online at: https://www.ifpri.org/blog/how-much-will-global-poverty-increase-because-COVID-19 (accessed January 18, 2021).

Walker, B., and Salt, D. (2012). *Resilience Thinking: Sustaining Ecosystems and People in a Changing World*. Available online at: https://islandpress.org/books/resilience-thinking (accessed January 19, 2021).

WHO (2020). *Impact of COVID-19 on People's Livelihoods, Their Health and Our Food Systems*. Available online at: https://www.who.int/news/item/13-10-2020-impact-of-COVID-19-on-people's-livelihoods-their-health-and-our-food-systems (accessed December 31, 2021).

Zurayk, R. (2020). Pandemic and food security: a view from the global south. *J. Agric. Food Syst. Community Dev*. 9, 1–5. doi: 10.5304/jafscd.2020.093.014

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SYSTEMATIC REVIEW
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Assessing the Impacts of the COVID-19 Pandemics on Sustainable Development Goals in Nepal

Toyanath Joshi[1], Rudra Prasad Poudel[1], Kamana Kafle[2], Bandana Bhattarai[3], Benu Prasad Prasai[4] and Santosh Adhikari[5]*

[1] Ministry of Agriculture and Livestock Development, Kathmandu, Nepal, [2] Himalayan College of Agricultural Sciences (HICAST), Kathmandu, Nepal, [3] Institute of Agriculture and Animal Sciences, Chitwan, Nepal, [4] Seed Quality Control Center, Lalitpur, Nepal, [5] University of Tasmania, Hobart, TAS, Australia

Globally, billions of people and their livelihood are threatened by the onset of COVID-19. In Nepal, resource-poor people who lost their job were the hardest hit among millions of impacted populations. Further, the associated effects of pandemics are food supply chain interruption and people's inferior physical and mental wellbeing. The COVID-19 pandemic and associated impacts have questioned Nepal's ability to achieve the 17 United Nations sustainable development goals (SDGs) in the post-pandemic era. Yet no scientific studies available to see COVID-19 and SDGs relationships in Nepal, government reports, and macroeconomic updates indicated that COVID-19 is likely to deter significantly in achieving SDGs targets. This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines to quantify the impacts of the COVID-19 pandemic in Nepal's macro-economy from March 2020 to December 2021. Our study indicated that the COVID-19 exerted inevitable challenges in achieving SDGs targets in terms of food security and household poverty. Therefore, this paper recommended creating more employment opportunities in the domestic economy and establishing a resilient food system.

Keywords: COVID-19, SDGs (sustainable development goals), food security, poverty, agriculture, Nepal

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José Antonio Teixeira,
University of Minho, Portugal

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Mohammad Mahfujul Haque,
Bangladesh Agricultural University, Bangladesh
José Anael Neves,
Universidade Metropolitana de Santos, Brazil

Correspondence:
Toyanath Joshi
joshitoyanath@gmail.com

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INTRODUCTION

The COVID-19 pandemic has highlighted the vulnerability of the global food system leading to an increase in food insecurity and poverty. Like many developing countries, Nepal is seriously threatened by its adverse impacts on people's physical and mental wellbeing and national food security. In Nepal, a total of 827,763 infections and 11,588 deaths associated with COVID-19 were reported until 29 December 2021 (Worldometer, 2021). It has impacted almost all economic sectors, including hospitality, health, trade, and production, among the hardest hit sectors (Joshi et al., 2021). In addition, Nepal's recent administrative restructuring to federalism has posed chaos among three tiers of government, namely federal, provincial and local government. Power and authority among these governments are still underway and result from poor coordination on implementing government policies.

To manage and control the spread of COVID-19, Nepal initially adopted social distancing, mandatory face-masks, and restrictive travel rules (19 March 2020). However, an increasing number of cases pushed the government to declare a national health emergency and put forward nationwide lockdown, local curfew and closure of non-essential services and businesses (23 April 2020, enhanced 21 June 2020). The lockdowns and restrictive mobility impacted people's physical, mental, social, and spiritual health and posed a threat to vulnerable populations (Adhikari et al., 2021). In addition, the government's poor health system and economic support system put many poor and daily wage laborer's lives on the edge of two swords, go outside and killed by disease or stay home and be killed by hunger. However, the majority of households coped with this economic and health crisis in their way.

Nepal is a predominantly agriculture-based economy that is a lifeline to more than two-thirds of the population and the source of one-third of the national gross domestic product. The majority of households follow a subsistence farming system that is self-sustaining in various crises. For example, a diversified farming system and sources of income in the hills and mountains buffered a severe economic crisis after a great earthquake and trade embargo with India in 2015 (Epstein et al., 2017). However, increasing labor migration in the last couple of decades has resulted in labor scarcity in this primary economic sector in Nepal, especially in the peak seasons. As a result, national production is declined every year and became more import reliant. Now, the COVID-19 pandemic has raised the question of how the COVID-19 would impact the food security and poverty situation of Nepali households and achieve the United Nations Sustainable Development Goals (SDGs) by 2030.

The paper investigated the immediate impact of COVID-19 in the farming system and livelihood and the long-term impacts on achieving the country's SDGs, with particular focus on SDGs 1 (No Poverty) and SDGs2 (Zero Hunger). Further, the review investigated government and community measures to cope with COVID-19 on farming systems and food security. Studies recognized that the COVID-19 pandemic has more explicit impacts on poverty (SDG1), food security (SDG 2), health and well-being (SDG3), the economy (SDG8) and multilateralism (SDG 17), as well as Gender Equality (SDG 5), and the governance (SDG 16) (Baniya et al., 2021; Fenner and Cernev, 2021). Nepal has proposed to graduate from an underdeveloped country to a middle-income developing country by 2026, which has been approved by the United Nations General Assembly. Hunger (SDG 1), food security (SDG 2), and income level have implications for the LDC's graduation (Rai, 2017).

The paper did a systematic review of literature collected through Google Scholar, PubMed, and Scopus. In addition, further information was collected from government and non-government agencies and their publications such as the Ministry of Agriculture and Livestock Development (MoALD), National Planning Commission (NPC), International Labor Organization (ILO) and news agencies and open databases such as Worldometer, World Bank Data Portals, Spotlight and others. This study adopted the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines that ended up analyzing 25 related and reliable literature (**Figure 1**).

FOOD SECURITY AND POVERTY SCENARIO IN NEPAL

Today, Nepal is a net food importer country that used to be a food exporter until the early 1970s. Various factors such as small land holding, rugged terrains, remoteness of farms, poor agricultural inputs (seed, fertilizer and irrigation) access, labor scarcity and farmers' low technical capacity have significantly hindered Nepal's food production capacity (Adhikari, 2020; Adhikari et al., 2021). Further, farmers receive limited support from the government in terms of input such as seed, fertilizer and loans, and services such as technology, marketing and training. Only a small portion of farmers in the peri-urban areas and the Terai plains follow a commercial farming system that could not satisfy the increasing population and trade competitiveness with the global producers. The agri-business sector is far less competitive than neighbors India and China because their farmers get higher subsidies in fertilizers, irrigation, machinery and technical service delivery.

Today, at least 10% of the country's population (2.8 million), including marginalized indigenous groups, is working in foreign countries that constitute half of the youths between 18 and 35 years (Adhikari, 2020). In general, economic and regional status are the determining factors in choosing their destinations; poor and marginalized people in the Western hills go to India, whereas the lower and upper-middle-class from the rest go to the Gulf countries. More than half of the households (56%) receive remittances from their foreign employed family members (Adhikari, 2020; GoN-NPC, 2020a). The majority of them are working in the Gulf countries. Their remittances have a significant contribution to national foreign exchange and poverty reduction. The share of migrant remittances is equivalent to 28.4% of the national gross domestic product (World Bank, 2020a). It is higher than any other highest economic sector in Nepal and has been a key contributor to reduce household poverty incidence, from 42% in 1996 to 18.6% in 2019 (GoN-NPC, 2020a; World Bank, 2020b) along with various other factors such as rise in wage rate, urbanization and rising other income sources (Pant, 2008).

IMPLICATIONS FOR ACHIEVING SDGS TARGETS

After adopting SDGs, Nepal developed SDGs status and roadmap 2016–2030, SDGs needs assessment, costing, and financing strategy. Nepal developed 494 indicators for 17 goals and 169 targets (GoN-NPC, 2020a) of United Nations Sustainable Development Goals. However, the COVID-19 pandemics have implications mostly on SDG1 (No Poverty) and SDG2 (Zero Hunger) (Pradhan et al., 2021), and the paper focused on only these couple of SDGs.

Impact of COVID-19 on SDGs 1 (No Poverty)

The COVID-19 pandemic has negatively impacted the global economy and squeezed new employment opportunities. As a

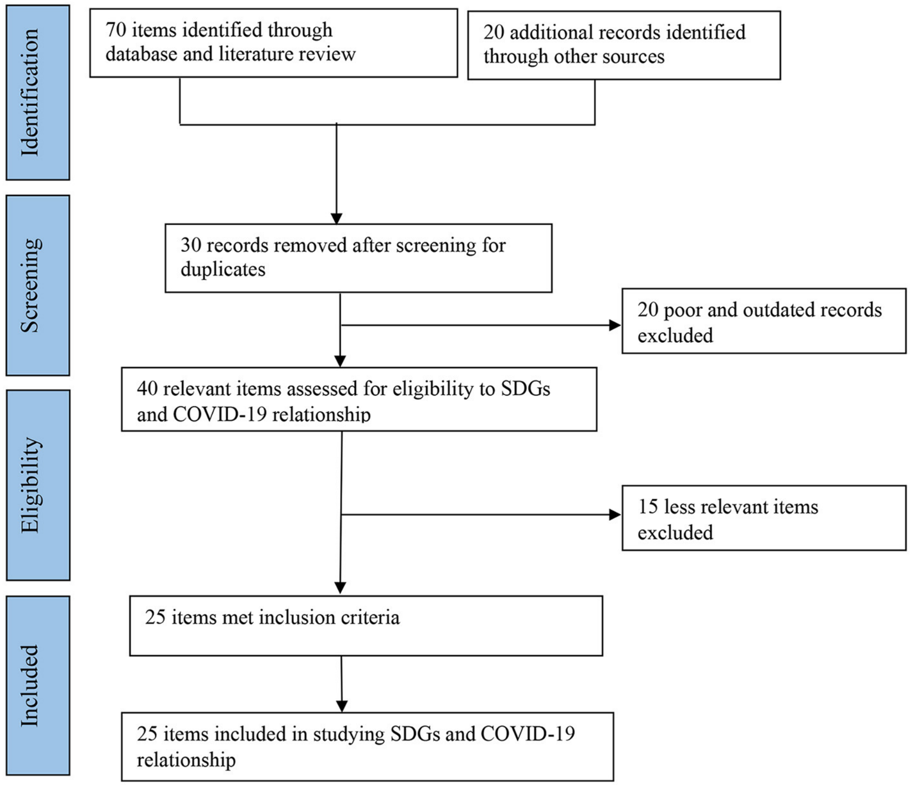

FIGURE 1 | Flow diagram of the study selection process.

result, ~1.6 million people have lost their job and sources of income (Joshi et al., 2021). Already dependent on labor migration for employment and household income experienced a significant implication to COVID-19. Further, a significant implication of the COVID-19 was observed in many parts of the country where people from a disadvantaged and low-income families experienced negative impacts on food security, health, and wellbeing (Singh et al., 2020). Jobs (domestic and overseas) and income are crucial factors determining household poverty and food security (Deaton and Deaton, 2020). COVID-19 questioned livelihood to already food insecure 4.6 million populations (Department of Health Services, 2016). Further, it shattered achieving targets Nepal set for SDG1; (1) Reduce extreme poverty (below 5%), (2) Reduce the poverty gap (<2.8%), (3) Raise per capita income (from US$766 to US$2,500), (4) Reduce national poverty (below 5%), and; (5) Reduce Multidimensional Poverty Index (MPI) (below 7%). The revenue collection of Nepal was reduced by 7.45% during the first wave of pandemics, and the country experienced a trade imbalance (Joshi et al., 2021). A decline in revenue collection and higher recurrent spending are likely to increase the fiscal deficit (Rasul et al., 2021). Amidst the COVID-19 pandemic, Nepal's Gross Domestic Product (GDP) growth rate has been reduced by 0.2% in 2019/20, which was 7% in the previous year (Magar et al., 2021). Further, the closure of the service sector excavated 31.5% of the total workers to lose their jobs (UNDP, 2020). Low or negative GDP growth, declining export earnings, and increased fiscal deficit have serious implications for household income and poverty (Rasul et al., 2021). It has been reported that of Nepal reported that the COVID-19 has pushed ~31.2% of the total population to poverty (Rasul et al., 2021). Nepal drafted a food governance-related policy, the Right to Food and Food Sovereignty Act in 2018 which is related to SDGs1 and SDGs2. However, this Act did not foresee COVID-19 or similar crises scenario in the future. The act has ensured the right to food for every citizen. The pandemic has disrupted the food production and supply system resulting in lower availability of food (Joshi et al., 2021). As a result, there might be implications for implementing such legislation.

Impact of COVID-19 on SDGs 2 (Zero Hunger)

The COVID-19 pandemic and associated impacts jeopardize all four food security dimensions: food availability, access, utilization, and stability. Despite the government's announcement of allowing people to continue their farming activities adopting health protocol, the continued lockdown hampered the production and distribution of foods, affecting their availability (Adhikari, 2020). At the same time, the COVID-19 pandemic exposed how fragile the country's food supply system is, which also realized the policymaker rethink the food governance of the country. The SDG 2, specifically "Target 2.1–By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round" (UN, 2015), is likely to deteriorate Nepali agricultural production system and supply chain due to policy changes after the COVID-19.

The onset of the COVID-19 pandemic has hampered access to food. Low-income families, daily wage workers, and job losers are more vulnerable to food insecurity due to their reduced financial capacity and insufficient food stocks (Adhikari et al., 2021). Early estimates of ILO indicated that at least 1.6–2 million people would be lost their job after the onset of the COVID-19 pandemic (ILO Nepal, 2020). However, 6.4 million people lost their job after the spread of the COVID-19 pandemic (GoN-NPC, 2020b). The demand for vegetables, fruits, milk, and meat products was reduced in major cities such as Kathmandu, Pokhara and Chitwan (Joshi et al., 2021). Similar was the situation as reported by Workie et al. (2020), who studied the impacts of COVID-19 pandemics in developing economies. The situation has exposed the need for a safety net to protect the acutely vulnerable groups in the future. About 90% of migrant workers were involved in the informal sector in cities and lost their job (Spotlight, 2020). As a result, their source of income is reduced, leading to remittance inflow declining by 14% in 2019/20 compared to the 2018/19 fiscal year (World Bank, 2020c). Further, a substantial increase in food commodity prices across the country constrained the accessibility of food for low socioeconomic and disadvantaged households (Subedi, 2020). The border closure, restrictive transportation, and inadequate food stock contributed to the reduced access to food in the Terai region of the country.

A significant impact of the COVID-19 pandemic was observed in food utilization due to various issues such as food sanitation, food contamination, and decaying of food (Adhikari et al., 2021). Lack of standard food safety procedures for food handling made foods contaminated because of frequent touch by people. Due to reduced availability and access to food, people bought the product that came to the market, which came as violating food safety standards (Adhikari et al., 2021). The COVID-19 and poor health infrastructure exacerbated the chronic problem of malnutrition among children and women. Also, the pandemic delayed children's immunization and safe delivery in hospitals, resulting in health issues in these populations (Singh et al., 2020), which impacted food utilization.

The COVID-19 pandemic has indicated some policy implications in the food stability dimension of food security. The pandemic has highlighted the importance of making provisions for unforeseen vulnerabilities, particularly the necessity to keep a larger supply of food on stock to the policymakers (Subedi et al., 2021). The provisions of buffer stock in the country need to be increased in the future for the stability of food. Further, the provision of a regular food-aid program to food insecure regions such as Far West Province, Karnali Province, and Province-2 of the country is the utmost need in the future.

CONCLUSIONS AND POLICIES RECOMMENDATIONS

Food insecurity is a severe public health issue in Nepal, particularly among low-income and disadvantaged households. During the pandemic, the families that relied on daily wages and remittances for their livelihood were largely faced food insecurity. The COVID-19 pandemic has pushed one-third of the population to poverty, and that could have long-term effects on national food security and the poverty situation. Though the government has responded to food security and self-employment endeavors, they are inadequate and could not reach affected groups. One of the reasons could be poor coordination and lack of food governance frameworks among the three tiers of the governments. Therefore, we suggest establishing an efficient food governance mechanism in the country, mainly in two aspects, creating local employment opportunities by providing vocational skills training to the people who lost their job, establishing a national employment promotion authority, and establishing an employment information and communication center. Further, its utmost needs to build capacities for resilient food systems in times of crisis. In addition, we advocate identifying acutely vulnerable populations and implementing long-term integrated food security policies to prevent long-term hunger and malnutrition among Nepal's most vulnerable households.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

TJ, SA, and BP: conceptualization. RP and TJ: methodology. TJ, SA, KK, and BB: writing—original draft preparation. TJ, BP, SA, and RP: validation. All authors writing—critical analysis, revisions, review and editing. All authors contributed to the article and approved the submitted version.

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REFERENCES

Adhikari, J., Timsina, J., Khadka, S. R., Ghale, Y., and Ojha, H. (2021). COVID-19 impacts on agriculture and food systems in Nepal: implications for SDGs. *Agric. Syst.* 186, 102990. doi: 10.1016/j.agsy.2020.102990

Adhikari, S. (2020). "Managing migrant remittance and agricultural development in Nepal: a case of policy dereliction?," in *The Migration Conference 2020 Proceedings Migration and Politics*, eds I. Sirkeci and M. Z. Alili? (London: Transnational Press), 45–56.

Baniya, B., Ghimire, A., and Mahat, A. (2021). *Impacts of COVID-19 on World Economy and Sustainable Development Goal in Nepal*.

Deaton, B. J., and Deaton, B. J. (2020). Food security and Canada's agricultural system challenged by COVID-19. *Can. J. Agric. Econ.* 68, 143–149. doi: 10.1111/cjag.12227

Department of Health Services (2016). *Nepal Demographic and Health Survey, Government of Nepal*. Available online at: https://www.mohp.gov.np/eng/publications/nepal-demographic-health-survey

Epstein, K., DiCarlo, J., Marsh, R., Ray, I., and Maren, I. (2017). Coping strategies of smallholder farming communities after the 2015 Nepal earthquake: insights into post-disaster resilience and social-ecological change. *Case Stud. Environ.* 1, 1–12. doi: 10.1525/cse.2017.000612

Fenner, R., and Cernev, T. (2021). The implications of the Covid-19 pandemic for delivering the sustainable development goals. *Futures*. 128, 102726 doi: 10.1016/j.futures.2021.102726

GoN-NPC (2020a). *Fifteenth Plan, 2076/077–2080/081*. Available online at: https://npc.gov.np/images/category/15th_plan_English_Version.pdf.

GoN-NPC (2020b). *Impacts of COVID-19 Pandemic on the Economy of Nepal*. Kathmandu: Singhadarbar.

ILO Nepal (2020). *COVID-19 Labour Market Impact in Nepal*. Available online at: https://www.ilo.org/wcmsp5/groups/public/---asia/---ro-bangkok/---ilo-kathmandu/documents/briefingnote/wcms_745439.pdf

Joshi, T., Mainali, R. P., Marasini, S., Acharya, K. P., and Adhikari, S. (2021). Nepal at the edge of sword with two edges: the COVID-19 pandemics and sustainable development goals. *J. Agric. Food Res.* 4, 100138 doi: 10.1016/j.jafr.2021.100138

Magar, D. B. T., Pun, S., Pandit, R., and Rola-Rubzen, M. F. (2021). Pathways for building resilience to COVID-19 pandemic and revitalizing the Nepalese agriculture sector. *Agric. Syst.* 187, 103022. doi: 10.1016/j.agsy.2020.103022

Pant, B. (2008). *Mobilizing remittances for productive use: A policy-oriented approach.* Nepal Rastra Bank, Research Department Working Paper, 4.

Pradhan, P., Subedi, D. R., Khatiwada, D., Joshi, K. K., Kafle, S., Chhetri, R. P., et al. (2021). The COVID-19 pandemic not only poses challenges, but also opens opportunities for sustainable transformation. *Earths Future* 9, e2021EF001996. doi: 10.1029/2021EF001996

Rai, T. R. (2017). Nepal's LDC graduation target and it's challenges. *Civil Service J.* 38, 167–175. Available online at: https://www.researchgate.net/profile/Tirtha-Rai/publication/323998127_Nepal's_LDC_Graduation_Target_and_It's_Challenges/links/5ab797d60f7e9b68ef50ce5b/Nepals-LDC-Graduation-Target-and-Its-Challenges.pdf

Rasul, G., Nepal, A. K., Hussain, A., Maharjan, A., Joshi, S., Lama, A., et al. (2021). Socio-economic implications of COVID-19 pandemic in South Asia: emerging risks and growing challenges. *Front. Sociol.* 23, 629693. doi: 10.3389/fsoc.2021.629693

Singh, D.R., Sunuwar, D.R., Adhikari, B., Szabo, S., and Padmadas, S.S. (2020). The perils of COVID-19 in Nepal: implications for population health and nutritional status. *J. Glob. Health* 10, 010378 doi: 10.7189/jogh.10.010378

Spotlight (2020). *Covid-19 in Nepal: Where Are We After 9 Weeks of Lockdown?* Available online at: https://www.spotlightnepal.com/2020/05/19/covid-19-nepal-where-are-we-after-9-weeks-lockdown/

Subedi, D. R. (2020). Impact of COVID-19 on food security in Nepal. *Int. J. Entrepreneurship Econ. Issues* 4, 97–102. doi: 10.32674/ijeei.v4i1.44

Subedi, Y. R., Kristiansen, P., Cacho, O., and Ojha, R. B. (2021). Agricultural land abandonment in the hill agro-ecological region of nepal: analysis of extent, drivers and impact of change. *Environ. Manag.* 67, 1100–1118. doi: 10.1007/s00267-021-01461-2

UN (2015). *Envision2030: 17 Goals to Transform the World for Persons with Disabilities*. Available online at: https://www.un.org/development/desa/disabilities/envision2030.html

UNDP (2020). *Rapid Assessment of Socio-Economic Impact of COVID-19 in Nepal*. Available online at: https://www.np.undp.org/content/nepal/en/home/library/rapid-assessment-of-socio-economic-impact.html

Workie, E., Mackolil, J., Nyika, J., and Ramadas, S. (2020). Deciphering the impact of COVID-19 pandemic on food security, agriculture, and livelihoods: a review of the evidence from developing countries. *Curr. Res. Environ. Sustain.* 2, 100014 doi: 10.1016/j.crsust.2020.100014

World Bank (2020a). *Personal Remittances Received by Country*. Available online at: https://data.worldbank.org/indicator/BX.TRF.PWKR.DT.GD.ZS?locations=NP

World Bank (2020b). *Against-All-Odds-What-Driving-Poverty-Reduction-Nepal*. Available online at: https://blogs.worldbank.org/endpovertyinsouthasia (accessed: December 29, 2021).

World Bank (2020c). *Nepal Development Update: Post-Pandemic Nepal–Charting a Resilient Recovery and Future Growth Directions*. Available online at: 26 December, 2021. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/473551595429740654/nepal-development-update-post-pandemic-nepal-charting-a-resilient-recovery-and-future-growth-directions

Worldometer (2021). *COVID-19 Coronavirus Pandemic*. Available online at: https://www.worldometers.info/coronavirus/country/nepal/

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Food Supply Chain Shocks and the Pivot Toward Local: Lessons From the Global Pandemic

E. Melanie DuPuis[1]*, *Elizabeth Ransom*[2] *and Michelle R. Worosz*[3]

[1] Department of Environmental Studies and Science, Pace University, Pleasantville, NY, United States, [2] School of International Affairs and the Rock Ethics Institute, The Pennsylvania State University, University Park, PA, United States, [3] Department of Agricultural Economics and Rural Sociology and Alabama Agricultural Experiment Station, Auburn University, Auburn, AL, United States

Studies of how consumers acquired food provisions during the COVID-19 lockdown indicate that some US consumers and institutional provisioners pivoted to locally produced food. In some locations local food system organizations, along with state governments, created the infrastructure to enable this pivot. Research on this phenomenon—what we call "the local pivot"—has been extensive. However, evidence collected so far has mostly been reports of case studies looking at particular communities. Using Google Trends and Twitter data, we examine whether "the local pivot" was evident as a general trend in the US during the depth of the COVID-19 food supply crisis in 2020, and whether places with high local food infrastructure allowed more people to pivot to local food provisioning. Our Google Trends analysis indicated a temporary rise in searches for local food. However, we found very little discussion of local food systems on Twitter. We then compared three states with a "high," "medium," and "low" local food infrastructure based on the Union of Concerned Scientists rankings. We found a weak but positive relationship between places that were classified as high local food system infrastructure and a pivot toward local food reflected on Twitter. We did, however, find strong support for local restaurant businesses during this period on Twitter, although this support did not necessarily reflect a local food system pivot. We acknowledge that Twitter results are not generalizable to the entire population: local food system actors may not be using Twitter in their interactions, so Twitter activity may not reflect local food system activity in general, or COVID food sourcing behavior in particular. However, our results do indicate the need for more research on whether or not the evidence of a pivot to local food systems during COVID in the United States reflected a larger national movement or occurred in just a few scattered communities. Further research on this topic can help ascertain the ability of local food system infrastructure to provide a resilient response to future global food supply chain crises.

Keywords: COVID-19, local food systems, infrastructure, Twitter, resilience, social infrastructure, food supply chains, supply chain crisis

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Edited by:
Claire Kremen,
University of British Columbia, Canada

Reviewed by:
Barbora Duží,
Institute of Geonics (ASCR), Czechia
Rodney Holcomb,
Oklahoma State University,
United States

***Correspondence:**
E. Melanie DuPuis
edupuis@pace.edu

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INTRODUCTION

The long-term response of consumers to COVID-19 food supply chain disruptions is not yet clear. Both in the United States and globally, all indicators point to a massive switch from eating in restaurants and institutions to eating at home (Bennett et al., 2021), at least during the initial COVID-19 lockdown. Yet, studies of how consumers acquired food provisions during the lockdown indicate two trends. First, national analyses by Mckinsey, Neilsen, and Gallup indicate a significant rise in online food ordering (Ahuja et al., 2021; Neilsen survey reported in Lo et al., 2021; Gallup reported in Brennan, 2021). Many studies found that home food provisioners turned to grocery store delivery and online shopping from large retailers like Amazon and Walmart (Weersink et al., 2021).

Second, food studies researchers reported case studies that indicate a pivot to local food systems, in terms of consumers who pivoted to locally produced food through food system organizations such as Community Supported Agriculture (CSA) farms and food hubs. In addition, a number of state programs were established or expanded to connect local farms with local food hubs and food banks (e.g., Sanderson, 2020; Hilchey, 2021; Oncini, 2021). The news media also covered a number of these stories (e.g., Ricker and Kardas-Nelson, 2020; Roberts, 2020; Robey, 2020). In particular, both news stories and peer reviewed case study research focused on how local food organizations bridged the gap between farmers in need of markets and consumers in need of fresh food. Based on these stories, some have argued that recent global food supply disruptions could lead to a restructuring of the food system in favor of more localized food system infrastructure (LFSI) (Garnett et al., 2020; Hendrickson, 2020; Thilmany et al., 2020) and that LFSIs could make communities more resilient against future food supply chain disruptions (Thilmany et al., 2020).

While research on local pivots are mostly case studies, polling companies collected data on the turn to online and grocery delivery at the national and global level. These studies have found a general turn to national online ordering from companies like InstaCart and Amazon (Redman, 2020). Surveys also note an increase in purchase of shelf-stable vs. fresh food (Food Insights, 2020; Hamstra, 2020). As Morgan (2020) notes in Forbes magazine:

> A year ago, 81% of consumers had never bought groceries online, but during the pandemic nearly 79% of shoppers have ordered online. In August 2019, U.S. online grocery sales totaled \$1.2 billion; in June 2020, that total was \$7.2 billion. Over that same time period, the number of online customers increased from 16.1 million to 45.6 million and the average spend per order grew from \$72 to \$84.

While grocery stores are stocking an increasing supply of local food products (Tropp, 2013), and some food hubs have implemented online ordering, indicators suggest that despite the global food supply chain crisis, consumers continued to provision themselves from national and global supply chains.

In contrast, case studies of "the local pivot" report that consumers turned to local food systems in response to the COVID-19 food supply chain crisis. Many states initiated programs that worked with community organizations to connect farmers and consumers. Our article is a first attempt to examine the extent of "the local pivot." We ask, to what extent did people across the country turn to their local food system when restaurants closed and their supermarket shelves were bare? Additionally, were states with a stronger local food system infrastructure—preexisting programs that connect farmers to food providers or consumers, food hubs, food policy organizations—better able to connect farmers and consumers at the local level?

Considering the potential for future food supply chain crises, it is important to determine whether local food system infrastructure (LFSI) is able to respond and adapt to these crises. Therefore, we examine in this study whether the local pivot cases are representative of a larger phenomenon. To do so, we look at data from US national social media. This examination provides a first step toward understanding the local pivot at a larger scale, asking whether it did, in fact, occur more broadly, if the occurrence varied by regions, and how might existing LFSI have influenced its occurrence. In particular, case studies indicate that a strong LFSI can provide a resilient response to future shocks (Thilmany et al., 2020). For this reason, we seek to understand the relationship between LFSI and the response by consumers and other key actors to food supply chain disruption during the COVID crisis.

To frame our research, we draw upon the alternative food network (AFN) and LFSI literature (e.g., Morley et al., 2008; Goodman et al., 2012). Our results are meant to contribute toward a better understanding of whether and how local food systems are currently able to provide a resilient response to future supply chain disruptions. The alternative food movement has long held that the relocalization of food systems, and the shortening of food supply chains, would have a positive impact on citizens by helping to fulfill health and equity goals (see, e.g., Hendrickson and Heffernan, 2002; Holloway and Kneafsey, 2004). Research on "the local pivot" indicates that relocalization could help meet food supply resiliency goals as well.

To understand the general response of food system actors to the first year of the pandemic, we examine two social media sources: Google Trends and Twitter. In our Google Trends analysis, we looked at searches related to terms that we determined are indicative of a local pivot including keywords "local," "food," and "farm." We also searched for terms indicative of a turn to alternative food systems such as "community supported agriculture" and its acronym: "CSA." In addition, we gathered trends on "food pantry" and "food bank," terms that are not identical but do intersect with the broader discourse on alternative food systems (e.g., food justice, food sovereignty). Finally, we gathered trends on the term "local restaurant" based on our discovery of the frequency of that term in our preliminary Twitter analysis.

In our examination of Twitter discourse, we conducted a comparative, nationwide study of tweets from 2015 and 2020 using a range of keywords related to local food systems. We found that while the Google Trends data indicates a strong, although perhaps temporary, pivot to the local in 2020, the Twitter data does not indicate a strong pivot to the local. Instead, we found Twitter discourse was more likely to focus on support for local restaurants. However, while not as robust as expected, we do see a trend in states identified as having a stronger LFSI (Union of Concerned Scientists, 2018) also have more tweets related to the local pivot. Yet, content analysis of the tweets from three contrasting states finds contextual differences in the concerns about "local" and much of the local discussion involves issues not necessarily related to local food systems or alternative food networks.

This research contributes to the question as to whether or not relocalization is an effective response to the food supply chain crisis, as some studies claim, or if it is a "side-show" to a larger move to ever-greater food system globalization and concentration. Our analysis of whether or not a local food system response is reflected in Twitter discourse is just a first step in answering that question.

BACKGROUND

The COVID-19 pandemic caused severe disruptions in global food supply chains. Potential supply chain disruptions continue to be part of media discourse, illuminating a continuing fragility (see, e.g., Farrer, 2021). Initial supply chain disruptions that occurred in the early months of the pandemic prompted food studies scholars to investigate how local food systems have responded to the crisis. Both *Agriculture and Human Values* (Sanderson, 2020) and the *Journal of Agriculture, Food Systems, and Community Development* (Hilchey, 2021) published flashpoint studies on COVID's effect on the food system. In addition, the Wallace Center (2021), a non-profit that is part Winrock International, coordinates an ongoing resource hub with food NGO partners, and three universities—Penn State, Colorado State, and University of Kentucky—to aggregate research that evaluates the impacts of COVID-19 on the food system.

Longer-term studies of pandemic-induced disruptions are beginning to emerge, and show in a more rigorous and systematic way how local food systems have responded. Both the short-term and the emerging longer-term studies indicate pivots in some consumer behaviors in response to COVID-related food supply chain disruption, especially during the quarantine lockdowns (e.g., Hobbs, 2020; Mahajan and Tomar, 2020; Banerjee et al., 2021). These articles describe the effects of restaurant and school closures, which strongly affected dairy, fishing, and other sectors that had traditionally provided significant proportions of their total production to the food service and restaurant sector (e.g., Petetin, 2020; Maples et al., 2021). News articles described how lockdowns and quarantines led to major changes in how consumers bought food (e.g., Dannenberg et al., 2020; Li et al., 2020; Ricker and Kardas-Nelson, 2020; Roberts, 2020; Robey, 2020). Finally, lockdowns led to significant concerns about how laid-off workers would feed themselves and their families, prompting research on how the food chain disruption affected food security (Gundersen et al., 2020; Laborde et al., 2021; Mueller et al., 2021).

Agriculture and food (agri-food) system researchers took notice of these changes. Scholars looked at whether and how local farmers would both survive without access to their usual food service and restaurant markets and how they would respond as consumers pivoted their food purchases away from these sectors and toward retail establishments (e.g., Weersink et al., 2021). One study, for instance, examined how LFSI might be leveraged to meet the food security needs of consumers who were stuck at home and without income (Casey et al., 2021). Researchers who have studied local food system infrastructure and food relocalization movements were particularly interested in whether the system could and would facilitate a pivot to more localized food provision in response to these disruptions (O'Hara and Toussaint, 2021).

The local pivot studies fall into two categories. First, are the stories of farm production areas that highlight chaotic bottlenecks in supply due to the loss of farm workers (e.g., Ridley and Devadoss, 2020) and food service markets (Hashem et al., 2020). These bottlenecks included both large scale farms such as livestock and milk producers, and fisheries operators, who had to euthanize animals, dump milk, or leave boats in the harbor in response to unexpected and widespread closures of fast-food retailers and chain restaurants [OECD (Organisation for Economic Co-operation Development), 2020; Weersink et al., 2021]. Within this stream of work are studies of smaller farms that served local farm-to-table restaurants that were also left without markets (Severson, 2020). In some states, farms that operate in local and regional supply chains were severely affected by the closure of farmers markets, often instituted by law (Martinez et al., 2021).

Second, are the stories of food sector pivots to new markets as an adaptation to the crisis (for an overview, see Wallace Center, 2021). For example, in one case a small dairy of only 50 cows was able to adapt its operation to supply grocery stores that were otherwise unable to obtain milk through their regular supply chain (Huber, 2020). The third line of research focused on the role of local food system organizations that helped both farmers and consumers adapt to the crisis. These stories describe how local food policy non-profits and other food hub organizations provided resources to connect producers and consumers at the local level (Ammons et al., 2021; Harden et al., 2021; Wallace Center, 2021). While often part of a more conventional food philanthropy sector, case studies showed that food banks also worked to provide connections between farmers without markets and local consumers in need (Thilmany et al., 2020). Moreover, several states implemented local food policy changes to reduce the supply chain bottlenecks and increase food access, followed shortly thereafter by federal policy responses, especially the Coronavirus Aid, Relief, and Economic Security (CARES) Act [HFPP (Health Food Policy Project), 2021]. An example of local policy changes included laws that allowed food service establishments to continue operating or operating in a modified manner (e.g., allowing for curbside pickup), and policies that focused on vulnerable populations that saw regular meal distribution disrupted (e.g., school lunches, Meals on Wheels). This fits with the general understanding that food system resilience depends not only on the impact of the initial shock or crises, but also how actors, including policymakers, respond to the crises (Béné, 2020).

Most of this research, however, involved examinations of specific case studies and communities: describing their problems, their successes, and the continuing weaknesses of producer-to-consumer local and global supply chains. There has been little work examining this phenomenon at a regional, comparative regional, or national level. In other words, although a number of stories have emerged, detailing the ways that particular groups in particular places worked to link local producers and consumers in new, more resilient, short food supply chains, there has been no overall assessment of the extent to which these efforts have been widespread. Through an analysis of social media, we seek to understand (1) to what extent "the local pivot" described in the case studies was typical in the United States as a whole, and (2) to what extent state food policies and LFSI were important to this pivot.

Alternative Food Networks and Local Food System Infrastructure

Participants in alternative food networks (AFNs: food policy and food movement organizations) in the United States have focused on building of LFSIs (e.g., farmers markets, CSAs, food hubs) as a means of creating alternative food economies. Measuring the benefits of LFSI has been the topic of nearly four decades of agri-food studies research. This body of work has focused on the promise of LFSI to counteract the disbenefits (e.g., loss of farm communities in rural areas; environmental degradation; highly processed, nutrient poor, foods) attributed to the global food system. Sometimes called "short food supply chains" or "distributed" systems (Morgan et al., 2006; Moragues-Faus et al., 2020), researchers have examined the positive potential for AFN/LFSIs to provide communities with more just, fair, healthy, sustainable foods, as well as economically revitalized rural communities (Kloppenburg et al., 1996; Hendrickson and Heffernan, 2002; Sonnino et al., 2016). Some argue, more broadly, that the building of LFSI will lead to greater economic democracy (Whatmore et al., 2003; Moragues-Faus et al., 2020). Other research has problematized these claims, critiquing food re-localization as an idealized and impractical "local trap" (Born and Purcell, 2006) that overestimates the potential benefits that LFSI can offer to "fix" food systems (DuPuis and Goodman, 2005; DeLind, 2011; Hinrichs, 2016). In the light of these critiques, some current research on AFN/LFSIs has taken a more reflexive approach, calling for an assessment of AFN/LFSIs' potential without assuming that LFSI is sufficient to solve food system problems (Goodman et al., 2012; Fonte, 2013).

In accordance with this reflexive approach, we seek to better understand the ability of LFSI to respond to the COVID pandemic. While there is significant research on LFSI response in other parts of the world, our focus is on the United States. Given the lack of national data on COVID-related food system relocalization, we chose to draw from an analysis of social media. Our analysis, therefore, measures: the extent to which consumers pivoted to the local and the role of LFSI in that pivot, as well as the ability of a national social media analysis to answer these questions. Our analysis, therefore, looks at how "local" and "food" are used in Twitter discourse as a whole, which included terms that focus on LFSI—local farms, CSAs, food hubs. Additionally, due to the impact of the lockdown, with large numbers of people unable to earn a living, we also consider food security, thus including food pantry and food banks in our searches. In our approach to the local pivot, we share a strong interest in how LFSI *can* contribute to the pragmatic goal of food system resilience during crises. In other words, we recognize that regions with an existing and perhaps more robust LFSI *should* be more capable of contributing to local food system resilience during supply chain crises. Our broader examination, however, seeks to understand *whether* these LFSI-enhanced local pivots, as described in published case studies, took place more generally or only in particular places at particular times.

Local Food Systems as Resilient Social Infrastructure

As noted above, a great deal of research has been carried out on the community benefits of local food systems. More recently, new conversations about the nature of local interaction have resulted in the emergence of a new concept: social infrastructure. Klinenberg et al. (2020: 653) describe social infrastructure as emerging out of, but distinguished from, the concept of social capital, which "largely attribute bonds and cohesion to cultural preferences and practices of particular groups…the theory of social infrastructure proposes that some variation in social capital is attributable to the quality of physical places and organizations at the neighborhood level." In other words, social infrastructure is rooted in the place-based organizations and interconnections between people possessed with "accessible gathering places, including branch libraries, community gardens and parks, playgrounds, religious and non-profit organizations, and certain commercial establishments (such as diners, cafes, barbershops, and salons), [which] foster interaction" (Klinenberg et al., 2020: 653). As is evident in this list, food plays a part in these notions of gathering places, indicating that elements of the food system would be a component of social infrastructure. Klinenberg's (2018; 2020) work on the Chicago Heatwave of 1995 and in New York resilience planning shows that place-based social infrastructure creates more resilient communities, capable of adapting and protecting themselves from disasters and disruptions. In the same way, one can argue that LFSI can help communities adapt to food supply chain crises by creating the ability to pivot toward local food systems when global and national food systems break down.

As published case studies show, in certain places during the COVID food supply chain crisis, local food systems acted as forms of social infrastructure, enabling communities to adapt food provisioning practices during the crisis (Thilmany et al., 2020; Wallace Center, 2021). Food hubs and local food banks created connections between farmers who lost access to local restaurant provisioning and brought local farmers together with interested consumers through various strategies including online farmers markets, expanded CSA programs, and other forms of adaptive direct marketing (Bachman et al., 2021). Flash studies looking at the first COVID wave reported that CSA farm shares sold out early in the 2020 sign-up season (White, 2021). In addition, several food banks reported not only increased interest in farmers who could provision these organizations with fresh food, but also increased demand for local produce from customers who had lost jobs (Siddiqi et al., 2021). This case study research shows that, in certain places and at certain times, local food system organizations responded quickly with new efforts to join local producers with local consumers.

It is worth asking, therefore, whether this local pivot was a general phenomenon, whether it was isolated to particular places and, if so, which communities were more likely to pivot toward the local. Secondly, it is also important to ask whether local pivots, where they happened, were linked to LFSI. To answer these questions, we turned to analysis of social media, looking at national and state level data, in combination with the Union of Concerned Scientist's LFSI rankings. We started with Google Trends to capture broad internet-based queries, then conducted a systematic analysis of Twitter "scrapes" before and during the initial 2020 COVID pandemic wave. Then we took a more targeted deep dive into the 2020 Twitter data to examine the context of pandemic era tweets in three states with differing levels of LFSI. We selected the Union of Concerned Scientists LFSI rankings for the breadth of metrics incorporated into their ranking scheme. The LFSI rankings considered five different indicators including: number of farmers markets per 100,000 residents; number of food hubs per 1 million residents; number of food policy councils, networks, coalitions per 1 million residents; capacity for food waste management via composting; and percent of census tracts with at least one healthier food retailer within 0.5 miles of the tract boundary (Union of Concerned Scientists, 2018).

While stronger or weaker LFSI can impact the capacity for consumers to pivot, how governments respond to a crisis also impacts food systems. There were two COVID-19 programs, the Coronavirus Food Assistance Program 1 and Coronavirus Food Assistance Program 2, at the federal level, which then were administered by states (USDA, 2022a,b). For example, within CFAP 1, New York received approximately $231 million, Pennsylvania received a total of $178 million, and Alabama $115 million in support of producers in these three states. The largest recipients of the funding by commodity were dairy farmers in New York and Pennsylvania, $169 million and $107 million, respectively, and cattle farmers in Alabama ($86 million). All three states also used federal funding to support feeding programs, especially for vulnerable populations. However, with a few exceptions (e.g., free school meals to all school children), the majority of this funding was channeled through existing programs, which means states that had more robust programming pre-pandemic had readymade avenues for distribution of additional funding. For example, the Pennsylvania Agricultural Surplus System (PASS) is a pre-pandemic program that makes connections between production agriculture and the non-profit sector to help feed vulnerable populations. In addition to the general PASS appropriation from the state, the Federal CARES Act infused an additional $10 million dollars in funding to PASS (Pennsylvania Department of Agriculture, 2022).

METHODS

This article is a first attempt to analyze the effects of the local food pivot at a national level, focusing on the general extent of the pivot and the role of local food infrastructure in that change. Using Google Trends data, we identified the prevalence of keywords searched during COVID as it related to food and agriculture in the United States. Google Trends has been used by other researchers to study consumption patterns (Kamiński et al., 2020), including COVID-19 era consumption (Schmidt et al., 2020), although it is used more frequently in the business and marketing literature. Based on the Google Trends data, our reading of LFSI case studies, and media reports, we identified 39 keywords to use in "scraping" Twitter. These keywords seemed most relevant to the food supply chain disruptions and responses at the onset of the pandemic. The search for relevant tweets encompassed the entire 2020 calendar year (January 1, 2020–December 31, 2020), with the goal of capturing the start of the COVID-19 pandemic and the supply chain disruptions that occurred in the U.S. To have a point of comparison, the same 39 keywords were used for scrapping tweets for the 2015 calendar year. Only tweets for the 48 contiguous states, plus Washington, D.C. were collected.

We also utilized Twitter data to determine if places with a stronger LFSI, as ranked by Union of Concerned Scientists (2018), were more likely to have social media conversations about local food as a way to adapt to food supply chain crises. The following key words were identified and analyzed: Local Food, Local Restaurant, Local Farm, Food Bank, Food Pantry, Farmers Markets, Community Supported Agriculture (including the abbreviation CSA), and Food Hub. We also included garden in our initial search, but discovered the term garden is widely used to identify restaurant names (e.g., Olive Garden Italian Restaurant^{TM}) or a location (e.g., beer garden, garden center), so we did not include garden in our final analysis. We analyzed these data to gauge consumers' interest in existing LFSI (i.e., tweets) and consumers' ability to pivot (i.e., LFSI ranking). We also examine in more detail three regions and states with low, medium, and highly developed local food system infrastructure resources, as identified by the Union of Concerned Scientists rankings, for evidence of adaptation to food supply chain disruption. In other words, we are examining to what extent the LFSI may have contributed to food system resilience during the COVID crisis.

These data included both tweets and retweets. We are primarily interested in 2020, as it included the initial pandemic lockdown and response period, but also used a non-COVID year, 2015, as a point of comparison. By examining the 2020 Tweets where local and food/farm/restaurant were discussed, but not necessarily referring to the local food system, we can make inferences about consumers' concerns and their thoughts about what the concept of local means.

Twitter data is increasingly used by social scientists to study a wide range of topics, including debates surrounding meat consumption (Maye et al., 2021), the rise of vaccine opposition (Bonnevie et al., 2021), and individual's perceptions of their government's handling of the unfolding COVID-19 crisis

(McKay et al., 2021). As a popular form of social media, Twitter has been studied as an important platform for communication during disasters (Kusumasari and Prabowo, 2020). Twitter is also viewed as a mechanism to better understand different attitudes and perspectives on a wide range of topics. As a recent Pew Report states, "Twitter is a modern public square where many voices discuss, debate and share their views" (Wojcik and Hughes, 2019). However, as the Pew report explains, users of Twitter are not representative of the U.S. population (Wojcik and Hughes, 2019). Rather, Twitter users are thought to be younger (40 vs. median age of 47), more educated (42% college educated vs. 31% in the U.S. population), and more likely to be democrat (36% of Twitter users vs. 30% of the U.S. population; while 21% of Twitter users identify as Republican compared to 26% of the U.S. population) than the general public. For these reasons, we cannot assume Twitter results are generalizable to the entire population. However, Twitter does give social scientists the opportunity to explore behavioral practices and attitudes.

Twitter also allows for geolocation of tweets. This feature has proven valuable for social science researchers interested in spatial patterns of behaviors and attitudes. However, in 2019 Twitter announced a change in their geolocation policies, which significantly reduced the number of tweets that are geocoded (Kruspe et al., 2021). For this reason, in our dataset, we have significantly fewer 2020 tweets (233,116) than 2015 tweets (4,118,001). Of the geocoded tweets for both years, we have tweets geocoded at the state level. In our analysis we are able to identify similarities and differences between states, but not within states. Given the significant differences between the 2 years in terms of tweets, as well as differences between states in terms of total tweets (e.g., New York has many more tweets than South Dakota), our results are reported out in percentages. Moreover, to ensure results were not skewed by a few large states (e.g., California, New York), we analyzed percentage of local tweets out of all tweets within each state.

For a deeper analysis of tweets, we focus on three states, New York (NY), Pennsylvania (PA), and Alabama (AL). These three states were selected due to each of the author's prior research and knowledge about food and agricultural issues within these three states. When referring back to the LFSI ranking by the Union of Concerned Scientists, we find that NY, PA, and AL were ranked 14th (high), 26th (medium), and 44th (low) in LFSI, respectively.

We also conducted a thematic analysis (Guest et al., 2011) of each individual tweet from our three states—NY, PA, AL—to better understand the issues of importance, as well as the context of the views expressed. Due to the brevity and casual nature of tweets, we focused on their functional meaning (Van Dijk, 1985) and sought to identify the surface or "semantic appearance" of themes (Javadi and Koroush, 2016). Analyzed were all 2020 tweets that included the word Local and at least one of the following: Food, Farm, or Restaurant. In addition, all tweets were searched for the words Food Bank, Food Pantry, Food Hub, and CSA within these three states and, if present, these tweets were also assessed.

The qualitative analysis began with a preliminary scan of each tweet and the development of a coding scheme. For example, during the initial assessment of LocalFarm tweets several themes emerged including frequent references to farmers markets; buying or supporting local foods, farms, and related businesses; specific foods, beverages, and products; and pandemic related health issues such as sanitation and social distancing. Each of these themes were assigned a code. Using Excel, each tweet (row of data) was coded for each theme (columns of data) accordingly, meaning that each tweet was assigned a 1 for the presence of an identified theme or a 0 for the absence of the theme. When a tweet referenced a type of enterprise, event, or activity that was unclear, a Google search was conducted before coding. For instance, the tweet "Please support the local non-profits [sic] that give your community its heart and soul Happy Dog Farm LLC" was found in a search of LocalFarm tweets in Pennsylvania. A Google search of Happy Dog Farm LLC revealed that it is an apple orchard and cider mill, which was not evident from the name, alone. During coding of this tweet a 1 for the "support/buy local" code was assigned, and a 0 for the "farm market," "food/product," and "human health" codes was used because these codes were not present in the tweet. After initial coding, the codes were reevaluated and the codebook was adjusted to assure consistency, then all tweets were coded again. The goal of this coding procedure was to identify thematic patterns. Thus, the last step was to record the frequency of each coded theme and to summarize the themes as a percentage of the coded tweets. Tweets counted as LFSI were those that specifically referenced nearby farms, farmers, or community supported agriculture (CSA); urban agriculture; farmers markets or specialty markets that aggregate local and/or regional foods; processing or manufacturing businesses that claimed to make foods from locally sourced ingredients (e.g., butcher, baker); and farm-to-table restaurants or special menus at restaurants created to highlight local foods.

FINDINGS

Google Trends Data

The Google Trends data shows a clear pivot to local food issues. Google Trends measures searches "scaled on a range of 0 to 100 based on a topic's proportion to all searches on all topics" (Google, 2021) over a specified period of time. **Figure 1** reflects these data over the period from December 4, 2016 to December 1st, 2021, with the goal of showing change overtime. Each graph emphasizes a few years prior to the pandemic and searches occurring during the COVID-19 pandemic. As the figure shows, searches for terms associated with local and food peaked at or around the date of the state and federal lockdowns for most of the search terms of interest. The exception is "community supported agriculture" (E) which tends to peak cyclically during the CSA signup season in the spring and "Local Restaurant" (C), which peaked both during lockdown and as restaurants re-opened. "Local" (A), "Local Food" (B), "Local Farm" (D), and "Food Bank and Pantry" (F) all peaked during the initial lockdown. "Local Farm" (D) searches continued to be high over time as the food supply chain crisis developed. Because the effect on farmers was covered in the news during that time period, we infer that the rise in searches indicates that the local pivot did occur among consumers, including a turn to local farms and local food, as well as, to some extent, local restaurants. Interestingly, "Food Bank and Pantry" (F) searches peaked quickly and then stabilized at a somewhat normal rate for this time period.

Twitter Data

Our examination of Twitter data provides a more granular set of evidence on the local pivot. Because our Twitter data is geolocated, we can also examine data by state. We find that, nationwide, Twitter data did not reflect a substantial pivot to the local. When comparing 2015–2020 data, nationwide there was an overall decline in references to Local and Food (30.2% in 2015 and 23.4% in 2020) and Local and Farm (15.9% in 2015 and 12.2% in 2020). In contrast there was an increase in references to Local and Restaurants (14.9% in 2015 and 28.4% in 2020). Not shown in the data tables are data associated with Community Supported Agriculture, Food Hubs, Food Bank, and Food Pantry. These data are not reported because we did not see a percentage change in tweets that reference Community Supported Agriculture or Food Hubs (<0.0% for 2015 and 2020) and the terms Food Pantry and Food Bank appear <1% of the time in both 2015 and 2020.

To understand whether or not states with higher LFSI were more likely to pivot, we grouped states into low, medium, and high LFSI based on the Union of Concerned Scientists (2018) rankings (split equally with 16 states in each stratum). Focusing on all local tweets within each state, we then compared low, medium and high LFSI states. We find a general trend toward states that have higher LFSI tweeting more about local farms in 2020, while states lowest in LFSI were more likely to tweet about local restaurants (see **Table 1**). To ensure no one state in a grouping was an outlier in tweeting excessively about local, we analyzed the percentage of Local Restaurant/Food/Farm tweets by state. The range of Local Food related tweets was 0.5% to 3.5%, with the median being 1.6% of all tweets within each state. In total across all states there were 3,980 (64%) Local Food/Restaurant/Farm tweets out of a possible 6,218 tweets that mention Local (excluding Washington, D.C.) in 2020. However, Local Food/Restaurant/Farm tweets make up only 1.7% of all 233,122 geocoded tweets in 2020.

For the three states in our analysis, 2.7% of Alabama tweets (32 out of 1,195), 2.4% of New York tweets (567 out of 23,275), and 2.6% of Pennsylvania tweets (279 out of 10,844) referred to local. When focusing on the tweets that reference local within each state (see **Table 2**), the smallest percentage of tweets was related to LocalFarm. New York had the largest percentage of LocalFarm tweets at 15.9% in 2020, compared to 19.9% in 2015. LocalFarm was tweeted 12.5% in Pennsylvania, compared to 16.1% in 2015. Only 3.1% of Alabama tweets were LocalFarm, which declined from 12.1% in 2015. Alabama had 37.5% of local tweets focused on restaurants in 2020 compared to 7.6% in 2015, while New York had 24.7% of local tweets focused on restaurants (vs. 15.3% in 2015), and Pennsylvania had 20.4% of local tweets focused on restaurants (vs. 12.6% in 2015). LocalFood represented 28.1% of the 2020 Alabama tweets, compared to 33.3% in 2015. Similarly, 26.5% of tweets from Pennsylvania focused on LocalFood, but this was a slight increase from 24.6% in 2015. The lowest percent of LocalFood tweets among the three states in 2020 were from New York at 22.9%, compared to 24.5% in 2015. Looking more deeply at the 2020 LocalFood tweets, we find differences in the context.

LFSI and the Local Pivot: Content Analysis in More Detail

To further understand the data presented above, we did a more detailed, thematic, analysis of the Local tweets in New York, Pennsylvania, and Alabama. Our goal was to determine the context in which word Local was used, particularly when combined with words associated with LFSI. As shown in **Table 3**, of the Local tweets, AL had the highest percentage of combined restaurant, food, and farm tweets (68.8%, $n = 22$). However, AL also had a far lower percentage (3.1%, $n = 1$) of combined LFSI tweets compared to the other states. The highest percent of combined LFSI tweets were from NY (18.9%, $n = 107$), followed by PA (13.6%, $n = 38$). Surprisingly, there were virtually no LFSI tweets focused on food banks and pantries or CSAs (**Table 4**) and there were no references to "food hubs" in any of the three states (not shown).

Local Restaurant Tweets by State

Across the three states, Alabama had the highest percent (37.5%, $n = 12$) of LocalRest tweets, but none of them were associated with LFSI. Instead, most of these tweets called for supporting local restaurants and to do so via take-out and delivery. One tweet focused on restaurants feeding health care providers. Among all Local tweets from Pennsylvania, 20.4% ($n = 57$) focused on LocalRest. Many of these tweets (65.0%, $n = 37$) focused on supporting local restaurants, primarily via take out. Several others mention a "Support Local Sunday" campaign while another noted the founding of a new NGO, the Independent Restaurant Coalition, which claims to represent independent restaurants and chefs and aims to lobby local, state and federal governments to save local restaurants and their impacted employees from the financial impacts of COVID-19. Support for local breweries was 14.0% ($n = 8$) of the LocalRest tweets. Only two of the Local Pennsylvania tweets (0.7%) mentioned LFSI; a co-op and a cottage bakery noted their connection to local farmers. Of New York's Local tweets, 24.7% ($n = 140$) focused on restaurants. More than half (52.1%, $n = 73$) of these LocalRest tweets were calls for support, particularly via takeout and delivery. None of the LocalRest tweets from New York mentioned local farms, farmers, or any other aspect of LFSI. Instead, 15.7% ($n = 22$) of the LocalRest tweets focused on health-related conditions of restaurant patronage (e.g., masks, social distancing) and meals supplied to health care and frontline workers.

Local Food Tweets by State

Alabama also had the highest percent of LocalFood (28.1%, $n = 9$) tweets, but only one was associated with LFSI. This tweet referenced farms associated with the USDA Farmers to Families Food Box program. These food boxes were authorized with the passage of the 2020 Families First Coronavirus Response Act, and were a response to reports of farm-level food waste coupled with increasing food insecurity. The Act authorized the US Secretary of Agriculture to buy fresh produce, dairy, and meats, and to distribute these products to food banks and non-profits

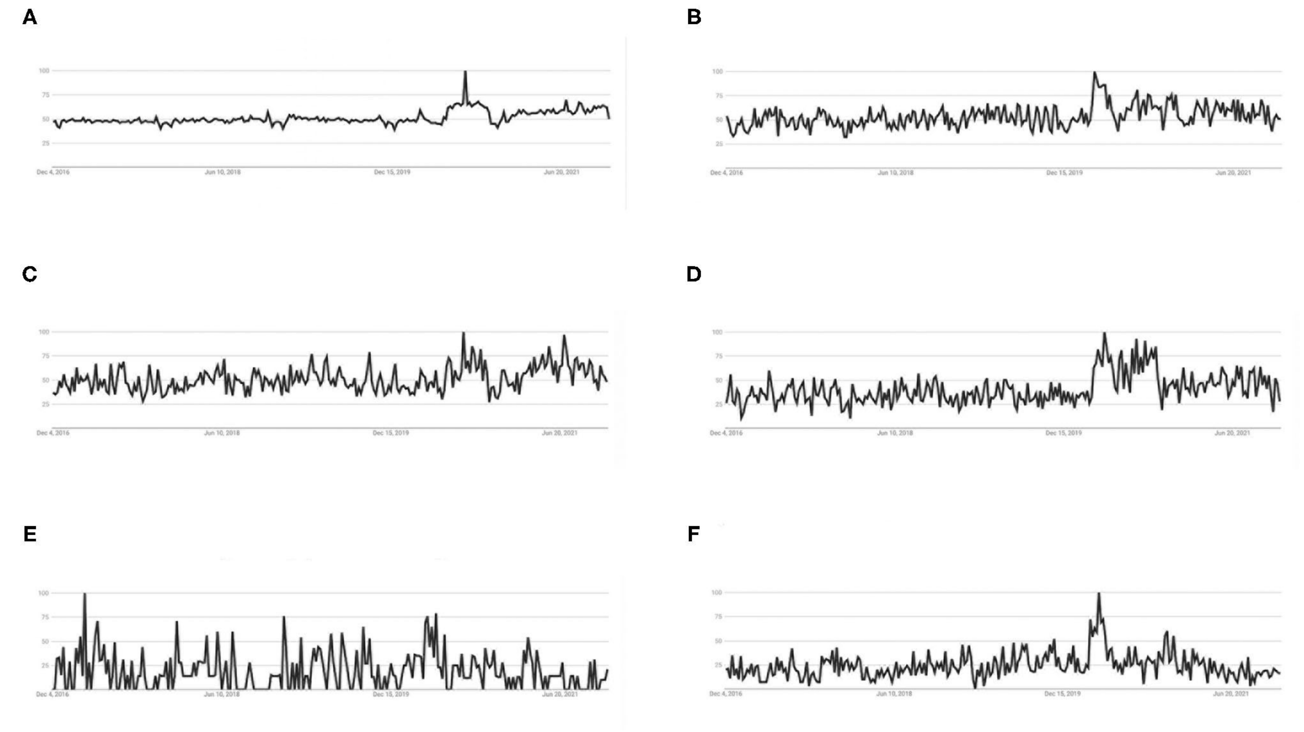

FIGURE 1 | Google Trends Local Food Related Searches between December 4, 2016 and December 1, 2021. **(A)** Local. **(B)** Local food. **(C)** Local restaurant. **(D)** Local farm. **(E)** Community supported agriculture. **(F)** Food bank and food pantry.

TABLE 1 | 2020 Results for local restaurant/food/farm tweets out of all local tweets ($n = 6{,}218$) for states ranked low, middle, and high in local food system infrastructure (LFSI)[a].

State rankings	States (UCS LFSI ranking)	LocalRest	LocalFood	LocalFarm
Lowest LFSI	NH, ND, GA, SC, AZ, IN, MS, LA, KY, AL, TN, UT, TX, AR, SD, OK	34.2%	25.4%	9.2%
Middle LFSI	FL, VA, MT, NE, OH, MI, WI, MN, PA, NJ, NM, WY, WV, MO, IL, ID	28.3%	22.7%	10.9%
Highest LFSI	VT, ME, OR, WA, CA, DE, CO, NC, KS, IA, MA, MD, NY, CT, NV, RI	25.5%	23.0%	15.1%

[a]*Data excludes Washington, D.C. because UCS does not include D.C. in their rankings.*

TABLE 2 | Results of local restaurant/food/farm tweets out of all local tweets within the state.

State	UCS LFSI* score	LocalRest		LocalFood		LocalFarm	
	2018	2015	2020	2015	2020	2015	2020
AL	44th	7.6%	37.5%	33.3%	28.1%	12.1%	3.1%
PA	26th	12.6%	20.4%	24.6%	26.5%	16.1%	12.5%
NY	14th	15.3%	24.7%	24.5%	22.9%	19.9%	15.9%

**Union of concerned scientists local food system infrastructure.*

who would provide the Boxes to families in need (Agricultural Marketing Service, 2020). Of the remaining eight tweets, one focused on food security broadly (i.e., a food drive competition between two major universities) whereas the remaining tweets focused on restaurants. Of these six restaurant tweets, half ($n = 3$) supported a specific establishment because it was owned and/or operated locally.

Of the Local tweets from Pennsylvania, 26.5% ($n = 74$) were LocalFood tweets, 9.5% ($n = 7$) of which mentioned food associated with LFSI including farmers, farmers markets,

TABLE 3 | Results of thematic analysis of local restaurant/food/farm tweets out of all 2020 local tweets within the state to identify tweets that reference local food system infrastructure (LFSI).

State	LocalRest		LocalFood		LocalFarm		Combined Tweets	
	Total	LFSI	Total	LFSI	Total	LFSI	Total	LFSI
AL	37.5% ($n = 12$)	0.0% ($n = 0$)	28.1% ($n = 9$)	3.1% ($n = 1$)	3.1% ($n = 1$)	0.0% ($n = 0$)	68.8% ($n = 22$)	3.1% ($n = 1$)
PA	20.4% ($n = 57$)	0.7% ($n = 2$)	26.5% ($n = 74$)	2.5% ($n = 7$)	12.5% ($n = 35$)	10.4% ($n = 29$)	59.5% ($n = 166$)	13.6% ($n = 38$)
NY	24.7% ($n = 140$)	0.0% ($n = 0$)	22.9% ($n = 130$)	7.4% ($n = 42$)	15.9% ($n = 90$)	12.5% ($n = 71$)	63.5% ($n = 360$)	18.9% ($n = 107$)

TABLE 4 | Results of thematic analysis of all 2020 food bank, food pantry, and community supported agriculture (CSA) tweets in the state to identify tweets that reference local food system infrastructure (LFSI).

State	Food bank/pantry		CSA	
	Total	LFSI	Total	LFSI
AL	0.3% ($n = 4$)	0.0% ($n = 0$)	0.1% ($n = 1$)	0.1% ($n = 1$)
PA	0.3% ($n = 29$)	0.0% ($n = 1$)	0.0% ($n = 0$)	0.0% ($n = 0$)
NY	0.2% ($n = 42$)	0.0% ($n = 1$)	0.0% ($n = 0$)	0.0% ($n = 0$)

and community gardens. Another 28.4% ($n = 21$) of the Pennsylvanian LocalFood tweets called for supporting a local business regardless of type. Overall, the highest percent (40.5%, $n = 30$) of LocalFood tweets referred to an unspecific food business or event (e.g., wine and food festival, food photographer, unnamed establishment), six of which focused on locally crafted beer. None of the latter noted the source of the ingredients brewed. A specific restaurant was mentioned in 31.1% ($n = 23$) of LocalFood tweets, including food trucks ($n = 6$) and food delivery ($n = 2$). Food security was the next most common topic, but it represented only 8.1% ($n = 6$) of the LocalFood tweets in the state.

The lowest percent of LocalFood tweets were from New York (22.9%, $n = 130$), but the state also had the highest percent of Local tweets related to LFSI (7.4%, $n = 42$). More than a third of New York's LocalFood (34.6%, $n = 45$) tweets focused on restaurants and other food related businesses such as bars and other unspecified food related establishments. More than a third of the LocalFood tweets (36.2%, $n = 47$) also made a direct plea to support local businesses, more than half of which were specific to restaurants (51.1%, $n = 24$). Food delivery and food trucks were noted in 2.9% ($n = 17$) of the New York LocalFood tweets. New York LFSI tweets focused on farms and farmers (31.0%, $n = 13$), specialty grocers or markets that sold local foods (21.4%, $n = 9$), and various food businesses associated with food and beverage production using locally sourced ingredients (e.g., soup maker, micro-bakery, tasting room) (19.0% $n = 8$). In addition, 11.9% ($n = 5$) of the LFSI tweets focused on waste composting including references to Flower City Pickers, an NGO focused on food recovery and Happy Scraps, a business that supplies local farms. New York LFSI tweets also noted supplies for community or urban gardens; a business taking orders for "organic farm to table local food;" a complaint about the "phalanx of regulatory hurdles" faced by local food systems actors; and an online service, Phrankly, that tracks the source of foods that are claimed to be local. Food security was the topic of 10.8% ($n = 14$) of the New York LocalFood tweets and of those, three specifically noted a collaboration among local farmers and a food pantry, whereas the others centered on the efforts of non-profits or faith-based organizations. In contrast, one stated that "Local food shops are our food security." There were also a small number (1.4%, $n = 8$) of LocalFood tweets that focused on feeding essential workers, particularly hospital personnel.

Local Farm Tweets by State

LocalFarm yielded a smaller percent of Local tweets from all three states. Only one of these tweets came from Alabama and it was specific to food security. In contrast, LocalFarm represented 12.5% ($n = 35$) and LFSI was 10.4% ($n = 29$) of the Local tweets from Pennsylvania. None of the Pennsylvanian LocalFarm tweets referenced food security, but one noted the importance of helping students make good food choices. Instead, LocalFarm tweets from Pennsylvania tended to focus on LFSI (82.9%, $n = 29$), naming a specific farm or farm stand (62.9%, $n = 22$), and to a lesser extent, a farmers' market (20.0%, $n = 7$). Many of the LocalFarm tweets that called for "support local" or "buy local" (31.4%, $n = 11$) also referenced a specific farm, although a few were general statements such as "Please support the local non-profits [sic] that give your community its heart." Many of the LocalFarm tweets from Pennsylvania also noted specific foods or locally produced items such as small batch cheese, Amish pies, and various forms of artwork (60%, $n = 21$). Of the LocalFarm tweets that were food focused, five concerned "burgers" or breakfast that was served at a pub or restaurant.

Of the Local tweets from New York, 15.9% ($n = 90$) were LocalFarm and 12.5% ($n = 71$) of Local were about LFSI. Like Pennsylvania, most LocalFarm tweets focused on a specific farm or farm stand (55.6%, $n = 50$), more than half of which (52.0%, $n = 26$) concerned specific foods that could be purchased—fruits, vegetables, meats. While farmers' markets received less attention than farms, when combined with specialty grocers that aggregated local foods, it represented 23.3% ($n = 21$) of New York LocalFarm tweets. Nearly a quarter of the LocalFarm tweets (23.3%, $n = 21$) specifically requested support for local farms or farmers. One, stated, however, "We are an open air farmers market providing an ESSENTIAL service to this city...." Food was the context of 15.6% ($n = 14$) of New York LocalFarm tweets; promoted were special meals, foods, or wines made with locally sourced ingredients. Only three of the New York LocalFarm tweets referenced food security, two of which said, "Pay the Farmer, Feed the People," an effort by the NGO, World Central Kitchen. World Central Kitchen was founded by celebrity chef José Andrés in 2010 to provide meals post-disaster. Some of the LocalFarm (16.7%, $n = 15$) tweets appeared to be health related as they referenced, for instance, protective measures—masking, social distancing, drive-thru farm tours—and operating according to a "new normal."

Food Pantry/Bank and CSA by State

All states had <1.0% of Local tweets that referenced food banks and food pantries. Of Local tweets that focused on a Food Bank/Pantry in Alabama (0.3%, $n = 4$) none of them were relevant to LFSI. Instead, these Local tweets focused on groups that supplied donations, as well as general bank/pantry operations. Pennsylvania had the same percent (0.3%, $n = 29$) of Local tweets relevant to Food Bank/Pantry, and only one was about LFSI. The latter tweet mentioned farmers and it appeared to be associated with the USDA Farmers to Families Food Box program. Like Alabama, the Pennsylvanian Food Bank/Pantry tweets concerned operations (e.g., hours, location), especially volunteerism (38.5%, $n = 10$) and donations (30.8%, $n = 8$). The lowest percent (0.2%, $n = 42$) of Local tweets that focused on food banks or pantries was from New York. Again, only one of these tweets reflected LFSI, a specific reference to eggs. The most common topic among the New York Food Bank/Pantry tweets was donations (40.5%, $n = 17$), nearly half of which (47.1%, $n = 8$) were related to actual meals; tweets about volunteerism were secondary (19.0%, $n = 8$).

Of all Local tweets from across the three states, CSA (community supported agriculture) yielded only one and it was from Alabama (0.1%). None of the three states had tweets referencing food hubs.

Summary of Local Tweets by State

Overall, the tweets from each state have somewhat different concerns. In Alabama, "local" was generally limited to supporting place-based businesses, particularly restaurants. Saving local businesses, including restaurants, was important to Pennsylvanian tweeters, but there was also an emphasis on events, activities, and especially products associated with the character or culture of state (e.g., craft beer, Amish foods). New York tweeters also showed a commitment to the well-being of restaurants, but they expressed a wider range of concerns, many of which were focused on LFSI, and to a lesser extent, food security, and public health.

Among all Local tweets, restaurants including pubs and food trucks was the most common topic. Very few of these tweets referred to either a chain or a farm-to-table restaurant. Instead, many focused on supporting specific neighborhood and/or family-owned businesses. Tweets about LFSI tended to focus on a specific business, as well. Surprisingly, food security including food banks and pantries, received relatively little attention via Twitter, even though the Farmers to Families Food Box program was a major policy initiative at the national level and the CARES Act provided important state and local level resources [HFPP (Health Food Policy Project), 2021].

DISCUSSION

We analyzed Google Trends and Twitter discourse to examine the extent to which consumers pivoted to the local during the 2020 COVID-19 food supply chain crisis. While Google Trends data showed a strong, although brief, pivot to local, the comparison of tweets pre- and during the food supply chain crisis did not reveal a major pivot to local. In fact, a smaller percentage of tweets included local as a topic in 2020 compared to 2015. There could be three reasons for our results: first, it may be the case that Twitter does not reflect the behavior we are seeking to examine. LFSI and consumers looking to provision themselves during the pandemic may not mention their concerns on this form of social media. Twitter is a very public form of communication and people looking to provision themselves may not find Twitter to be useful for this purpose. Secondly, despite massive lines at food banks early on in the pandemic, Twitter is an unlikely communication choice for the food insecure, both because Twitter users tend to be younger and over-represented among professional occupations and because the public nature of Twitter is not a place where people are likely to publicize something as private as hunger. However, we did find that people used Twitter to support local restaurants, indicating that Twitter is used by communities for local purposes beyond provisioning. In that case, tweets supported a local food business rather than a local food system. It is interesting, however, that Twitter was used more sparingly to support local farmers who had lost markets, particularly during the shutdown, even in rural areas. This is particularly important to note given that tweeters tend to be demographically similar—younger, professional, Democrats—to those who engage in local food movements (Wojcik and Hughes, 2019). Because people did use Twitter to talk about local restaurant issues, we believe that the lack of Tweets on local food systems provides some evidence that "the local pivot" was not a nationwide phenomenon.

This leads to the question of whether LFSIs have the capacity to respond to food supply chain crises. We did find that states with a strong LFSI had a somewhat higher percentage of tweets referring to local in general and to locally related to AFNs in particular, confirming previous case studies of the role of LFSI coordinating local pivots.

Our analysis of Twitter data also indicates that social media was used by some LFSI during the crisis. New York tweets about local food systems included World Central Kitchen (WCK). As previously mentioned, WCK was initiated by José Andrés as an extension of DC's Central Kitchen. Similar to Central Kitchen's mission, the goal of WCK is to provide emergency food relief, but with a focus on sustainable, locally sourced foods, and strengthening LFSI. Given that one of Twitter's features is its global reach (Leetaru et al., 2013) it might be WCK, as a global actor, was more likely to use this form of social media. Takhteyev et al. (2012) did find that two-fifths of all tweets are tied to the local. However, they also note that compared to other social media, Twitter forges weaker social ties.

Our findings indicate that using Twitter data to discover LFSI activity needs to be treated with caution. Except for World Central Kitchen, LFSI members do not appear to be using Twitter to inform communities about food availability, need for volunteers, or participating farms. People without food also did not appear to engage with Twitter to find food. Instead, Google Trends indicates that people were more likely to do a google search.

One major finding from our analysis is that "local" is not solely the provenance of the relocalization movement. "Local" can mean many things not related to AFNs (see Hendrickson and Heffernan, 2002). In particular, people can support local businesses even if they are not familiar with or part of AFNs. Tweets indicate that people were more concerned about getting their local restaurants over the hump of the crisis than they were with local food systems resilience or local farmers. Local farms, farmers, and farm markets were hardly mentioned, although they were mentioned the most in states with higher LFSI. The idea of supporting local restaurants in general was high across all locations, but contextually, states higher in LFSI were more likely to engage with topics related to supporting LFSI, indicating some overlap in the idea of maintaining local economies as alternatives to global food supply chains, even if those restaurants were dependent on global food providers. Concomitantly, there was little indication that residents of local places were concerned about the survival of chain restaurants in their cities and towns, despite the fact that many chain restaurants experienced a rise in drive-in customers during this period (Northfield, 2021). In other words, we learned that local means different things to different people. And yet, states with higher LFSI do have a higher percentage of tweets focused on farms or locally sourced foods. This may indicate that places with strong social infrastructure may be overlapping, but not entirely congruent with, alternative local food system infrastructure.

Research on responses to the COVID-19 food supply crisis indicates that LFSI can play a strong role in maintaining food system resilience. However, as our data show, the role that LFSI may have played so far has been spotty and varied from one place to the next. This does not mean that tweeters are uninterested in local issues: a deep dive into the tweets found strong support for local businesses and presumably the local community. We found that only through a deeper dive into the tweets were we able to understand what people were talking about when they mentioned local food. Keywords mean different things in different tweets. Thus, it was necessary, we found, to analyze tweets through a manual content analysis. What we found was informative. For example, reference to "local farm" is as likely to refer to a wedding venue as to a food source.

The literature on LFSI contributions to food system resilience during supply chain crises indicates a strong potential role for AFNs to strengthen LFSI to respond to crises. It makes sense that maintaining active shorter food chains function as insurance to protect from potential future global food chain crises. It remains to be seen as to whether the places that did pivot to the local will maintain a strong LFSI between crises. However, it is important to note the critical role of local, state, and federal policies in not only maintaining food supplies during the crisis, but also ensuring a resilient food system (Darnhofer, 2014; Béné, 2020). Critical perspectives on relocalization remind us that placing the burden on small local organizations to "fix" the food system may be asking too much of these actors. Instead, some agri-food scholars have called for a "multi-actor" approach (e.g., Morgan et al., 2006; Sachs, 2021) to a more resilient food system. Such multi-actor engagement is something not reflected in Twitter discourse. However, the results of our analysis of Twitter suggests that a multi-scalar approach during moments of crises or food system disruption may be necessary to support LFSI. Recognizing that Twitter is not generalizable to the entire U.S. population, further studies need to explore in a more systematic manner a more multi-scalar approach. Additional studies should further explore questions surrounding the types of "local" that consumers seek to support.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article. Further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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REFERENCES

Agricultural Marketing Service (2020). *USDA Farmers to Families Food Box*. Washington, DC: U.S. Department of Agriculture. Available online at: https://www.ams.usda.gov/selling-food-to-usda/farmers-to-families-food-box (accessed November 20, 2021).

Ahuja, K., Chandra, V., Lord, V., and Peens, C. (2021). *Ordering in: The rapid evolution of food delivery*. McKinsey & Company. Available online at: https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/ordering-in-the-rapid-evolution-of-food-delivery (accessed March 31, 2022).

Ammons, S., Blacklin, S., Bloom, D., Brown, S., Cappellazzi, M., Creamer, N., et al. (2021). A collaborative approach to Covid-19 response: the Center for Environmental Farming Systems Community-Based Food System Initiatives. *J. Agric. Food Syst. Commun. Dev*. 10, 297–302. doi: 10.5304/jafscd.2021.102.004

Bachman, G., Lupolt, S., Strauss, M., Kennedy, R., and Nachman, K. (2021). An examination of adaptations of direct marketing channels and practices by Maryland fruit and vegetable farmers furing the COVID-19 pandemic. *J. Agric. Food Syst. Commun. Dev*. 10, 1–19. doi: 10.5304/jafscd.2021.104.010

Banerjee, T., Nayak, A., and Zhao, H. Y. (2021). A county-level study of the effects of state-mandated COVID-19 lockdowns on urban and rural restaurant visits using consumers' cell phone geo-location data. *J. Public Health*. 15, 1–10. doi: 10.1007/s10389-020-01473-y

Béné, C. (2020). Resilience of local food systems and links to food security–a review of some important concepts in the context of COVID-19 and other shocks. *Food Secur*. 11, 1–18. doi: 10.1007/s12571-020-01076-1

Bennett, G., Young, E., Butler, I., and Coe, S. (2021). The impact of lockdown during the COVID-19 outbreak on dietary habits in various population groups: a scoping review. *Front. Nutr*. 8, 53. doi: 10.3389/fnut.2021.626432

Bonnevie, E., Gallegos-Jeffrey, A., Goldbarg, J., Byrd, B., and Smyser, J. (2021). Quantifying the rise of vaccine opposition on Twitter during the COVID-19 pandemic. *J. Commun. Healthc*. 14, 12–19. doi: 10.1080/17538068.2020.1858222

Born, B., and Purcell, M. (2006). Avoiding the local trap: scale and food systems in planning research. *J. Plann. Educ. Res*. 26, 195–207. doi: 10.1177/0739456X06291389

Brennan, M. (2021). More in US grocery shopping online, fewer eating out. *Gallup News*. Available online at: https://news.gallup.com/poll/353090/grocery-shopping-online-fewer-dining.aspx (accessed February 1, 2022).

Casey, H., DeAtley, J., Eckle, C. R., Burger, M., Maxwell, J., and Valpine, E. (2021). Case study of a food relief grocery model: the neighborhood pop-up grocery project. *J. Agric. Food Syst. Commun. Dev*. 10, 273–278. doi: 10.5304/jafscd.2021.102.012

Dannenberg, P., Fuchs, M., Riedler, T., and Wiedemann, C. (2020). Digital transition by COVID-19 pandemic? The German food online retail. *Tijdschrift Voor Economische En Sociale Geografie* 111, 543–560. doi: 10.1111/tesg.12453

Darnhofer, I. (2014). Resilience and why it matters for farm management. *Euro. Rev. Agric. Econ*. 41, 461–484. doi: 10.1093/erae/jbu012

DeLind, L. B. (2011). Are local food and the local food movement taking us where we want to go? Or are we hitching our wagons to the wrong stars? *Agric. Human Values* 28, 273–283. doi: 10.1007/s10460-010-9263-0

DuPuis, E. M., and Goodman, D. (2005). Should we go "home" to eat?: toward a reflexive politics of localism. *J. Rural Stud*. 21, 359–371. doi: 10.1016/j.jrurstud.2005.05.011

Farrer, M. (2021). *The Global Supply Chain Crisis Could Last Another Two Years Warn Experts*. Available online at: https://www.theguardian.com/business/2021/dec/18/global-supply-chain-crisis-could-last-another-two-years-warn-experts (accessed February 2, 2022).

Fonte, M. (2013). Reflexive localism: toward a theoretical foundation of an integrative food politics. *Int. J. Sociol. Agric. Food*. 20, 397–402. doi: 10.48416/ijsaf.v20i3.175

Food Insights (2020). *COVID-19: Impact of Food Purchasing, Eating Behaviors, and Perceptions of Food Safety*. Available online at: https://foodinsight.org/wp-content/uploads/2020/04/COVID-19-Consumer-Research.April2020.pdf (accessed February 2, 2022).

Garnett, P., Doherty, B., and Heron, T. (2020). Vulnerability of the United Kingdom's food supply chains exposed by COVID-19. *Nat. Food* 1, 315–318. doi: 10.1038/s43016-020-0097-7

Goodman, D., DuPuis, E. M., and Goodman, M. K. (2012). *Alternative Food Networks: Knowledge, Practice, and Politics*. Newark, NY: Routledge.

Google (2021). *Facts About Google Trends data*. Available online at: https://support.google.com/trends/answer/4365533?hl=en (accessed March 12, 2022).

Guest, G., MacQueed, K. M., and Namey, E. E. (2011). *Applied Thematic Analysis*. Sage Publications.

Gundersen, C., Hake, M., Dewey, A., and Engelhard, E. (2020). Food insecurity during COVID-19. *Appl. Econ. Perspectives Policy* 43, 153–161. doi: 10.1002/aepp.13100

Hamstra, M. (2020). *Shoppers Turn to Shelf-Stable Grocery to Keep The Pantry Stocked*. Available online at: https://www.supermarketnews.com/center-store/shoppers-turn-shelf-stable-grocery-keep-pantry-stocked (accessed February 2, 2022).

Harden, N., Bertsch, B., Carlson, K., Myrdal, M., Bobicic, I., Gold, A., et al. (2021). Cass clay food partners: a networked response to Covid-19. *J. Agric. Food Syst. Commun. Dev*. 10, 181–196. doi: 10.5304/jafscd.2021.102.050

Hashem, N. M., González-Bulnes, A., and Rodriguez-Morales, A. J. (2020). Animal welfare and livestock supply chain sustainability under the COVID-19 outbreak: an overview. *Front. Vet. Sci.* 7, 679. doi: 10.3389/fvets.2020.582528

Hendrickson, M. K. (2020). Covid lays bare the brittleness of a concentrated and consolidated food system. *Agric. Human Values* 37, 579–580. doi: 10.1007/s10460-020-10092-y

Hendrickson, M. K., and Heffernan, W. D. (2002). Opening spaces through relocalization: Locating potential resistance in the weaknesses of the global food system. *Sociol. Ruralis* 42, 347–369. doi: 10.1111/1467-9523.00221

HFPP (Health Food Policy Project) (2021). *Municipal Policies to Support Food Access During Emergencies*. Avaialble online at: http://healthyfoodpolicyproject.org/wp-content/uploads/Municipal-Policies-to-Support-Food-Access-During-Emergencies.pdf (accessed December 12, 2021).

Hilchey, D. (2021). The impact of COVID-19 on the food system. *J. Agric. Food Syst. Commun. Dev*. 10, 1–5. doi: 10.5304/jafscd.2021.103.021

Hinrichs, C. (2016). Fixing food with ideas of "local" and "place." *J. Environ. Stud. Sci*. 6, 759–764. doi: 10.1007/s13412-015-0266-4

Hobbs, J. E. (2020). Food supply chains during the COVID-19 pandemic. *Can. J. Agric. Econ*. 68, 171–176. doi: 10.1111/cjag.12237

Holloway, L., and Kneafsey, M. (2004). "Producing–consuming food: closeness, connectedness and rurality," in *Geographies of Rural Cultures and Societies*, eds L. Holloway and M. Kneafsey (London: Ashgate), 262–282.

Huber, A. G. (2020). "Let Us Be Small": a case study on the necessity for intentionally small producers. *J. Agric. Food Syst. Commun. Dev*. 10, 269–272. doi: 10.5304/jafscd.2020.101.032

Javadi, M., and Koroush, Z. (2016). Understanding thematic analysis and its pitfall. *Demo* 1, 33–39. doi: 10.15412/J.JCC.02010107

Kamiński, M., Skonieczna-Zydecka, K., Nowak, J. K., and Stachowska, E. (2020). Global and local diet popularity rankings, their secular trends, and seasonal variation in Google Trends data. *Nutrition*. 79–80. doi: 10.1016/j.nut.2020.110759

Klinenberg, E. (2018). *Palaces for the People: How Social Infrastructure Can Help Fight Inequality, Polarization, and the Decline of Civic Life*. New York, NY: Broadway Books.

Klinenberg, E., Araos, M., and Koslov, L. (2020). Sociology and the climate crisis. *Annu. Rev. Sociol*. 46, 649–669. doi: 10.1146/annurev-soc-121919-054750

Kloppenburg, J., Hendrickson, J., and Stevenson, G. W. (1996). Coming in to the foodshed. *Agric. Human Values* 13, 33–42. doi: 10.1007/BF01538225

Kruspe, A., Häberle, M., Hoffmann, E. J., Rode-Hasinger, S., Abdulahhad, K., and Zhu, X. X. (2021). Changes in Twitter geolocations: Insights and suggestions for future usage [Preprint]. *arXiv:2108.12251*. doi: 10.18653/v1/2021.wnut-1.24

Kusumasari, B., and Prabowo, N. P. A. (2020). Scraping social media data for disaster communication: how the pattern of Twitter users affects disasters in Asia and the Pacific. *Natural Hazards*. 103, 3415–3435. doi: 10.1007/s11069-020-04136-z

Laborde, D., Martin, W., and Vos, R. (2021). Impacts of COVID-19 on global poverty, food security, and diets: Insights from global model scenario analysis. *Agric. Econ*. 52, 375–390. doi: 10.1111/agec.12624

Leetaru, K., Wang, S., Cao, G., Padmanabhan, A., and Shook, E. (2013). Mapping the global Twitter heartbeat: the geography of Twitter. *First Monday* 18. doi: 10.5210/fm.v18i5.4366 Available online at: https://journals.uic.edu/ojs/index.php/fm/article/view/4366 (accessed February 2, 2022).

Li, J., Hallsworth, A. G., and Coca-Stefaniak, J. A. (2020). Changing grocery shopping behaviours among Chinese consumers at the outset of the COVID-19 outbreak. *Tijdschrift Voor Economische En Sociale Geografie* 111, 574–583. doi: 10.1111/tesg.12420

Lo, A., Duffy, E., and Ng, S. W. (2021). Who's grocery shopping online and why: cross-sectional analysis of a nationally-representative sample since the pandemic. *Curr. Dev. Nutr*. 5, 231. doi: 10.1093/cdn/nzab029_032

Mahajan, K., and Tomar, S. (2020). COVID-19 and supply chain disruption: evidence from food markets in India. *Am. J. Agric. Econ.* 103, 35–52. doi: 10.1111/ajae.12158

Maples, J. G., Thompson, J. M., Anderson, J. D., and Anderson, D. P. (2021). Estimating COVID-19 impacts on the broiler industry. *Appl. Econ. Perspect. Policy* 43, 315–328. doi: 10.1002/aepp.13089

Martinez, C. C., Maples, J. G., and Benavidez, J. (2021). Beef cattle markets and COVID-19. *Appl. Econ. Perspect. Policy* 43, 304–314. doi: 10.1002/aepp.13080

Maye, D., Fellenor, J., Potter, C., Urquhart, J., and Barnett, J. (2021). What's the beef?: Debating meat, matters of concern and the emergence of online issue publics. *J. Rural Stud*. 84, 134–146. doi: 10.1016/j.jrurstud.2021.03.008

McKay, K., Wayland, S., Ferguson, D., Petty, J., and Kennedy, E. (2021). "At Least until the second wave comes…": a Twitter analysis of the NHS and COVID-19 between March and June 2020. *Int. J. Environ. Res. Public Health*. 18, 3943. doi: 10.3390/ijerph18083943

Moragues-Faus, A., Marsden, T., Adlerová, B., and Hausmanova, T. (2020). Building diverse, distributive, and territorialized agrifood economies to deliver sustainability and food security. *Econ. Geogr*. 96, 219–243. doi: 10.1080/00130095.2020.1749047

Morgan, B. (2020). 3 Lasting changes to grocery shopping after Covid-19. *Forbes*. Available online at: https://www.forbes.com/sites/blakemorgan/2020/12/14/3-lasting-changes-to-grocery-shopping-after-covid-19/?sh=14a3888854e7

Morgan, K., Marsden, T., and Murdoch, J. (2006). *Worlds of Food: Place, Power, and Provenance in the Food Chain*. Oxford: Oxford University Press.

Morley, A. S., Morgan, S. L., and Morgan, K. J. (2008). *Food Hubs: The 'Missing Middle' of the Local Food Infrastructure?* Cardiff: Centre for Business Relationships, Accountability, Sustainability and Society (BRASS), Cardiff University. Avaialble online at: http://orca.cardiff.ac.uk/id/eprint/20508

Mueller, V., Grépin, K. A., Rabbani, A., Navia, B., Ngunjiri, A. S. W., and Wu, N. (2021). Food insecurity and COVID−19 risk in low- and middle-income countries. *Appl. Econ. Perspect. Policy*. 44, 92–109. doi: 10.1002/aepp.13200

Northfield, R. (2021). The future of fast food. *Eng. Technol.* 16, 42–46. doi: 10.1049/et.2021.0208

OECD (Organisation for Economic Co-operation and Development) (2020). *Food Supply Chains and COVID-19: Impacts and Policy Lessons*. Available online at: https://www.oecd.org/coronavirus/policy-responses/food-supply-chains-and-covid-19-impacts-and-policy-lessons-71b57aea/ (accessed November 21, 2021).

O'Hara, S., and Toussaint, E. C. (2021). Food access in crisis: food security and COVID-19. *Ecol. Econ*. 180:106859. doi: 10.1016/j.ecolecon.2020.106859

Oncini, F. (2021). Food support provision in COVID-19 times: a mixed method study based in Greater Manchester. *Agric. Human Values* 38, 1201–1238. doi: 10.1007/s10460-021-10212-2

Pennsylvania Department of Agriculture (2022). *Pennsylvania Agricultural Surplus System.* Available online at: https://www.agriculture.pa.gov/Food/food_assistance/Pages/Pennsylvania-Agricultural-Surplus-Program.aspx (accessed February 2, 2022).

Petetin, L. (2020). The COVID-19 crisis: an opportunity to integrate food democracy into post-pandemic food systems. *Eur. J. Risk Regul.* 11, 326–336. doi: 10.1017/err.2020.40

Redman, R. (2020). *Nearly 80% of U.S. Consumers Shopped Online for Groceries Since COVID-19 Outbreak*. Available online at: https://www.supermarketnews.com/online-retail/nearly-80-us-consumers-shopped-online-groceries-covid-19-outbreak (accessed February 1, 2022).

Ricker, H., and Kardas-Nelson, M. (2020). *Community Supported Agriculture Is Surging Amid the Pandemic: People Are Signing Up for CSAs in Record Numbers. Could the Once-Struggling Model Sustain Small Farms Through Hard Times—and Beyond?* Available online at: https://civileats.com/2020/04/09/community-supported-agriculture-is-surging-amid-the-pandemic/ (accessed November 20, 2021).

Ridley, W., and Devadoss, S. (2020). The effects of COVID-19 on fruit and vegetable production. *Appl. Econ. Perspect. Policy* 43, 329–340. doi: 10.1002/aepp.13107

Roberts, L. (2020). Rebuilding American groceries: the farmers market in the new era - outdoor venue allows customers to distance. *Wichita Falls Times Record News*. A6. Wichita Falls, TX: USA TODAY NETWORK.

Robey, C. (2020, May 8). Small farms in N.Y. are experiencing a surprising boom. Here's why. *New York Times*. Available online at: https://www.nytimes.com/2020/05/08/nyregion/small-farms-ny-coronavirus.html (accessed November 29, 2021).

Sachs, C. (2021). Feminist food justice and food sovereignty. *J. Dev. Perspect*. 4, 79–90. doi: 10.5325/jdevepers.4.1-2.0079

Sanderson, M. R. (2020). Here we are: Agriculture and Human Values in the coronavirus (COVID-19) pandemic. *Agric. Human Values* 373, 515–516. doi: 10.1007/s10460-020-10040-w

Schmidt, C., Goetz, S., Rocker, S., and Tian, Z. (2020). Google searches reveal changing consumer food sourcing in the COVID-19 pandemic. *J. Agric. Food Syst. Commun. Dev*. 9, 9–16. doi: 10.5304/jafscd.2020.093.032

Severson, K. (2020, April 9). The farm-to-table connection comes undone. *New York Times*. Available online at: https://www.nytimes.com/2020/04/09/dining/farm-to-table-coronavirus.html (accessed November 29, 2021).

Siddiqi, S. M., Cantor, J., Dastidar, M. G., Beckman, R., Richardson, A. S., Baird, M. D., et al. (2021). SNAP participants and high levels of food insecurity in the early stages of the COVID-19 pandemic. *Public Health Rep*. 136, 457–465. doi: 10.1177/00333549211007152

Sonnino, R., Marsden, T., and Moragues-Faus, A. (2016). Relationalities and convergences in food security narratives: towards a place-based approach. *Trans. Inst. Br. Geogr.* 41, 477–489. doi: 10.1111/tran.12137

Takhteyev, Y., Gruzd, A., and Wellman, B. (2012). Geography of Twitter networks. *Soc. Netw*. 34, 73–81. doi: 10.1016/j.socnet.2011.05.006

Thilmany, D., Canales, E., Low, S. A., and Boys, K. (2020). Local food supply chain dynamics and resilience during COVID-19. *Appl. Econ. Perspect. Policy* 43, 86–104. doi: 10.1002/aepp.13121

Tropp, D. (2013). *Why Local Food Matters: The Rising Importance of Locally-Grown Food in the US Food System* (No. 1471-2016-120680). Washington, DC: USDA, AMS.

Union of Concerned Scientists (2018). *50-State Food System Scorecard: Ranking the States on Farm and Food Health*. Available online at: https://www.ucsusa.org/resources/50-state-food-system-scorecard (accessed November 14, 2021).

USDA (2022a). *Coronavirus Food Assistance Program 1 Data*. Available online at: https://www.farmers.gov/coronavirus/pandemic-assistance/cfap1/data (accessed January 31, 2022).

USDA (2022b). *Coronavirus Food Assistance Program 2 Data*. Available online at: https://www.farmers.gov/coronavirus/pandemic-assistance/cfap2/data (accessed January 31, 2022).

Van Dijk, T. A. (1985). Semantic discourse analysis. *Handb. Discourse Anal*. 2, 103–136.

Wallace Center (2021). *Local Food Systems Response to COVID-19*. Available online at: https://lfscovid.localfoodeconomics.com/ (accessed December 7, 2021).

Weersink, A., von Massow, M., Bannon, N., Ifft, J., Maples, J., McEwan, K., et al. (2021). COVID-19 and the agri-food system in the United States and Canada. *Agric. Syst.* 188. doi: 10.1016/j.agsy.2020.103039 Available online at : https://www.sciencedirect.com/science/article/pii/S0308521X20309008?dgcid=rss_sd_all (accessed February 2, 2022).

Whatmore, S., Stassart, P., and Renting, H. (2003). What's alternative about alternative food networks? *Environ. Plann. A* 35, 389–391. doi: 10.1068/a3621

White, N. (2021). Farming in the time of pandemic. *J. Agric. Food Syst. Commun. Dev*. 10, 1–3. doi: 10.5304/jafscd.2021.102.008

Wojcik, S., and Hughes, A. (2019). *Sizing Up Twitter Users*. Pew Research Center 24. Available online at: https://www.pewresearch.org/internet/wp-content/uploads/sites/9/2019/04/twitter_opinions_4_18_final_clean.pdf (ER: Online report, pages 1–23).

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An Assessment of the Impact of COVID-19 on the Agri-Food System in Caribbean Small Island Developing States

Oral Daley[1], Wendy-Ann P. Isaac[1], Afiya John[1], Ronald Roopnarine[1] and Keon Forde[2]*

[1] Department of Food Production, Faculty of Food and Agriculture, The University of the West Indies, Saint Augustine, Trinidad and Tobago, [2] Department of Agricultural Economics and Extension, Faculty of Food and Agriculture, The University of the West Indies, Saint Augustine, Trinidad and Tobago

Edited by:
*Todd Rosenstock,
Alliance Bioversity International and CIAT, France*

Reviewed by:
*Suparna Ghosh-Jerath,
Indian Institute of Public Health Delhi, India*
*Henry Jordaan,
University of the Free State, South Africa*

***Correspondence:**
*Oral Daley
oral.daley@sta.uwi.edu*

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The COVID-19 pandemic impacts have arguable been more pronounced in the developing world, such as the Small Island States (SIDS) of the Caribbean, where a plethora of geophysical and socio-political factors have led to increased vulnerability, particularly in fragile sectors such as agriculture. The pandemic added another layer of complexity to the unstable agri-food systems of SIDS in the Caribbean. Measures to contain the unfolding crisis have tremendously disrupted food systems by threatening the production, distribution, and marketing of commodities which exposed the frailty of the region's food security. Caribbean SIDS are highly dependent on food imports and relies on international markets to secure food. Many are also dependent on agricultural exports and have a large portion of their population involved in agriculture making them particularly vulnerable to the rigors of the pandemic. Export restrictions on foodstuff and prohibitions due to lockdowns and border closures further exacerbated these challenges. Additionally, food and nutrition security in the region is also subjected to the effects of climate change and climate-related disasters. Dealing with the impacts of co-occurring disasters is, therefore, an ever-present threat. This study examines the impact of COVID-19 on the agri-food supply in the Caribbean. It also identified measures and initiatives adopted to cope with these disruptive consequences. The study involves the use of internet-based surveys and focus group discussions and internet-based surveys with stakeholders and online searches for related literature. A total of 96 farmers, 60 food distributors, 84 food service operators, and 237 consumers from the region participated in the online survey and 4 focus group discussions between January and November 2021. The results confirmed that the impacts of the COVID-19 pandemic were evident along the entire agri-food supply chain and numerous challenges and shocks were identified across all participating groups and countries. Some challenges and shocks such as loss of income and related challenges including lower sales and loss of markets affected all groups in the study but to varying degrees and based on socio-demographic factors. In general people of lower income status and smaller businesses were more susceptible to the negative impacts of the pandemic.

Keywords: agri-food system, Caribbean SIDS, food security, food system resilience, COVID-19 pandemic

INTRODUCTION

The COVID-19 pandemic has significantly impacted and continues to impact all sectors of society globally. The impacts have been arguably more pronounced in the developing world, particularly in the Small Island Developing States (SIDS) including those of the Caribbean, where a plethora of geophysical and socio-political factors have led to increased vulnerability, of fragile sectors such as agriculture (Blazy et al., 2021). The pandemic added another layer of complexity to the traditionally unstable agri-food systems of SIDS in the Caribbean, further limiting local production and exposing the need to address crucial food security issues primarily linked to the high dependence on food imports (Blazy et al., 2021). Sudden shocks mainly from supply chain bottle necks are becoming more and more evident and are now considered a serious threat to not only food and nutrition security, but also the general livelihoods of people to an unprecedented degree as impacts extend to other key socio-economic sectors across the region. Regional governments were forced to implement measures in response to the pandemic that have also contributed to the status of food insecurity in the region (Stephens et al., 2020). The restrictions on movement, border closures, and lockdowns, which all served as containment measures to curb the spread of the COVID-19 virus had and continue to have adverse impacts on the regional agricultural sector (Goswami et al., 2021). In many instances, the flow of inputs to farmers and their produce to markets have been disrupted leading to significant quantities of fresh fruits and vegetables being either dumped or left to decay in farmers' fields (Stephens et al., 2020; Torero, 2020). During the early stages of the pandemic, most countries in the region were able to adequately cope with the initial shocks and supply chain disruptions but as the pandemic ensued countries in the region are finding it increasingly difficult to manage, with many countries battling to supplement their food supplies and minimize food price inflation. The pandemic coupled with the geophysical and climate-related limitations, has placed Caribbean SIDS in a precarious position that needs urgent redress. According to Blazy et al., (2021), the pandemic led to a drop in income, production losses due to difficulties in marketing through conventional channels, but also difficulties in managing the farming systems due to reduced access to inputs and labor.

In February 2021 it was estimated that there were ∼2.7 million food insecure people in the Caribbean compared to 1.7 million in April 2020 according to the Caribbean Community and Common Market (CARICOM) COVID-19 Food Security and Livelihoods Impact Survey conducted by the World Food Programme (WFP) in partnership with the CARICOM [Caribbean Community (CARICOM) et al., 2021]. This survey was conducted to rapidly gather data on the impacts on livelihoods, food security, and access to markets in CARICOM. Caribbean SIDS are net food importers, with at least seven of these countries importing more than 80–90% of all food consumed and only three Caribbean countries (Guyana, Belize, and Haiti) produce more than 50% of their own food [Caribbean Community (CARICOM) et al., 2021]. In fact, Caribbean food supply is heavily dependent on imports, primarily from the USA where 15 CARICOM countries source up to 94% of their food imports from the USA market. The analysis of this survey showed that disruptions in transport routes resulted in many low-income countries having to devolve food distribution or seek alternative delivery routes which led to considerable food price inflation that consequently limited access to lower income sectors of society [Caribbean Community (CARICOM) et al., 2021].

The Caribbean region attempted to unite to reduce loss of life and further spread after the first confirmed case of the COVID-19 was reported on March 1st, 2020, in the Dominican Republic and on March 11th in Jamaica (Murphy et al., 2020). This came at a time when the region was preparing to roll out their annual disaster management plans (from June to November) for the 2020 Atlantic hurricane season (Marshall et al., 2021). A "COVID-19 Response Agri-Food Plan" was developed throughout the region to minimize the impact on food security, concentrating on adequate food access and production within the region (Marshall et al., 2021). National disaster and public health agencies in the region having to deal with managing these co-occurring hazards using generic policies shared by global public health agencies, therefore downplayed the urgency in dealing with place-based food security considerations (Marshall et al., 2021). Generic policies only provide general guidelines with limited consideration for the intrinsic geophysical and socio-cultural characteristics of Caribbean SIDS, and thus were ineffective (Marshall et al., 2021). On the consumer end, the demand for imported products is considerably high throughout the region, as large-scale external producers benefit from a competitive advantage that local producers are unable to match, in terms of quality, quantity, and price (Marshall et al., 2021). FAO (2021) data reports that 94% of all CARICOM imports of cereals, 90% of edible fruit and nut imports, and 90% of edible vegetables, as well as certain roots and tubers imports all come from the USA. Staple foods such as wheat and rice form the bulk of food imports to the region in addition to highly processed, sugary foods and beverages, which contribute to the high levels of obesity and other diet related lifestyle diseases and the triple burden of malnutrition (Fanzo et al., 2019; Saint Ville et al., 2019; Hickey and Unwin, 2020). According to Heck et al. (2020), wheat and rice prices compared to March 2019 have jumped by 8 and 25%, respectively. These trends highlight the complexity of addressing the food security dimensions of the COVID-19 pandemic, amidst climate shocks, loss of soil fertility, increasing pests and diseases, limited available land and the interplay of loss of incomes and availability and affordability of local and imported foods (Ganpat and Isaac, 2015; Beckford and Rhiney, 2016).

Globally, agri-food systems contribute an estimated 11 billion tons of food each year and significantly contribute to the GDP of many economies. Risk is inherent in agri-food systems and their vulnerability became a stark reality in 2020, when measures to contain the COVID-19 pandemic disrupted global and national supply chains and caused economic downturns in many countries due to loss of purchasing power, impacting food security and nutrition of vulnerable people, especially women and children in developing countries. The first 3 months of the pandemic disrupted connections between supply and demand, even within well-established supply chains. Heck et al. (2020) described the pandemic as threatening the "software" and not the "material hardware" of food production, as other concurrent climatic and ecological crises do.

Having more resilient agri-food systems are critical to food and nutrition security, especially for vulnerable SIDS. The United Nations Common Guidance on Helping Build Resilient Societies defines agri-food systems' resilience as "the capacity over time of agri-food systems, in the face of any disruption, to sustainably ensure availability and access to sufficient, safe and nutritious food for all, and sustain the livelihoods of agri-food systems' actors" (United Nations, 2020). It calls for sustained efforts to merge tradition and modern agri-food systems by examining their three major components: (i) primary production; (ii) food distribution, linking production to consumption through food supply chains and transport networks; and (iii) household consumption, including intra-household food distribution. Key actors are farmers or producers; those providing input supply, post-harvest, storage, transport, and food processing services; food distributors, wholesalers, and retailers; food service operators and households and individuals as final consumers. Resilient agri-food systems must have a robust capacity to prevent, anticipate, absorb, adapt, and transform in the face of any disruption, with the functional goal of ensuring food security and nutrition for all and decent livelihoods and incomes for agri-food systems' actors. Such resilience addresses all dimensions of food security but focuses specifically on the stability of access and sustainability, which ensure food security in both the short and the long term (FAO, 2021). This study explores the impact of the COVID-19 pandemic on agri-food systems in selected countries in the Caribbean. It also identifies some measures and alternative food initiatives that could be adopted to mitigate some of the negative impacts.

METHODS

Data Collection

Data collection involved the use of online surveys, and focus group discussions among farmers, food distributors, food service operators, and consumers. The surveys were done over the course of 11 months (January to November 2021) and involved nine Caribbean countries (Trinidad and Tobago, Barbados, Jamaica, Antigua and Barbuda, Dominica, Grenada, St. Kitts and Nevis, St. Lucia, and St. Vincent and the Grenadines). The surveys were publicized and distributed using various crowdsourcing approaches including direct emails and social media. Due to the limitations of the online survey, random selection was not possible. A total of 96 farmers, 60 food distributors, 84 food service operators and 237 consumers from the region participated in the online survey (**Figure 1**). All respondent group were asked to provide various socio-demographic information including gender, age, and nationality. To assess the impact of the COVID-19 pandemic on the agri-food supply chain in Small Island Developing States in the Caribbean, survey participants were asked whether they experienced challenges and shocks, and if so, to identify the type of challenges and shocks and to describe coping strategies they may have employed. Respondents were also asked to rank the impact of the pandemic on a scale of 1–10, with 1 being very negative and 10 being very positive.

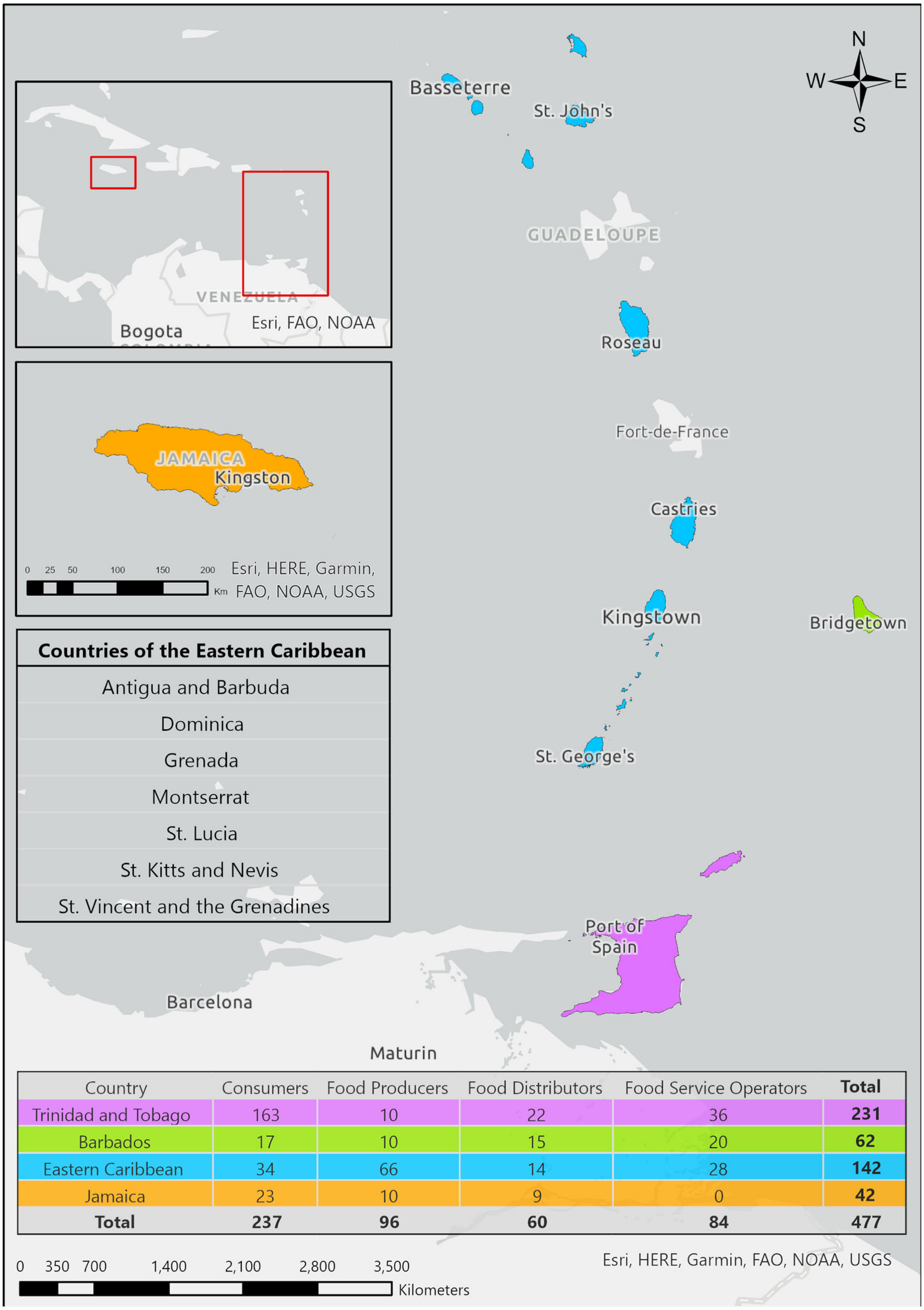
Focus Group Discussions (FGD)

A focus group is a small group discussion on issues relevant to a topic and is frequently used to collect qualitative data (Krueger, 1994). This methodology was used to develop an understanding of the impact on lives and livelihoods across the region because of the COVID-19 pandemic. Focus groups discussions have been successfully used in numerous food security studies to obtain information regarding food choices and diets within the context of lived experiences as stated by Raibee (2004). In this study, four (4) focus groups discussion were conducted using informal face to face focus group sessions in Farmers' markets in Trinidad (vendors, farmers, and consumers). For face-to-face discussion, COVID-19 safety protocols had to be observed so no more than 2 people were questioned at a time, which limited the number of respondents. Each focus group took between 10 and 15 min and all responses were documented. Discussions were guided by ten open ended core questions which were as follows:

1. What are the main sectors affected by COVID-19 in your community?
2. What are some of the main challenges faced?
3. How have these challenges been overcome?
4. Any new opportunity because of the challenges encountered?
5. Were new markets accessible?
6. Was money accessible?
7. Do you have better access to markets now compared to the start of the COVID-19 pandemic)
8. Were there changes in the cost of food items/raw materials compared to the same period during the past 4 years?
9. Could you mention some food items for which prices have increased or decreased?
10. Were you the recipient of any support from the Government/private sector or NGO?

Coding and Data Analysis

Data obtained from the online surveys were numerically coded and statistically analyzed using the Statistical Package for Social Sciences (SPSS v. 28). Coded data were then subjected to both descriptive and inferential statistical analysis (frequencies, and cross-tabulation). Chi-square tests of association were performed to examine significant associations between qualitative variables and socio-demographic factors. Similarly, one-way analysis of variance (ANOVA) tests with the associated *post-hoc* test (Tukey's b) was performed to examine significant differences among means of impact scores with the socio-demographic factors as independent variables.



Countries of the Eastern Caribbean
Antigua and Barbuda
Dominica
Grenada
Montserrat
St. Lucia
St. Kitts and Nevis
St. Vincent and the Grenadines

Country	Consumers	Food Producers	Food Distributors	Food Service Operators	**Total**
Trinidad and Tobago	163	10	22	36	**231**
Barbados	17	10	15	20	**62**
Eastern Caribbean	34	66	14	28	**142**
Jamaica	23	10	9	0	**42**
Total	**237**	**96**	**60**	**84**	**477**

FIGURE 1 | Map of the Caribbean highlighting countries and different groups in the agri-food system involved in the survey.

TABLE 1 | Socio-demographic characteristics of the COVID-19 pandemic survey participants from the Caribbean.

Categories and description	Proportion of respondents %			
	Farmers (N = 96)	Food distributors (N = 60)	Food service operators (N = 84)	Consumers (N = 237)
Gender				
Male	66.7	53.3	50.0	31.2
Female	33.3	46.7	50.0	68.8
Age (years)				
<25	4.2	18.3	16.7	21.2
25–44	56.3	51.7	42.9	51.8
45–64	39.6	23.3	35.7	25.9
≥65	0.0	6.7	4.8	1.2
Level of education				
Primary school	10.4	13.3	4.8	0.6
Secondary school	16.7	40.0	35.7	12.4
Vocational/technical training	6.3	3.3	7.1	5.9
Tertiary	66.7	43.3	52.4	81.2
No formal education	0.0	0.0	0.0	0.0
Country				
Trinidad and Tobago	10.4	36.7	42.9	68.2
Barbados	10.4	25.0	23.8	8.2
Eastern Caribbean	68.8	23.3	33.3	14.1
Jamaica	10.4	15.0	0.0	9.4
Rurality				
Rural	62.5	60.0	57.1	42.4
Urban	37.5	40.0	42.9	57.6
Household size (members)				
1–3	47.9	33.3	44.0	42.9
4–6	41.7	63.3	53.6	51.8
≥7	10.4	3.3	2.4	5.3
Monthly household income (USD‡)				
<500	16.7	20.0	14.3	8.2
500–1,999	29.2	20.0	14.3	30.0
2,000–3,999	29.2	43.3	20.2	32.4
4,000–5,999	16.7	13.3	15.5	14.1
6,000–7,999	2.1	0.0	16.7	6.5
≥8,000	6.3	3.3	19.0	8.8
Employment status				
Government employed	n/a*	n/a	n/a	20.6
Privately employed	n/a	n/a	n/a	28.8
Self employed	n/a	n/a	n/a	19.4
Unemployed	n/a	n/a	n/a	25.3
Student	n/a	n/a	n/a	4.1
Retiree/Pensioner	n/a	n/a	n/a	1.8
Land ownership status				
Rent or leased state land	25.0	n/a	n/a	n/a
Rent or leased private land	16.7	n/a	n/a	n/a
Full ownership	16.7	n/a	n/a	n/a
Family-owned land	41.7	n/a	n/a	n/a
Time in operation (years)				
<2	12.5	30.0	17.5	n/a
2–5	18.8	23.3	20.0	n/a
6–10	31.3	10.0	23.8	n/a
11–15	18.8	6.7	11.3	n/a
>15	18.8	30.0	27.5	n/a
Business type				
Sole proprietorship	n/a	63.3	61.9	n/a
Partnership	n/a	20.0	20.2	n/a
Limited liability company	n/a	16.7	17.9	n/a
Business registration				
Registered	n/a	53.3	76.2	n/a
Unregistered	n/a	46.7	23.8	n/a
Type of food service				
Dine in restaurant	n/a	n/a	25.0	n/a
Fast-food restaurant	n/a	n/a	23.8	n/a
Street food stall/ shop	n/a	n/a	34.5	n/a
Catering service	n/a	n/a	16.7	n/a

(Continued)

TABLE 1 | Continued

*n/a, not assessed.
‡USD, United States Dollar.

RESULTS

Characteristics of Respondents

The socio-demographic characteristics of respondents are presented in **Table 1**. Of the 96 farmers, 66.7% were male and 56.3% were between 25 and 44 years, 39.6% were 45–64 years old, and 4.2% were <25 years old. Most farmers (68.8%) in the study were from the Eastern Caribbean, with 10.4% each from Trinidad and Tobago, Barbados, and Jamaica. In terms of land ownership, some 41.7% of farmers produced food on family-owned land, 25% rented or leased state land while rent or leased private land and full ownership both separately accounted for 16.7%. Most food distributors were male (53.3%), with the age category 25–44 years accounting for a majority (51.7%), followed by 45–64 years (23.3%), <25 years (18.3%) and 65 years and older" (6.7%). Some 36.5% of food distributors in the study came from Trinidad and Tobago, 25% from Barbados, 23.3% from the Eastern Caribbean and 15% from Jamaica. Food distributors from rural areas comprised 60% of the sample and the remaining 40% from urban areas. Equal proportions (50%) of male and female food service operators participated in this study. Some 42.9% was in the age category 25–44 years old, 35.7% 45–64 years old, 16.7% was <25 years old and 4.8% was 65 years or older. Some 42.9% operated in Trinidad and Tobago, 33.3% operated in the Eastern

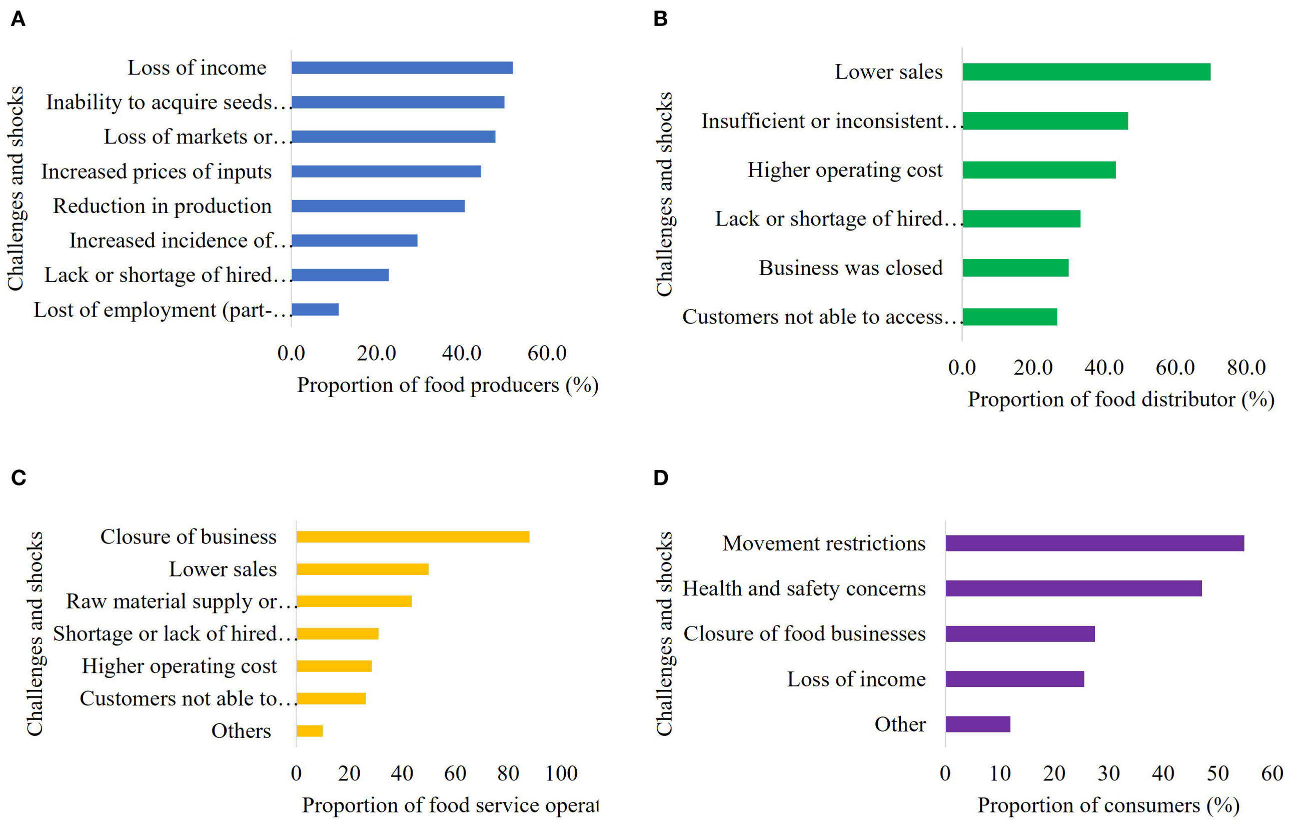


FIGURE 2 | Challenges and shocks caused by the COVID-19 pandemic based on the experiences of different groups in the agri-food system in the Caribbean: **(A)** Farmers; **(B)** Food distributors; **(C)** Food service operators, **(D)** consumers.

Caribbean, and 23.8% operated in Barbados. Most (57.1%) food service operator were from rural areas and 42.9% in urban areas. The highest number of consumer respondents were female (68.8%) and 51.8% of the sample was 25–44 years, 25.9% was 45–64 years, 21.2% was <25 years and 1.2% was 65 years or older. Most consumers lived in urban areas (57.6%), while the remaining 42.4% lived in rural areas. Finally, 51.8% of consumers reported that their household size was between 4–6 members, 42.9% 1–3 members, and 5.3% of households had 7 or members.

Impact of the COVID-19 Pandemic

Farmers

Most farmers (52.1%) reported that they faced challenges and shocks which were directly related to the COVID-19 pandemic. Some 37.5% did not face any challenges and shock while 10.4% were unsure. Some respondents from Trinidad and Tobago reported a boost to their production because of Migrant workers from Venezuela with one interviewee explaining that it was migrant labor that saved the production of vegetables on his farm. Chi-square test of association showed no statistically significant association between experiencing challenges and shocks and any of the socio-demographic factors evaluated. However, several challenges and shocks were reported based on multiple responses, which included loss of income (51.9%), inability to acquire seeds and planting materials (50%), loss of markets or difficulties selling produce (47.9%), increased prices of inputs (44.4%), reduction in production (40.4%), increased incidence of pest and diseases (29.6%), lack or shortage of hired labor (22.9%), and loss of employment among part-time farmers (11.1%) (**Figure 2**). Focus group discussions in Trinidad and Tobago revealed that farmers were also impacted by employee absenteeism either because of sickness or quarantine orders and 75% of all respondents reported a decrease in direct income because of loss of market or loss of employment. Apart from being affected by lower incomes, smallholder farmers also faced food security challenges in their households. Another finding highlighted by focus group discussions in Trinidad and Tobago was praedial larceny with several farmers reporting increased theft of farm produce, livestock, and agricultural inputs during the pandemic. Among those farmers that experienced difficulties to access seeds and planting materials, 65.4% attributed their experience to markets or stores being closed, 42.3% cited movement restrictions imposed by the country, 42.2% believe there was a scarcity or inadequate supplies, 23.1% cited loss of income, 15.4% cited health or safety concerns and 11.5% attributed it to lack of transportation. Further analysis showed that difficulties to access seeds and planting materials was significantly associated with time in operation (χ^2 =18.95, df = 8, $p \leq 0.018$) with those

TABLE 2 | ANOVA model on the socio-demographic variables for respondent ranking of the impact of the COVID-19 pandemic in the Caribbean.

Categories and description	Respondent impact ranking (Mean ± SEM)		
	Farmers	Food distributors	Food service operators
Gender			
Male	5.88 ± 0.263	5.00 ± 0.336	3.62 ± 0.337a[#]
Female	5.81 ± 0.372	5.07 ± 0.359	2.67 ± 0.337b
P-value[†]	0.891	0.885	0.049
Age (years)			
<25	6.50 ± 1.053	4.27 ± 0.542ab	4.71 ± 0.547a
25–44	5.70 ± 0.287	5.39 ± 0.323a	3.50 ± 0.341ab
45–64	6.00 ± 0.342	5.43 ± 0.480a	2.13 ± 0.374b
≥65	0.00	3.00 ± 0.899b	2.00 ± 1.024b
P-value	0.660	0.039	0.001
Level of education			
Primary school	4.20 ± 0.642b	4.25 ± 0.667	3.50 ± 1.118
Secondary school	6.00 ± 0.508ab	4.83 ± 0.385	2.93 ± 0.408
Vocational/ technical	7.00 ± 0.829a	5.00 ± 1.334	4.33 ± 0.913
Tertiary	5.97 ± 0.254ab	5.46 ± 0.370	3.09 ± 0.337
P-value	0.037	0.401	0.557
Country			
Trinidad and Tobago	5.60 ± 0.651	5.41 ± 0.399	3.89 ± 0.353a
Barbados	7.20 ± 0.651	5.40 ± 0.483	2.00 ± 0.474b
Eastern Caribbean	5.61 ± 0.253	4.29 ± 0.500	3.00 ± 0.400ab
Jamaica	6.40 ± 0.651	4.67 ± 0.623	0.00
P-value	0.115	0.268	0.007
Rurality			
Rural	5.87 ± 0.272	5.22 ± 0.315	2.88 ± 0.320
Urban	5.83 ± 0.351	4.75 ± 0.385	3.50 ± 0.369
P-value	0.940	0.346	0.204
Household size (members)			
1–3	5.78 ± 0.311	5.10 ± 0.429	3.41 ± 0.364
4–6	5.85 ± 0.334	5.00 ± 0.311	3.02 ± 0.330
≥7	6.20 ± 0.668	5.00 ± 1.357	1.00 ± 1.567
P-value	0.852	0.982	0.289
Monthly household income (USD[‡])			
<500	4.25 ± 0.451	5.00 ± 0.478bc	2.75 ± 0.618
500–1,999	6.21 ± 0.341	6.12 ± 0.478ab	2.58 ± 0.618
2,000–3,999	5.36 ± 0.341	4.85 ± 0.324bc	2.41 ± 0.520
4,000–5,999	6.25 ± 0.451	3.25 ± 0.585c	3.46 ± 0.594
6,000–7,999	8.00 ± 1.276	0	2.86 ± 0.573
≥8,000	9.00 ± 0.737	8.00 ± 1.170a	4.63 ± 0.536
P-value	0.001	0.001	0.055
Land ownership status			
Rent or leased state land	5.75 ± 0.418	n/a*	n/a
Rent or leased private land	4.75 ± 0.512	n/a	n/a
Full ownership	6.63 ± 0.512	n/a	n/a
Family-owned land	6.05 ± 0.324	n/a	n/a
P-value	0.050		
Time since operating (years)			
<2	6.00 ± 0.596	5.11 ± 0.369bc	3.14 ± 0.605
2–5	6.56 ± 0.486	3.57 ± 0.418c	3.94 ± 0.566
6–10	5.60 ± 0.377	7.67 ± 0.639a	3.42 ± 0.519
11–15	6.33 ± 0.486	6.00 ± 0.782ab	2.44 ± 0.754
>15	5.00 ± 0.486	5.00 ± 0.369bc	2.73 ± 0.482
P-value	0.116	0.001	0.434
Type of business			
Sole proprietorship	n/a	5.21 ± 0.306	3.48 ± 0.306
Partnership	n/a	4.43 ± 0.505	2.65 ± 0.535
Limited Liability Company	n/a	5.25 ± 0.668	2.53 ± 0.570
P-value		0.397	0.206
Business registration			
Registered	n/a	5.63 ± 0.317	3.16 ± 0.280
Unregistered	n/a	4.36 ± 0.338	3.10 ± 0.500
P-value		0.008	0.922
Type of food service			
Dine in restaurant	n/a	n/a	3.48 ± 0.490
Fast-food restaurant	n/a	n/a	3.00 ± 0.503
Street food stall/ shop	n/a	n/a	2.86 ± 0.417
Catering service	n/a	n/a	3.43 ± 0.601
P-value			0.748
Overall mean	5.85 ± 0.214	5.03 ± 0.244	3.14 ± 0.243

(Continued)

TABLE 2 | Continued

**n/a, not assessed.*
[#]Means within a category, for each group of respondents, that do not share a common letter is significantly different at the p-value stated.
[†]P-value from one-way ANOVA.
[‡]USD, United States Dollar.

farmers that have been operating for 2–5 years and more than 15 years being more likely to experience shocks or difficulties compared to other categories.

Most of those farmers who experienced loss of market or difficulties with selling produce (52.1%) were forced to give away or destroy part of their production due to the lack of marketing and storage capacity. This action was significantly associated with the level of education of farmers ($\chi^2 = 27.51$, $df = 6$, $p \leq 0.001$). Farmers who achieved primary school and secondary school education were more likely to giveaway or destroy their produce than those that achieved vocational/technical training and tertiary training. Among those farmers that experienced a lack or shortage of hired labor, a combined 56.5% resorted to hiring alternate labor for their businesses while 37.5% did nothing and 6.1% had no need. The hiring of alternate labor included family members (18.8%), new local labor (18.8%) and migrant labor (18.8%). There was no significant association between experiencing lack or shortage of hired labor and any of the socio-demographic factors evaluated.

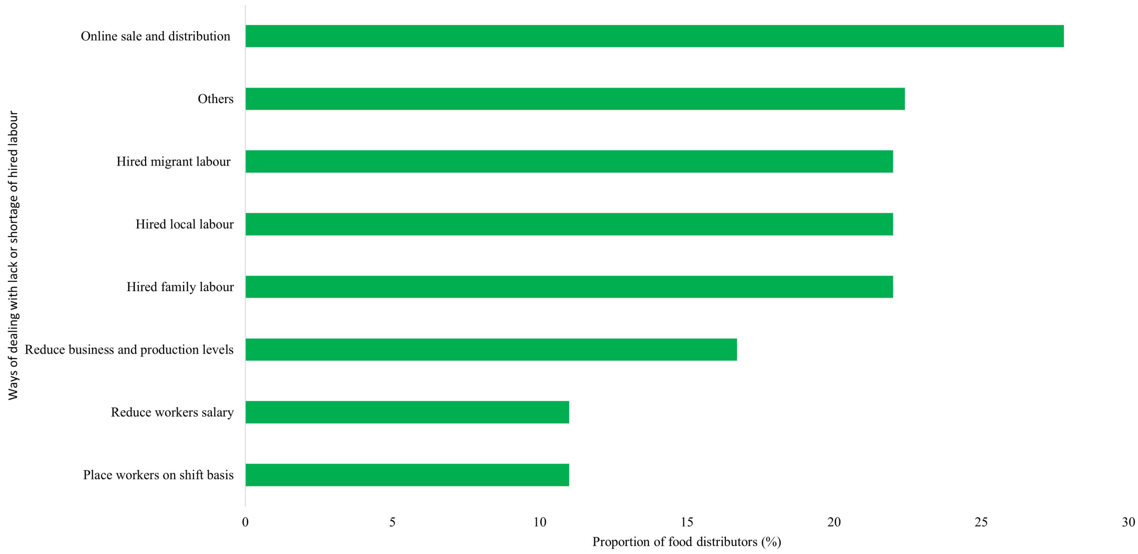


FIGURE 3 | Measures used by food distributors to handle the lack or shortage of hired labor caused by the COVID-19 pandemic in the Caribbean.

Most farmers (58.3%) did not implement any biosecurity measure on their farm or production areas, but 35.4% did and 6.3% were unsure of what to do. This was significantly associated with gender ($\chi^2 = 6.753$, df =2, $p \leq 0.034$) and education ($\chi^2 = 20.326$, $df = 6$, $p \leq 0.002$). Male farmers were more likely to implement biosecurity measures than their female counterparts. Furthermore, farmers with vocational or technical training were less likely to implement biosecurity measures than those of other education categories.

Finally, the overall mean impact score for farmers ranking of the impact of the COVID-19 pandemic on their food production or business operation was 5.85 (SEM ± 0.214). Mean impact scores were significantly different based on level of education ($F = 2.943$, $p \leq 0.05$), monthly household income ($F = 7.541$, $p \leq 0.001$) and land ownership status ($F = 2.543$, $p \leq 0.037$) (**Table 2**). Among education categories, farmers with vocational or technical level training had the highest mean score of 7.00 (SEM ± 0.829), which was significantly higher than the mean score for those with primary school education (4.20, SEM ± 0.642) (**Table 2**). Farmers who had a monthly household income of ≥8,000 USD were very optimistic about the impact of the COVID-19 pandemic with a mean score of 9 (SEM ± 0.737), which was significantly higher than households with 2000–3999 USD (5.4 SEM ± 0.341), and households with ≤500 USD (4.3 SEM ± 0.451) (**Table 2**). Full ownership of their land made farmers more optimistic about the impact of the COVID-19 pandemic with mean a score of 6.6 (SEM ± 0.512) and significantly higher than those that rented or leased private land (4.8 SEM ± 0.512) (**Table 2**).

Food Distributors

Most food distributors (73.3%) experienced challenges because of the COVID-19 pandemic but 23.4% indicated that they experienced increased sales and 3.3% felt that sales were normal. Based on focus group discussion in Trinidad and Tobago, when asked about new opportunities because of challenges encountered, some respondents indicated that they had more flexibility in working from home, others indicated that there were more opportunities through the burgeoning online markets and delivery services. Experiencing challenges and shocks among food distributors, was significantly associated with business type ($\chi^2 = 11.267$, $df = 2$, $p \leq 0.004$), business registration ($\chi^2 = 4.115$, $df = 1$, $p \leq 0.042$), rurality ($\chi^2 = 4.602$, $df = 1$, $p \leq 0.001$), level of education ($\chi^2 = 17.583$, $df = 3$, $p \leq 0.001$), and monthly household income (χ^2 =20.533, $df = 4$, $p \leq 0.001$). A significantly higher proportion of food distributors that operated sole proprietorship and partnership businesses experienced challenges compared to those that operated limited liability companies. Furthermore, unregistered businesses were affected by the COVID-19 pandemic in higher proportions than registered businesses. The data also showed that a significantly higher proportion of businesses that operated in rural areas were negatively impacted by the COVID-19 pandemic compared to those operating in urban areas. In terms of education, food distributors with primary and secondary school education were more likely to be affected by the COVID-19 pandemic than those that achieved tertiary training and vocational and technical training. The data also showed that food distributors from households with monthly income of ≤500 USD were more likely to be affected by the COVID-19 pandemic than all other monthly household income categories. In terms of the challenges experienced, 70% of food distributors attributed it to lower sales, 46.7% experienced difficulties with accessing raw materials, 43.3% believed that it was due to higher operating cost, while 26.7% felt it was because customers were not able to access the business and 20% indicated that it was because their businesses were closed (**Figure 2**). Food distributors gave various responses for how the COVID-19 pandemic affected the supply of agricultural raw materials used in their operation. Most (53.3%) reported that the supplies of raw materials were inconsistent, 36.7% received insufficient quantity of raw materials, and 16.7% indicated that there was a reduction in the quality of raw material received. On the other hand, 30% felt no impact, 23.3% experienced an increase in the quantity of raw materials received. Lack or shortage of hired labor were significantly associated with businesses registration status ($\chi^2 = 6.562$, $df = 1$, $p \leq 0.010$), and level of education ($\chi^2 = 11.769$, $df = 3$, $p \leq 0.008$). Unregistered businesses were likely to experience higher levels of labor shortages compared to registered businesses. Food distributors with only secondary school education were more likely to experience lack or shortage of labor in their businesses compared to those with primary school education and tertiary education. Various measures were used by food distributors to deal with shortage or lack of hired labor including online sales and distribution (27.8%), hiring family members (22%), hiring migrant workers (22%), hiring local labor (22%) and reducing business and production levels (16.7%), placing workers on shift (11%) and reducing workers salary (11%) (**Figure 3**).

Most food distributors (96.7%) were able to adopt biosecurity measures which became standard practices throughout the COVID-19 pandemic. There was no significant association in biosecurity measures adoption rate among any of the demographic categories evaluated. Food distributors ranked the impact of the COVID-19 pandemic on their distribution business with an overall mean of 5.03 (SEM $\pm$ 0.244). Mean impact scores were significantly different based on age ($F = 2.988$, $p \leq 0.039$), business registration status ($F = 7.488$, $p \leq 0.008$) and monthly household income ($F = 5.423$, $p \leq 0.001$) (**Table 2**). Mean scores for food distributors in the age categories 45–64 (5.43 SEM $\pm$ 0.480) and 25–44 (5.39 SEM $\pm$ 0.323) were significantly higher than those 65 years and older (3.00 SEM $\pm$ 0.899) (**Table 2**). Registered food distribution companies had a more positive outlook on the COVID-19 pandemic with a mean score of 5.6 (SEM $\pm$ 0.317) compared to operators of unregistered businesses 4.4 (SEM $\pm$ 0.338) (**Table 2**). Food distributors who had a monthly household income of $\geq$8,000 USD were very optimistic about the impact of the COVID-19 pandemic with a mean score of 8 (SEM $\pm$ 1.170), which was significantly higher than households with 4,000–5,999 USD (3.3 SEM $\pm$ 0.585), 2,000–3,999 USD (4.8 SEM $\pm$ 0.324) and $\leq$500 USD (5.0 SEM $\pm$ 0.478) (**Table 2**).

Food Service Operators

All food service operators (100%) in this study experienced challenges during the COVID-19 pandemic. The challenges experienced included closure of businesses (88.1%), lower sales (50%), raw materials supply or quality (43.6%), shortage or lack of hired labor (31%), higher operating cost (28.6%), customers not able to access the business (26.2%) and other (10%) (**Figure 2**). Some 35.7% of food service businesses were closed for 6–10 weeks, 28.6% closed for 2–5 weeks, 23.8% closed for 10 or more weeks and 11.9% closed for <2 weeks. Food service operators had various experiences regarding access and supply of agricultural raw materials. Some 43.6% experienced insufficient supply, 33.3% experienced inconsistent supply and 12.8% suggested that there was a reduction in the quality of raw materials supplied. However, 23.1% indicated that they did not experience any noticeable impact on the supply of raw materials. Lack or shortage of hired labor was significantly associated with business registration status ($\chi^2 = 10.364$, $df = 1$, $p \leq 0.001$), country ($\chi^2 = 11.259$, $df = 2$, $p \leq 0.004$), and monthly household income ($\chi^2 = 17.124$, $df = 5$, $p \leq 0.004$). Unregistered businesses were more likely to suffer from a lack or shortage of hired labor compared to registered businesses. Furthermore, shortage or lack of hired labor was more prevalent in Trinidad and Tobago and Barbados than in the Eastern Caribbean countries. Finally, food service operators with a monthly household income of $\leq$500 USD experienced more labor shortages than those with higher monthly household incomes. Various measures were used to deal with shortage or lack of hired labor. Some 33% resorted to hiring family labor, 26.7% each, increased sale price, reduced workers salary, reduced days/hours for sales and operation and business restructuring. Some 20% each, carried out employment adjustments and reduced business and production levels while 20% did nothing (**Figure 4**).

Food service operators ranked the impact of the COVID-19 pandemic as negative with an overall mean of 3.14 (SEM $\pm$ 0.243). Mean impact scores were significantly different based on gender ($F = 3.992$, $p \leq 0.049$), age ($F = 5.961$, $p \leq 0.001$), and country ($F = 5.206$, $p \leq 0.007$) (**Table 2**). Male food service operators (3.62 SEM $\pm$ 0.337) were more optimistic about the impact of the COVID-19 pandemic compared to their female counterpart (2.67 SEM $\pm$ 0.337) (**Table 2**). Similarly, food service operators <25 years old (4.71 SEM $\pm$ 0.547) were more optimistic than those 45–64 (2.13 SEM $\pm$ 0.374) and 65 years and older (2.00 SEM $\pm$ 1.024) (**Table 2**). Finally, food service operators from Trinidad and Tobago were more optimistic about the overall impact of the COVID-19 pandemic than those from Barbados (**Table 2**).

Consumers

Most consumers (67.1%) indicated that they experienced difficulties in accessing food throughout the pandemic and this was significantly associated with country ($\chi^2 = 14.245$, $df = 6$, $p \leq 0.027$). Although consumers from all countries in the study experienced difficulties in accessing food, it appears that significantly higher proportion in Barbados and Jamaica compared to Trinidad and Tobago and the Eastern Caribbean. In terms of the factors that contributed to the difficulties in accessing food, majority of consumers (54.9%) attributed it to movement restrictions such as curfew and lockdowns, 47.1% experienced difficulties because of their health and safety concerns, 27.5% attributed it to closure of food businesses and 25.5% reported that loss of income and increased food prices caused difficulties for them to access and obtain food (**Figure 2**). Consumers from the focus group discussion in Trinidad and Tobago when asked to identify the food items for which prices increased or decreased all reported an overall increase in almost all food. Most consumers (79.4%) changed their shopping behavior because of the COVID-19 pandemic. Change in shopping behavior was significantly associated with household size ($\chi^2 = 7.055$, $df = 2$, $p \leq 0.029$)

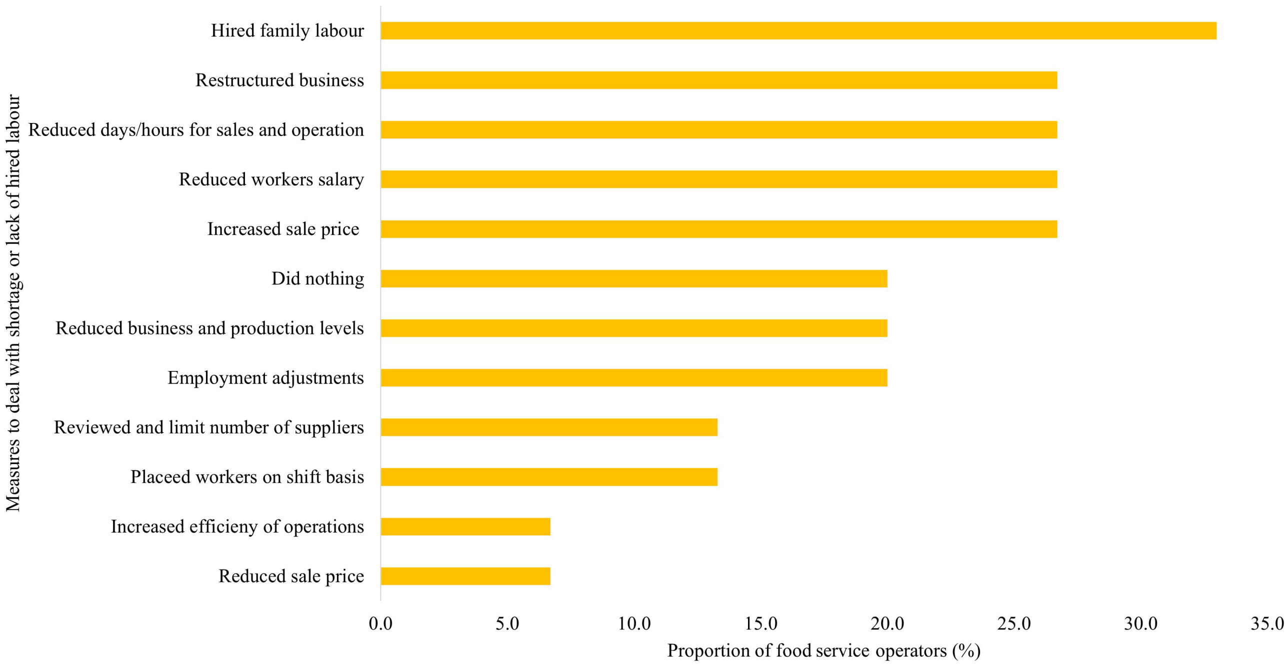


FIGURE 4 | Measures used by food service operators to handle the lack or shortage of hired labor caused by the COVID-19 pandemic in the Caribbean.

with higher proportions of household having 4–6 members changing their shopping behavior. There were multiple ways in which consumers' shopping behavior changed. Most consumers (66.4%) reduced the number of shopping trips, 47.7% bought larger quantities of food than usual, 26.3% bought cheaper and less preferred food, 17.5% started using curbside pickup, 14.5% bought from suppliers with home delivery options and 13.9% bought smaller quantities (**Figure 5**). Most consumers (63.9%) indicated that they adopted a healthier diet since the COVID-19 pandemic. The adoption of a healthier diet was significantly associated age ($\chi^2 = 10.329$, $df = 3$, $p \leq 0.016$) and gender ($\chi^2 = 6.692$, $df = 1$, $p \leq 0.008$). A significantly higher proportion of consumers between the ages of 45–64 adopted healthier diets compared to other age categories. The data also showed that a significantly higher proportion of female consumers adopted a healthier diet compared to males. Among those consumers that adopted a healthier diet, 58.8% did so because they felt eating a healthier diet would boost their immunity to infection, 19.1% attributed eating a healthier diet to the fear of contracting the virus, 15.5% reported that healthier options became available and 6.6% reported that limited transport affected their access to fast food restaurants and food outlets. These consumers used different means to adopt healthier diets. Most (75.5%) of those consumers adopting a healthier diet indicated that they did so by choosing to consume more home-cooked meals, 36% indicated they used more locally produced food and food ingredients, and 35.1% felt that growing their own food or home gardening contributed to them having a healthier diet. Majority of consumers (65.1%) indicated that they have eaten or used more locally produced food and food ingredients since the COVID-19 pandemic. This was also significantly associated with country ($\chi^2 = 8.474$, $df = 3$, $p \leq 0.037$), rurality ($\chi^2 = 6.784$, $df = 1$, $p \leq 0.009$) and household size ($\chi^2 = 5.914$, $df = 2$, $p \leq 0.050$). A significantly higher proportion of Trinidad and Tobago consumers believed they consumed or used more locally produced food and food ingredients since the COVID-19 pandemic compared to other countries in the study. Furthermore, a significantly higher proportion of consumers from rural areas have consumed or used more locally produced food and food ingredients compared to those from urban areas. Finally, a significantly higher proportion of consumers from households with 4–6 members consumed or used more locally produced food and food ingredients compared to consumers from other household size categories.

DISCUSSION

The results indicated that the impacts of the COVID-19 pandemic were felt along the entire agri-food supply chain and numerous challenges and shocks were identified across all participating groups and countries. Some challenges and shocks such as loss of income and related challenges including lower sales and loss of markets affected all groups in the study but to varying degrees. The level of challenges and shocks experienced by each group were also based on various socio-demographic factors. For example, the results indicated that business type, business registration, rurality, level of education and monthly household income were important factors that influenced how food distributors responded to shocks or challenges. Nevertheless, there were also some

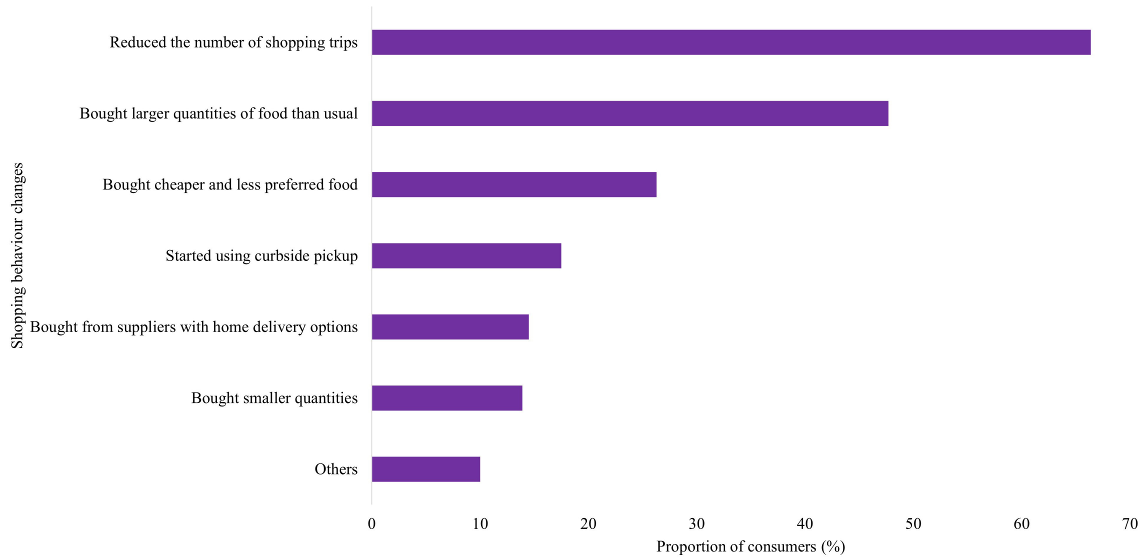


FIGURE 5 | Changes in consumer shopping behavior caused by the COVID-19 pandemic in the Caribbean.

opportunities that arose due to the COVID_19 pandemic. For example, online sale and delivery services of agricultural produce increased tremendously in Trinidad and Tobago, since people were advised to limit crowd interaction to minimize the spread of the disease. This opportunity, while not new, provided a lifeline for food producers and other operators in a hurting agri-food service industry. The pandemic disruptions sparked technological and organizational innovations that will likely prove permanent. What was notable from respondents in Trinidad and Tobago was the increase in value-added commodities from local foods, such as cassava and sweet potato flour, packaging of a range of other commodities from herbs to vegetables and food crops. Institutions such as the Caribbean Research and Development Institute (CARDI) and the Inter-American Institute for Cooperation in Agriculture (IICA) located throughout CARICOM have been providing training to farmers throughout the region promoting the use and consumption of local foods in agro-processing, good manufacturing processes and health and safety. These interventions will be complemented by the deployment of ICT enabled data collection and analytical tools. With respect to consumers, significant association was observed with country, as higher proportion of consumers in Jamaica and Barbados experienced challenges and shocks compared to Trinidad and Tobago and Eastern Caribbean countries. On the other hand, no significant association was detected among any socio-demographic factors for farmers and food service operators in this study which was an indication that challenges, and shocks experienced by these groups were equally felt across all socio-demographic categories. All food service operator in this study reported challenges and shocks and this was the most affected category of respondents. This is linked to the fact that most countries in the survey, instituted complete closure or restricted opening hours of food service businesses during the pandemic. Challenges and shocks associated with COVID-19 are widely reported globally and several studies have highlighted the impact of COVID-19 on actors in the agri-food supply chain in specific countries. Iese et al. (2021) reported that in the Pacific Islands, namely Fiji and Solomon Islands the impacts on national economies and agricultural production, markets, food systems and socio-cultural processes have been experienced at the household level, increasing poverty and hardship. Xie et al. (2021) reported that the COVID-19 pandemic has adversely impacted the agricultural supply chain, export of agricultural products, and overall food security in China. Another study done in North America pointed out that the COVID-19 pandemic and the near-total temporary loss of the foodservice distribution channel, exposed the vulnerability of agri-food supply chain in the early stages of the pandemic in that region (Weersink et al., 2021). Furthermore, Coluccia et al. (2021) suggested that the negative trend of agri-food exports in Italy was a clear consequence of the pandemic and demand shocks highlighted food supply chain vulnerability.

The results indicated that 51.9% of farmers experienced loss of income, 70 and 50% of food distributors and food service operators, respectively, experienced lower sales and 25.5% of consumers experienced loss of income. This is another clear example of the impact of the COVID-19 containment measures affected livelihood. For example, in Trinidad and Tobago, between March to June 2020, on-farm activities were severely impacted and the movement restrictions during this period affected the most time-critical activities which were labor dependent, especially for general crop management and harvesting. Loss of income and increased poverty during COVID-19 was a speculative reason for the increase in theft in Trinidad and Tobago. The World Bank (2020) projected that loss of income caused by COVID-19 containment measures would be one of the many channels through which poverty would expand globally (Mahler et al., 2020). Further projections indicated that 71 and 100 million people will return to the extreme poverty condition (living on a per capita monthly income <US $ 1.90 PPP a day). In the present study, poorer families and smaller businesses were more susceptible to loss of income which is similar to findings from other regions. Gu and Wang (2020) reported that in China, farmers' incomes generally declined due to the COVID-19 pandemic, and traditional small-scale farmers have suffered more losses. Income inequality among countries also affected ability to respond to the COVID- 19 pandemic with low- and middle-income countries, including those in this study facing greater challenges to cope. A study using data on income streams under lockdown in developing countries, suggested that an additional 9.1% of the population in sub-Saharan Africa have immediately fallen into extreme poverty because of COVID-19, with about 65% of this increase resulting from loss of income due to lockdowns (Teachout and Zipfel, 2020). The hiring of migrant labor is posited as one way to bolster and develop resilience in the agri-food system. Alvarado (2021) reported that many of the Venezuelan migrants who are in Trinidad and Tobago are highly trained University graduates in agriculture and could offer a lot more to develop the sector.

Loss of income was directly linked to stay-at-home orders and business closure which had a ripple effect throughout economies because consumers could not access goods and services, and the businesses were unable to earn income. Eventually, this led to some businesses laying off employees or forcing them to accept reduced or no salary for the period. All groups involved in this study indicated that they experienced challenges and shocks because of the stay-at-home and business closure order. The ILO (2020) estimated that the COVID-19 crisis could throw millions of workers into unemployment with an estimated rise in unemployment of between 5.3 and 24.7 million people, from a base of 188 million unemployed in 2019. The resulting increase in unemployment or underemployment will have severe consequences on livelihood and has already been reported with greatest impact on the poor and vulnerable (Economic Commission for Latin America the Caribbean, 2020).

Some 47.9% of farmers indicated that they experienced difficulties in acquiring agro-inputs throughout the COVID-19 pandemic, while 45.8% did not experience any difficulty and 6.3% was not sure. In several African countries Nchanji and Lutomia (2021) and Middendorf et al. (2021) reported similar findings where farmers faced difficulties in accessing farm inputs, access to seed, and to extension services. The opposite was observed in Europe where there was limited impact on food production and transportation as well as agricultural products (Meuwissen et al., 2021). Most countries in the Caribbean however provided support, encouraging home-gardening by distributing seeds, seedlings and other inputs to householders, smallholder farmers and vulnerable families for growing basic products—such as corn, beans, vegetables, and tubers—in their own homes and even initiating home garden competitions while some countries even made state lands available for cultivation. The findings of other studies support home gardening initiatives because of the benefits that may be achieved including enhanced food availability at the household and community levels (Lal, 2020) and supporting diverse diets when on-farm production is low, or market access is limited (Connors et al., 2021). Another study showed that higher frequency of garden usage during the COVID-19 lockdown was associated with better self-rated physical health (Corley et al., 2021). Therefore, home gardening may be an important tool to help achieve food security and support mental well-being. Some governments in the Caribbean provided food to quarantined communities and public-private partnership agreements were established to control domestic prices of the basic food basket. A similar mitigation strategy was reported in Fiji and Solomon Islands where Iese et al. (2021) explained that early actions by most Pacific Island governments included increased access to farms, increased production of root crops, vegetables, and seasonal fruits. A shift to traditional barter systems, land and resource sharing between households enabled households to cope with challenges and shocks (Iese et al., 2021).

More established, farmers, over 15 years seemed to have had more access to supplies of agro-inputs than relatively newer establishments between 2 and 5 years. Respondents cited the closure of outlets, movement restrictions, loss of income, health or safety concerns and lack of transportation as being the major reasons affecting raw materials supply. This could be attributed to distribution constraints experienced during the pandemic. The difficulty of importing inputs has been exacerbated by the extreme shortage of foreign exchange necessary to purchase animal health products, agrochemicals and even farm equipment. Only the largest agro-input suppliers usually have their own sources of foreign exchange, while small, and medium-sized agro-input suppliers which usually service farmers almost never have their own sources of foreign exchange and usually relies on credit. It is worthwhile to note that the demand for agro-inputs increased as many persons got involved in home gardening (Marshall et al., 2021). Although the exact demand caused by home-gardening throughout the pandemic has not been quantified it may have contributed to supply shortage of agro-inputs in some areas that were already stressed to meet existing demands.

The enabling environment for agro-input suppliers affect farmers that rely on timely and reliable availability of critical inputs for their production. Agro-Input suppliers operating throughout the Caribbean reported that the COVID-19 crisis has hindered the enabling environment for agro-input systems in the following ways: First, the availability of imported inputs was constrained due to logistical barriers, manufacturer challenges, and domestic firm access to foreign exchange. Second, farmer demand for inputs declined due to initial restrictions and the uncertainty associated with the general economic slowdown and then after a sudden increased demand with relaxed restrictions. Thirdly, the restrictions on mobility and social distancing requirements have limited agro-input marketing, distribution, and embedded services for farmers. In general, the negative impacts of COVID-19 on smaller firms were more severe than on larger firms, demonstrating that smaller firms were more vulnerable than larger firms during the pandemic.

Just under 50% of farmers in this study indicated that they experienced challenges with selling or marketing their produce during the pandemic and some had to give away or leave their produce in the field. Interestingly, food distributors, food service operators and consumers had challenges with accessing food or fresh agricultural produce which shows the disruptions experienced were also linked to communication and logistical challenges. Inconsistencies with transportation and limited economic activities posed numerous threats to food distributors. Food distributors and food service operators experienced delays in the supply of raw materials, and the quantity and quality of raw material received, however, food distributors had a positive outlook toward the COVID-19 pandemic compared to food service operators. This positive outlook of food distributors in some countries was probably due to the shift in new market opportunities. Domestic markets for food production and distribution channels have to some extent become more diversified through improved technological services and innovations. In many Islands, these systems have become more coordinated and adapted to changing patterns in demand and have taken advantage of new business opportunities, in processing and online shopping, which were some of the ways that food distributors in this study cope with the challenges and shocks. During the COVID-19 pandemic, agricultural, Business to Business (B2B) and Business to Consumer (B2C), e-commerce platforms have significantly increased and begun to facilitate access to perishable products. From the consumer side, increased support toward healthy food and local markets was also strengthened which includes increased uptake of domestically sourced fruit and vegetables and some animal products and the ability of local and regional supply chains to meet these needs. In the United States, Ahuja et al. (2021) reported that market opportunity doubled during the COVID-19 with an historical 8% growth rate. In fact, this expanding ecosystem of farm-to-consumer marketing schemes have grown just as consumers have sharply expanded use of online grocery purchases, food delivery, and home gardens (Guo et al., 2020). The food industry which was providing hotels (many of which have been closed in the region) is redistributing fresh food in support of the most vulnerable through Governmental support programmes. In Trinidad and Tobago for example, small farmers and small and medium business enterprises have access to adapted finance so they can continue to produce, increasing supply patterns. Many agri-food suppliers had some business opportunities for online food delivery systems and online digital payments by scaling up online ordering systems, while supermarkets have enabled groceries to be ordered through WhatsApp and even email. Restaurants and other food service providers also participated in school-feeding programmes which are important contributors to food security.

The impact of the COVID-19 pandemic caused a shift in which 67.1% of consumers in this study indicated that they experienced difficulties in accessing food with 54.9% attributing the issues to movement restrictions such as curfew and lockdowns, loss of income, stay-at-home orders, and market disruptions, all to help curb the spread of the virus. Although the results indicated that a significantly higher proportion of consumers in Jamaica and Barbados were affected compared to Trinidad and Tobago and the Eastern Caribbean, the issues were common throughout the region. Besides the direct impact of the measures taken, there were other local socioeconomic factors not identified in this study that may have contributed to the differences among countries. In Jamaica for example, the lockdown and stay-at-home order provided opportunities for the Government to institute other measures to fight crime creating a very complex social dynamic (Crawford et al., 2021). Several studies from different parts of the world also reported issues with food access, food security and related social issues because of the COVID-19 pandemic. The Central Bank of Trinidad and Tobago (CBTT) reported an increase in food prices which they attributed to a surge in international commodity prices and inclement weather (Central Bank of Trinidad and Tobago 2021). Furthermore, food inflation (year-on-year) rose from 3.2 in January to 4.9% in July 2021 with the largest increases recorded for vegetables, fruits, milk, cheese, and eggs (Central Bank of Trinidad Tobago., 2022). Wang et al. (2020) reported that over 20 million school students in the United States of America, experienced food access problems because schools were closed. The World Food Programme (2020) estimated an increase of 130 million people facing acute food insecurity because of the COVID-19 pandemic (World Food Programme, 2020).

A positive effect of the widespread lockdowns and restrictions is that consumers used more locally produced food and food ingredient (36%) and 35.1% grew their own food which helped to reduce household expenditure since public measures were put in place for people to stay at home thus reducing their household income similar to the findings of Blazy et al. (2021). The stay-at-home order forced some households to prepare more home-cooked meals, which caused a change in eating behavior (Kartari et al., 2021). However, with this change, households were consuming foods with an extended shelf-life compared to fresh fruits and vegetables (Janssen et al., 2021). The switch in eating behaviors can be associated to changes in socioeconomic status, employment, and psychological traits (Vidal et al., 2021).

CONCLUSIONS, RECOMMENDATIONS AND LIMITATIONS

It is necessary to examine the impact of the COVID-19 pandemic on agri-food systems in the Caribbean and to identify mechanisms employed to cope. An understanding of the impacts and effective coping strategies employed will inform effective data-driven decision making and highlight best practices as these countries continue to navigate the perils of the pandemic. This study found that challenges and shocks related to the COVID-19 pandemic were experienced along the entire agri-food supply chain in the Caribbean. Some of these challenges and shocks were common to all actors while others were more specific and showed significant associations with socio-demographic variables. In general people of lower income status and smaller businesses were more susceptible to the negative impacts of the pandemic. The findings also suggest that to overcome the challenges and shocks related to the COVID-19 pandemic some existing businesses used creative means or capitalized on opportunities such as online marketing. In some cases, new businesses were created because of the opportunities that arose. Some consumers reported developing healthier eating habits and consuming more locally produced food. This is important because the Caribbean is generally considered one of the unhealthiest regions and the high dependence on food importation makes it very food insecure.

Based on the findings of this study the following recommendations are made. Food security policies should be designed and implemented to protect the most vulnerable populations such as the poor, uneducated, small businesses, and rural areas inhabitants. These policies should focus on the entire agri-food supply chain with specific intervention measures depending on vulnerabilities. Governments across the Caribbean should create an enabling environment to stimulate increased local production and foster behavioral change in consumer choices. These two factors are interdependent and must be collectively addressed to help countries across the region to become more food secure. The findings of this study also support the views that Governments, private sector, and all stakeholders must all work together to build a more resilient agri-food system that can withstand the challenges and shocks associated with pandemics but also those caused by natural disasters. To develop a more resilient, sustainable, and efficient local agri-food system, climate-smart agricultural practice must be encouraged and incentivized. This will enhance local production capacity and efficiency and reduce foreign input requirements. It is also necessary that intra-regional trade is promoted which will ensure easier access to markets and minimize the socio-economic impacts of external shocks.

The present study has some limitations. Firstly, because of the restriction put in place for the COVID-19 pandemic, it was difficult to get information from a larger number of participants from more countries in the region. The online surveys were completed only by individuals who have access to online resources which were non-representative and convenient samples. Therefore, these findings represent the populations in these countries who had access to the various online resources. Future studies should focus on a capturing data from more participants and other methodologies can be considered for assessing and increasing the reliability of the data obtained.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by The University of The West Indies. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

OD, WA-I, and AJ conceived the study. OD, WA-I, AJ, and KF conducted the surveys and interviews. OD and RR performed quantitative analysis. All authors contributed to the development of survey instruments. All authors contributed to the article and approved the submitted version.

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REFERENCES

Ahuja, K., Chandra, V., Lord, V., and Peens, C. (2021). *Ordering In: The Rapid Evolution of Food Delivery*. Available online at: https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/ordering-in-the-rapid-evolution-of-food-delivery (accessed March 20, 2022).

Alvarado, G. (2021). *Venezuelan Expert to Trinidad and Tobago: 'Take Advantage of Land to Recover Post-Pandemic.'* Newsday Newspaper. Thursday July 1, 2021. Available online at: https://archives.newsday.co.tt/?s=Thursday%20July%201,%202021%20alvarado# (accessed January 20, 2022).

Beckford, C. L., and Rhiney, K. (2016). *Globalization, Agriculture and Food in the Caribbean.* Climate change, Gender and Geography. London: Macmillan Publishers Ltd.

Blazy, J. M., Causeret, F., and Guyader, S. (2021). Immediate impacts of COVID-19 crisis on agricultural and food systems in the Caribbean. *Agric. Syst.* 190:103106. doi: 10.1016/j.agsy.2021.103106

Caribbean Community (CARICOM), Caribbean Disaster Emergency Management Agency (CDEMA), World Food Programme (WFP), and Food and Agriculture Organization (FAO) (2021). *Caribbean COVID-19 Food Security and Livelihoods Impact Survey – Regional Summery Report 2021.* Christchurch, Barbados, United Nations World Food Programme (WFP).

Central Bank of Trinidad and Tobago. (2022). *CBTT Economic Bulletin January 2022, Volume XXIV. No.1.* Port of Spain, Trinidad and Tobago: CBTT.

Coluccia, B., Agnusdei, G. P., Miglietta, P. P., and De Leo, F. (2021). Effects of COVID-19 on the Italian agri-food supply and value chains. *Food Control* 123, 107839. doi: 10.1016/j.foodcont.2020.107839

Connors, K., Jaacks, L. M., Prabhakaran, P., Veluguri, D., Ramanjaneyulu, G. V., and Roy, A. (2021). Impact of crop diversity on dietary diversity among farmers in india during the COVID-19 pandemic. *Front. Sustain. Food Syst.* 5:695347. doi: 10.3389/fsufs.2021.695347

Corley, J., Okely, J. A., Taylor, A. M., Page, D., Welstead, M., Skarabela, B., et al. (2021). Home garden use during COVID-19: associations with physical and mental wellbeing in older adults. *J. Environ. Psychol.* 73:101545. doi: 10.1016/j.jenvp.2020.101545

Crawford, T. V., Parchment, K. F., and Robinson, S. S. (2021). Impact of COVID-19 pandemic restrictions on major crimes and sexual offences in Jamaica: A comparative analysis of crimes reported by the Jamaica Constabulary Force (2014–2020). *Int. J. Soc. Sci. and Humanit. Res.* 9, 162–172.

Economic Commission for Latin America and the Caribbean (2020). *ECLAC Latin America and the Caribbean and the COVID-19 Pandemic: Economic and Social Effects*. Santiago: ECLAC.

Fanzo, J. C., Hawkes, E., Udomkesmalee, A., Afshin, L., Allemandi, O., Assery, P., et al. (2019). *"2018 Global Nutrition Report-Shining a Light to Spur Action on Nutrition*. Bristol: Development Initiatives Poverty Research Ltd.

FAO (2021). *The State of Food and Agriculture 2021. Making Agrifood Systems More Resilient to Shocks and Stresses*. Rome: FAO. doi: 10.4060/cb4476en

Ganpat, W. G., and Isaac, W. P. (2015). *Impacts of Climate Change on Food Security in Small Island Developing States*. IGI Global Publishers.

Goswami, P., Roy, K., Dutta, S., Ray, K., Sarkar, S., Brahmachari, K., et al. (2021). Multi-faceted impact and outcome of COVID-19 on smallholder agricultural systems: integrating qualitative research and fuzzy cognitive mapping to explore resilient strategies. *Agric. Syst.* 189:103051. doi: 10.1016/j.agsy.2021.103051

Gu, H., and Wang, C. (2020). Impacts of the COVID-19 pandemic on vegetable production and countermeasures from an agricultural insurance perspective. *J. Integr. Agric.* 19, 2866–2876. doi: 10.1016/S2095-3119(20)63429-3

Guo, H., Liu, Y., Shi, X., and Chen, K. Z. (2020). The role of e-commerce in the urban food system under COVID-19: lessons from China. *China Agric. Econ. Rev*. 13, 436–455. doi: 10.1108/CAER-06-2020-0146

Heck, S., Campos, H., Barker, I., Okello, J. J., Boy, E., Brown, L., et al. (2020). Resilient agri-food systems for nutrition amidst COVID-19: evidence and lessons from food-based approaches to overcome micronutrient deficiency and rebuild livelihoods after crises. *Food Secur.* 12, 823–830. doi: 10.1007/s12571-020-01067-2

Hickey, G. M., and Unwin, N. (2020). Addressing the triple burden of malnutrition in the time of COVID-19 and climate change in Small Island Developing States: what role for improved local food production? *Food Secur.* 12, 831–835. doi: 10.1007/s12571-020-01066-3

Iese, V., Wairiu, M., Hickey, G. M., Ugalde, D., Salili, D. H., Walenenea, J., et al. (2021). Impacts of COVID-19 on agriculture and food systems in Pacific Island countries (PICs): Evidence from communities in Fiji and Solomon Islands. *Agric. Syst.* 190:103099. doi: 10.1016/j.agsy.2021.103099

ILO (International Labour Organization) (2020). *COVID-19 and the World of Work: Impact and Policy Responses*. Available online at: https://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/documents/briefingnote/wcms_738753.pdf (accessed March 18, 2020).

Janssen, M., Chang, B. P. I., Hristov, H., Pravst, I., Profeta, A., and Millard, J. (2021). Changes in food consumption during the COVID-19 pandemic: analysis of consumer survey data from the first lockdown period in Denmark, Germany, and Slovenia. *Front. Nutr.* 8:635859. doi: 10.3389/fnut.2021.635859

Kartari, A., Özen, A. E., Correia, A., Wen J, and Kozak, M. (2021). Impacts of COVID-19 on changing patterns of household food consumption: an intercultural study of three countries. *Int. J. Gastron. Food Sci.* 26:100420. doi: 10.1016/j.ijgfs.2021.100420

Krueger, R. A. (1994). *Focus Groups. A Practical Guide for Applied Research. 2nd Edn*. Thousand Oaks: Sage.

Lal, R. (2020). Home gardening and urban agriculture for advancing food and nutritional security in response to the COVID-19 pandemic. *Food Secur.* 12, 871–876. doi: 10.1007/s12571-020-01058-3

Mahler, D. G., Lakner, C., Castaneda, R. A. A., and Wu, H. (2020). *Updated Estimates of the Impact of COVID-19 on Global Poverty*. World Bank Blog. Available online at: https://blogs.worldbank.org/opendata/updated-estimates-impact-covid-19-global-poverty

Marshall, T., Saint Ville, A., Fletcher-Paul, L., and Isaac, W. P. (2021). "COVID-19: the impact of a complex disaster on household food security in Caribbean SIDS," in Campbell Y, Connell J, editors. *COVID in the Islands: A Comparative Perspective on the Caribbean and the Pacific*. Singapore: Palgrave Macmillan.

Meuwissen, M., Feindt, P. H., Slijper, T., Spiegel, A., Finger, R., de Mey, Y., et al. (2021). Impact of Covid-19 on farming systems in Europe through the lens of resilience thinking. *Agric. Syst.* 191:103152. doi: 10.1016/j.agsy.2021.103152

Middendorf, B. J., Faye, A., Middendorf, G., Stewart, Z. P., Jha, P. K., and Prasad, P. V. V. (2021). Smallholder farmer perceptions about the impact of COVID-19 on agriculture and livelihoods in Senegal. *Agric. Syst.* 190:103108. doi: 10.1016/j.agsy.2021.103108

Murphy, M. M., Jeyaseelan, S. M., Howitt, C., Greaves, N., Harewood, H., Quimby, K. R., et al. (2020). COVID-19 containment in the Caribbean: the experience of Small Island Developing States. *Res. Global.* 2, 1–9. doi: 10.1016/j.resglo.2020.100019

Nchanji, E. B., and Lutomia, C. K. (2021). Regional impact of COVID-19 on the production and food security of common bean smallholder farmers in Sub-Saharan Africa: implication for SDG's. *Global Food Secur.* 29:100524. doi: 10.1016/j.gfs.2021.100524

Raibee, F. (2004). Focus-group interview and data analysis. *Proc. Nutr. Soc*. 63, 655–660. doi: 10.1079/PNS2004399

Saint Ville, A., Po, J. Y. T., Sen, A., Bui, A., and Melgar-Quiñonez, H. (2019). Food security and the Food Insecurity Experience Scale (FIES): ensuring progress by 2030. *Food Secur.* 11, 483–491. doi: 10.1007/s12571-019-00936-9

Stephens, E. C., Martin, G., van Wijk, M., Timsina, J., and Snow, V. (2020). Editorial: Impacts of COVID-19 on agricultural and food systems worldwide and on progress to the sustainable development goals. *Agric. Syst.* 183, 102873. doi: 10.1016/j.agsy.2020.102873

Teachout, M., and Zipfel, C. (2020). *The Economic Impact of COVID-19 Lockdowns in Sub-Saharan Africa*. London: International Growth Centre.

The World Bank (2020). *Poverty and Shared Prosperity 2020 - Reversal of Fortune*. Available online at: https://www.worldbank.org/en/publication/poverty-and-shared-prosperity (accessed January 20, 2022).

Torero, M. (2020). Without food, there can be no exit from the pandemic. *Nature* 580, 588–589. doi: 10.1038/d41586-020-01181-3

United Nations (2020). *UN Executive Summary: United Nations Common Guidance on Helping Build Resilient Societies*. New York, NY: UN.

Vidal, L., Brunet, G., Curutchet, M. R., Girona, A., Pardiñas, V., Guerra, D., et al. (2021). Is COVID-19 a threat or an opportunity for healthy eating? An exploration of the factors that moderate the impact of the pandemic on eating habits in Uruguay. *Appetite.* 167:105651. doi: 10.1016/j.appet.2021.105651

Wang, Q., Liu, C., Zhao, Y., Kitsos, A., Cannella, M., Wang, S., et al. (2020). Impacts of the COVID-19 pandemic on the dairy industry: Lessons from China and the United States and policy implications. *J. Integr. Agric.* 19, 2903–2915. doi: 10.1016/S2095-3119(20)63443-8

Weersink, A., von Massow, M., Bannon, N., Ifft, J., Maples, J., McEwan, K., et al. (2021). COVID-19 and the agri-food system in the United States and Canada. *Agric. Syst.* 188:103039. doi: 10.1016/j.agsy.2020.103039

World Food Programme (2020). *WFP Hunger Map*. Available online at: https://hungermap.wfp.org/ Available online at: https://hungermap.wfp.org/ (accession January 20, 2022).

Xie, Y., Sarkar, A., Hossain, M. S., Hasan, A. K., and Xia, X. (2021). Determinants of farmers' confidence in agricultural production recovery during the early phases of the COVID-19 pandemic in China. *Agriculture* 11, 1075. doi: 10.3390/agriculture11111075

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Diversified Farming Systems: Impacts and Adaptive Responses to the COVID-19 Pandemic in the United States, Norway and China

Inger Elisabeth Måren[1*], *Heidi Wiig*[2], *Kathryn McNeal*[3], *Sally Wang*[4], *Sebrina Zu*[5], *Ren Cao*[6], *Kathinka Fürst*[7] *and Robin Marsh*[8]

[1] Department of Biological Sciences, University of Bergen, Bergen, Norway, [2] Department of Strategy and Entrepreneurship, BI—Norwegian Business School, Oslo, Norway, [3] Department of Geography, University of California, Berkeley, Berkeley, CA, United States, [4] Department of Social Science, Duke Kunshan University, Kunshan, China, [5] Department of Agriculture and Resource Economics, University of California, Berkeley, Berkeley, CA, United States, [6] Department of Geography, San Diego State University, San Diego, CA, United States, [7] Norwegian Institute for Water Research (NIVA), Oslo, Norway, [8] Institute for the Study of Societal Issues (ISSI), University of California, Berkeley, Berkeley, CA, United States

The COVID-19 pandemic fully exposed the vulnerability of the global agri-food system to shocks and stresses, highlighting the need for transformation and action to make it more resilient and inclusive. This paper offers a unique insight into the global nature of the COVID-19 pandemic by examining impacts and responses in the agri-food sector within three very distinct contexts, namely the United States, Norway, and China. Focusing on small, diversified farms, the study builds on prior research with the same farmers and support organizations from an on-going collaboration. Firstly, we conducted a short review of policy adaptations to understand how governments, the private sector, non-profit organizations, and communities "stepped up" to provide emergency relief, specialized training, and recovery support for farmers, support that was instrumental in preventing more devastating impacts in all three countries. Secondly, drawing from in-depth interviews with farmers (23) and government and non-governmental support organizations (19), we mapped the vulnerability and resiliency of selected farmers to shocks that severely disrupted traditional supply chains during the COVID-19 pandemic. Data were collected on both the negative and positive impacts of the pandemic to farmer inputs, including labor, operations, and markets, how these changed from the initial lockdowns in early 2020 and through 2021, and on farmer adaptive responses to these impacts. In some contexts, innovation and adaptive responses counteracted negative impacts. We saw diversifying markets, catering to consumer safety concerns, switching to direct and e-markets, hiring in more labor or relying on family labor, and switching to high demand crops and products as the most prominent adaptive responses. Farmers who lacked access to information and government programs, in large part because of language, technology and institutional barriers, missed out on pandemic related opportunities and suffered the most. As we enter the post-pandemic new normal it is important to take stock of lessons learned, and to continue to support those initiatives and innovations that were pivotal not only for weathering the storm, but for building a more inclusive and resilient agri-food system in the long-run.

Keywords: community-supported agriculture, e-commerce, farmer impacts, policy adaptations, post-disaster resilience, small-scale farmers, sustainable food systems, agri-food systems

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Gabriel da Silva Medina,
University of Brasilia, Brazil

***Correspondence:**
Inger Elisabeth Måren
inger.maaren@uib.no

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INTRODUCTION

"*Historically, pandemics have forced humans to break with the past and imagine their world anew. This one is no different. It is a portal, a gateway between one world and the next.*" (Arundhati Roy, The Financial Times, 2020).

Massive agri-food system disruptions have been commonplace throughout history. Disaster events, such as the COVID-19 pandemic (hereafter called "the pandemic"), can radically change agricultural landscapes (Eklund et al., 2016; Epstein et al., 2018; Lopez-Ridaura et al., 2021) and influence the adoption of new farming practices, crop choices and distribution mechanisms (Lin, 2011; Altieri et al., 2015; DiCarlo et al., 2018; Barrett et al., 2021), indeed, disasters can become critical moments of transformation (Folke, 2006; Bacon et al., 2012; Scheffer et al., 2012; Lioutas and Charatsari, 2021). This research builds on the important and burgeoning canon of literature that looks at rural livelihoods (Du et al., 2005; Valdés and Foster, 2010; Carreras et al., 2020; Gatto and Islam, 2021; Rasul et al., 2021), livelihood diversification (Gautam and Andersen, 2016), and smallholder farming (Hazell et al., 2010; Jayne et al., 2010), in the context of shocks. Given the pervasiveness and increasing frequency of human-environmental induced disasters, especially related to climate and health, there is widespread interest in understanding their impacts on agricultural systems broadly, as well as in the capacity of farmers to recover and adapt (Scheffer and Carpenter, 2001; Adger et al., 2005; Bacon et al., 2012; Kremen et al., 2013; Marín et al., 2014; Tendall et al., 2015; Folke et al., 2016; Kremen and Merenlender, 2018). Recovery in this context refers to a process of "bouncing back" to, or close to, a pre-disaster state (Klein et al., 2003; Cutter et al., 2008), whereas adaptation refers to the potential to be transformed into stable new states (Folke, 2006; Cutter et al., 2008).

Beginning February of 2020, the COVID-19 virus spread rapidly across the world with serious environmental, social and economic consequences (IPBES, 2020). The pandemic underscores how novel shocks to agri-food systems compound the already dire global impacts of climate change, biodiversity loss, and food insecurity (Carlisle et al., 2019; IPBES, 2019; IPCC, 2019; Petersen-Rockney et al., 2021). During the pandemic, farmers in all corners of the globe were challenged in unprecedented ways to adapt their production, marketing, sales, and food and labor safety practices to abide by COVID-restrictions in health and society in general. Under these circumstances, building resilience and adaptive capacity in the food system takes on new urgency with important experiences for sharing across nations and for planning a more secure global post-pandemic food system.

Our work builds on previous examinations of small-scale farming, disasters and agricultural change (Holt-Giménez, 2002; Shivakumar et al., 2005; Lin, 2011; Steffen et al., 2011; Epstein et al., 2017, 2018; DiCarlo et al., 2018) by examining how disasters or crises converge with ongoing agricultural transitions and may act as a catalyst for change. Using a qualitative and case-based approach, we examine the health pandemic in three globally important socio-political and food system contexts; the United States, Europe and China, to shed light on the impacts and adaptive responses of small-scale farmers in these distinct contexts. In general terms, in California, United States, small-scale farmers rely on the "free market" for economic survival, while in Vestland, Norway, the Norwegian "social contract" is a model case of government-supported family farm agriculture, and in Kunshan, Southeast China, as throughout China, the central government plays a dominant role in agriculture development.

Combining new empirical data derived from in-depth interviews with small-scale farmers and governmental and non-governmental organizations serving farmers, with a comprehensive mapping of relevant pandemic-related policies in these three countries, we find both commonalities and differences that provide fertile ground for cross-country learning and future planning. We aim to answer the following questions: (1) How have small-scale farmers been impacted by the severe challenges of the pandemic, and how have they responded to this crisis? (2) Which institutions are most effective in supporting small-scale farmers to weather the crisis? Who benefitted? Who lost out? (3) What can we learn from each other for building a more just, resilient and sustainable agri-food system post-pandemic?

MATERIALS AND METHODS

This study used in-depth interviews and case studies combined with policy response mapping to explore the research questions. A geographically diverse case-study approach was used to generate a multi-faceted understanding of the complex issues of the pandemic in distinct real-life contexts (Crowe et al., 2011) where in-depth interviews with farmers and support organizations elicited experiences and explanations from multiple perspectives. The inclusion of support organizations provides insight into the pandemic-related impacts experienced by a larger number of farmers that they represent or serve. Farmers and support organizations interviewed were chosen based on meeting at least two of three criteria; (1) already part of established research collaboration, (2) snowball recommendations from key informants, and (3) locally recognized and appreciated as sustainable small-scale farmers or support organizations. Hence, some of the interview candidates were part of prior research relationships, building on trust already established with the research team, and expanded on to ensure a diversity of farm types and support organizations. We also conducted desktop research on the policy responses to the global pandemic in the agri-food sector for a "birds eye" view of the situation in three distinct socio-political contexts. An important component of this research was to capture the initial and on-going array of governmental and non-governmental responses to the pandemic. This involved consultation of government websites and policy documents available to the public, news articles, NGO websites, blogs and reports that continue to document pandemic related events, impacts and responses in real time as the pandemic enters its third year. Journal articles presenting research from the early stages of the pandemic were obtained through literature searches and referenced if relevant.

Study Regions

We chose three geographical locations for our policy and case-study investigation: United States/north-central California, European Union/western Norway and China/southeastern China, building on a previous comparative collaboration on sustainability perspectives in agriculture (Elias and Marsh, 2019). This study, therefore, presents a unique opportunity to explore and compare the impacts of a global pandemic on farmers and agri-food supply chains, and to assess and compare both farmer and policy responses, in three very distinct regions.

1. California, United States

California is characterized by a Mediterranean type climate with hot and dry summers, mild winters, and most agriculture depends on some type of irrigation system. It is a well-known center of agricultural technological and institutional innovation to support sustainable landscapes and food systems (Kremen et al., 2013; Iles et al., 2016; Carlisle et al., 2019; Elias and Marsh, 2019) and therefore a good candidate for studying self-driven diversified farming systems and small-scale farming. California horticulture farmers do not receive crop subsidies, relying on "free market" sales for economic survival and smaller farmers are often outcompeted by large operations (Iles and Marsh, 2012; Scheitrum, 2020). Those that do survive and thrive tend to have strong direct marketing strategies that respond to growing consumer demands for local, fresh and healthy produce. For this study, we selected eight farmers for in-depth interviews, and ensuring a diversity of sizes, crops, practices and markets. The farms, located in seven different counties of northern and central California, range from 7 to 270 acres—small to mid-size, with one outlier at 1,500 acres of orchards. Half of the farms grow tree crops—fruits, almonds and walnuts, three grow row crops, mainly vegetables, and one is a mix of tree and row crops. Five of the eight farms are 100 percent organic, while three are a mix of organic and conventional crops. Approximately 80 percent of hired labor on these farms, and in California generally, are immigrants from Mexico.

2. Vestland, Norway

Western Norway is characterized by a Northern Atlantic climate with cool summers, relatively mild winters and high precipitation year around. In Norway cultivated land accounts for only 3% of the country's total area. Meat (beef, pork, sheep and poultry/eggs) and dairy (cow and goat) production take place in rural areas all over the country, while the production of grains, vegetables, fruits and berries mainly takes place in central parts of Norway. The farm structure is characterized by relatively small family farms. Norway's agricultural and rural policies have historically been related to food security, farm incomes, maintaining population in rural areas and regional distribution of production and employment objectives (Bjørkhaug and Richards, 2008; Forbord et al., 2014; OECD, 2021c). We selected 10 farmers from the Nordhordland region on the west coast of Norway. This area was designated in 2019 as a UNESCO Biosphere Reserve as part of UNESCO's Man and the Biosphere (MAB) Programme (UNESCO, 2017; Kaland et al., 2018). Biosphere Reserves are model areas for sustainable development, where agricultural activities play an important role. The farms included in this study range from 22 to 461 acres (mean of 181 acres), where a large proportion of land on each farm constitutes uncultivated rangeland or woodlots (outfields). Farms combine fodder production (hay) with livestock rearing, mostly sheep, cattle, pigs, goats and chicken, and/or vegetable and fruit and berry growing. Most farms are run as family operations where members of the workforce have part-time jobs elsewhere, and labor is only hired in for the summer months.

3. Kunshan, China

Southeastern China is characterized by hot and rainy summers and cold and dry winters, and large areas are dominated by agricultural activities. This project continues past research in Kunshan County, located in the highly urbanized and affluent Yangtze River Delta adjacent to Shanghai. Alternative Food Networks (AFNs) have become popular here because of a demand-driven civic movement for greater access to healthy and safe food (Shi et al., 2011; Schumilas and Scott, 2015). AFNs appeal particularly to educated and conscious urban consumers who are willing to pay for the price premium of organically grown food. A number of sustainability farms have emerged in Kunshan, one of them being the Yue Feng Dao Organic Farm (YFD). YFD, established in 2010, is a hybrid business and state-owned enterprise consisting of 83 acres of organically grown rice, vegetables and poultry. YFD caters to the Shanghai market by selling directly to consumers through a Consumer-Supported Agriculture (CSA) model. As with California and Norway, the choice of YFD as the China site builds on relationships formed in prior research. However, due to severe lockdown conditions during the pandemic for YFD and the China-based research team, and the inability to conduct interviews by phone, only five interviews were possible. Furthermore, four of these farmers differ as they are farm labor-employees of YFD, having their own small farms in the nearby village of Chuodun (绰墩), while the fifth is a YFD marketing supervisor living in Shanghai. Therefore, their perspectives on pandemic impacts, and ability to respond, will be different than the other two cases.

Interviews

The same questionnaire was used for conducting interviews in the United States, Norway and China. It was translated into the local languages with minor adaptations to improve clarity, allowing for comparability in impacts, responses and perspectives across the three countries. The research protocol was reviewed and approved by the Office for the Protection of Human Subjects, UC Berkeley and Duke Kunshan University, and by the Norwegian Center for Research Data (NSD) for the Vestland case. Data were anonymized before data entry and all audio files will be deleted by the end of the project period. In California and Kunshan, the study teams comprised lead faculty and students (University of California, Berkeley, Duke Kunshan University, respectively), conducting and analyzing interviews and policy research, while in Norway the study team comprised lead faculty and a technical assistant (University of Bergen). The questionnaire started with a section where respondents were asked to rank various categories of pandemic-related impacts on a scale from 1 (no impact) to 6 (very highly impacted), for both negative and positive impacts. This was followed by a qualitative section on specific impacts with a set of ten open-ended questions. Interviews were audio-recorded (except in one case with a Chinese organization that did not consent), and in most cases were fully transcribed, coded and text analyzed, while in others key themes and quotes were excerpted and directly transferred to the data analysis excel sheets. Data on ranked negative and positive impacts were converted to percentage distributions of the six ranked options and presented as bar charts for easy cross-country comparison.

In total, 23 farmers were interviewed: 8, 10, and 5 from California, Vestland and Kunshan, respectively (**Supplementary A**). Interviews with farmers were conducted in person, over a digital meeting platform like Zoom or Teams or *via* cell phone due to lockdowns and pandemic restrictions and lasted one to two hours. In addition, 19 staff from 17 farmer support organizations; 6, 7 and 6 from California, Vestland and Kunshan, respectively, were interviewed with interviews lasting from 30 to 90 minutes (**Supplementary A**). Interviews with organizations were held virtually *via* cell phone, Teams or Zoom, except two in-person interviews in Beijing and Shanghai, China. These governmental and non-governmental organizations (NGOs) or agencies provide farmers with technical advice on agriculture and marketing practices, policy advocacy on behalf of farmers and sub-sectors of small, organic and socially disadvantaged farmers, as well as networking connections with programs and financing provided by government at different levels, in addition to their own emergency fundraising for impacted farmers. Interviews captured both the impacts on the organization's functioning as well as negative and positive impacts on the farmers they serve or represent.

RESULTS

Impacts and Adaptive Responses—Policy Measures

1. The United States/California

Beginning in March 2020, there were severe pandemic-related supply chain disruptions with coolers, packers, and food distributors across the United States (Congressional Research Service, 2020). Many farmers who sold directly to restaurants or through wholesalers to school and corporate cafeterias lost income as the demand from these sources dramatically reduced at the onset of the pandemic (California Farm Bureau Federation, 2020). Larger farms and ranches entirely reliant on major wholesalers fared worse. At the same time, supply chain and processing limitations hampered farmer responsiveness to increased consumer demand from supermarkets (ERA Economics, 2020). Farmers faced lost markets, health and safety issues, supply chain disruptions, and labor shortages. Farmers markets initially shut down, disproportionately hurting smallholder farmers, many organic, but later reopened with strict health protocols when designated as "essential services" after concerted lobbying (Woods and Zare, 2021) by such California-based organizations as Community Alliance with Family Farms (CAFF). "*While the state has declared that farmers markets are essential services just like grocery stores or pharmacies . . . a number of jurisdictions have decided to ban them anyway. And so we spent the past four weeks advocating. . . talking to local policymakers, city councils, to say no, this is an essential service. They're not special events. They're not luxury items. These are essential services, where people, including low-income families, using SNAP [Supplemental Nutrition Assistance Program] and other market match programs actually get their healthiest groceries*" (CAFF staff member).

Numerous non-governmental organizations (NGOs), state, and federal institutions played pivotal roles in the pandemic response. While wholesale markets decreased significantly, opportunities for farmers who were able to deftly pivot to direct and on-line marketing increased as demand for low touch, locally grown produce skyrocketed. Organizations such as CAFF and Kitchen Table Advisors (KTA) implemented on-line training to help family farmers adapt to the demands of switching to digital platforms with required safety measures. The United States Department of Agriculture (USDA) supported a program from May 2020 to May 2021 called "Farmers to Families" that provided funding for farms to produce food boxes for local communities, especially schools, food banks, and farmers markets (USDA, 2020a; USDA-AMS, 2020). During the first round, with the business, marketing and networking assistance of California-based NGOs such as Fresh Approach and KTA, many smaller farms participated in USDA programs, including previously excluded socially disadvantaged farmers (Fresh Approach, 2020). The USDA defines a socially disadvantaged farmer or rancher as "a farmer or rancher who has been subjected to racial or ethnic prejudices because of their identity as a member of a group without regard to their individual qualities. Those groups include African Americans, American Indians or Alaskan natives, Hispanics, and Asians or Pacific Islanders" (USDA, 2020b). During the second round, however, many organic farmers became ineligible for USDA programs that required Good Agricultural Practices (GAP) certification, which prohibits common practices of organic farming such as wildlife conservation and on-farm composting, and further lacked the expertise and capital to fund the GAP verification process (Bitker, 2020; interviews).

The USDA also implemented three rounds of the Coronavirus Food Assistance Program (CFAP) to provide pandemic assistance for producers in 2020 who faced market disruptions (USDA, 2020b). The Paycheck Protection Program (PPP) was an important US Small Business Administration (SBA) loan that helped farms keep their workforce employed during the pandemic (NSAC, 2020). The American Rescue Plan Act of 2021, signed into law by President Biden on March 11, 2021, allocates $1.9 trillion to COVID-19 relief measures, with an estimated $10.4 billion designated to strengthen the agricultural and food supply chain (see **Supplementary B** for more detail). A designated $4 billion will be used to provide debt forgiveness for socially disadvantaged farmers.

ARPA provided funding for the extension of federal programs such as Pandemic-EBT, PPP, and CFAP. Enrollment in CalFresh (food stamps) increased by 25% between January 2020 and June 2020 with 2.6 million households (CalFresh Data Dashboard). In California, Governor Gavin Newsom distributed $75 million in state funds, with an additional philanthropic effort to raise $50 million in private donations, providing cash relief assistance for undocumented individuals, many who are farmworkers. Socially disadvantaged/non-English speaking farmers experienced greater losses when their traditional markets closed (wholesales, farm stands). Many organizations made it their goal to close the information and linguistic gap, such as CAFF, Kitchen Table Advisors, and Fresh Approach, as well as the CDFA Farmer Equity Program by translating easy to understand information into Spanish, and offering webinars with simultaneous translation (CDFA, 2020; Bacon, 2021; CAFF, 2021). A large study by the California Institute for Rural Studies (CIRS) showed disproportionate economic burdens and household and community-level suffering and stress as compared to the overall population. It also revealed poor access to adequate healthcare, partially mitigated by local clinics, highlighting severe social and economic inequalities within the California food system leading to heightened food insecurity and health risks for farmworkers and their families during the pandemic (CIRS, 2021; Committee on Agriculture, 2021).

2. Europe/Norway

In the European Union (EU), three main types of policies were implemented in the agricultural sector in response to the pandemic (OECD, 2021a,b,c): (i) flexibility extended to implementation of Common Agricultural Policy (CAP) regulations, (ii) exceptional market measures, and (iii) direct support to farmers and rural areas. Policy packages directed toward the most affected sectors were made by each individual Member State based on their own specific circumstances, as long as they complied with the EU's state aid rules and did not distort competition within the EU (OECD, 2017). Various measures directed to the functioning of the food supply chains were implemented in the different Member States as they were recognized as essential services, e.g., trade in food products was facilitated through green corridors and restrictions on people's movement were alleviated. Further, to secure recruitment of agricultural labor, different measures were put in place in Member States, e.g., through schemes encouraging workers laid off in other sectors or students to temporarily work in the agri-food sector. For instance, the Czech Republic set up platforms to connect the supply and demand of seasonal workers, and eased processing of seasonal visas for the sectors (OECD, 2021c). The reduced availability of imported food gave a growth in sales primarily serviced by small (or mid-size) farms, food, and beverage companies. This has left local food producers uniquely affected, and perhaps, well-positioned to reinforce or grow their place in the portfolio of food offerings and markets (Lusk and Anderson, 2020). Pandemic response policies directed toward consumers also had an impact on producers of agri-food products. Income losses and economic uncertainties, together with restrictions for restaurants and other away-from-home food suppliers, generated changes in food demand among consumers which the industry needed to cope with. Many customers turned to delivery services and e-commerce, putting a pressure on farmers and producers to adapt to these services and change their value-chains (OECD, 2021c).

Norway is not a member of the EU but is largely influenced by EU policy through the EEA agreement between the EU Member States and the EFTA countries Norway, Iceland and Liechtenstein. Norway has implemented several measures in response to the pandemic, many of which are relevant to the agricultural sector which was designated as a critical sector early on (see **Supplementary C** for an overview of schemes). Most of the measures that were implemented are general and apply both to full-time and part-time farmers. Among these are government provided economic stimulus packages to businesses in general to mitigate the long-term effects of the pandemic, the so-called "corona package" [(Ministry of Finance, Norway, 2020)]. Here, one element is aimed at producers who experienced substantial cost increases related to labor, infection control regulations, and other factors. A second element is aimed at livestock farmers who experienced a sharp increase in the price of feed over a short period of time. Support was given to those farmers who were unable to carry out their activities due to the lack of seasonal workers, for example, a temporary scheme provided incentives for laid-off workers to take up jobs in agriculture; Norwegian workers would keep 50% of their unemployment benefits if they took up work in the sector. As such, the agriculture sector was the only sector that had a rise in employment so far in this pandemic (Holgersen et al., 2020). Further, farmers who were unable to harvest in 2020 due to the lack of workers were eligible for payments under the crop insurance compensation scheme. Farmers producing local and high-end products for restaurants struggled to make ends meet. Farmers and farm workers with small children initially had reduced capacity to run their farms when they also had to take care of their children due to lock-downs of schools. However, early in the pandemic farmers were classified as critical workers, and kindergartens and schools for their children under the age of 12 were reopened during periods of full lock-down.

3. China/Kunshan

China was the first country in the world to battle the pandemic, with person-to-person transmission of the coronavirus nationwide in January 2020 (Wu and McGoogan, 2020). During the early stages China faced a rapidly developing food supply shortage as transportation disruption resulted in a large amount of overstocked perishable products, especially poultry, meat, and vegetables (Pu and Zhong, 2020). In February 2020, when virus containment measures were in effect across most provinces in China, food prices had grown by 22% compared to February 2019, especially for perishable produce (Reuters News, 2020). In rural China, where the food system consists of mostly subsistence farms, farmers encountered less disruption from the lockdowns because they mostly produce for home consumption and are not directly involved in the food supply chain. However, many subsistence farmers temporarily lost their main source of income, as they work as migrant workers in urban areas outside of seeding and harvest seasons. Most severely affected were the low-income migrant farm workers, who juggled the risk of failing to be self-sufficient at their home farms, and the reduction in income and inadequate governmental support.

Before the pandemic, the Government of China (GoC) had already created a series of national level risk-management strategies for its food system in preparation for natural disasters (Pu and Zhong, 2020), and these strategies have helped China to define the responsibilities of different levels of governments and coordinate efforts across the multi-level governance during the pandemic. Existing programs include the Cereal Bag Provincial Governor Responsibility Mechanism and the Food Basket Major Responsibility Mechanism that facilitate provincial governments to proactively intervene in food production and circulation during emergencies and require municipal governments to regulate food prices in their cities, respectively (Pu and Zhong, 2020). These preventive measures have helped China to quickly adapt to a food crisis mode during the pandemic in terms of resource allocation and responsibility distribution. The major additional policy responses of the GoC and private sector to the pandemic outbreak started immediately after the on-set at the end of Jan/beginning of Feb 2020 (see **Supplementary D** for more details). The top priority of the government's policy response was to resume agricultural production and ensure farmers' work by providing transportation and financial support and guiding local governments to prioritize essential small and medium-size enterprises. Special attention was given to agricultural enterprises that focused on inputs production, distribution, slaughtering, and products processing (Pan et al., 2020).

In response to overstocking issues and in order to protect rural households from falling into poverty (again), the GoC focused on improving the logistical and marketing channels for perishable agricultural products (Luo et al., 2020), as a means to ensure a steady flow of agricultural products to consumers, and as a way to prevent price increase and discontent within the general population as a result of lack of access to affordable foods. For instance, the Ministry of Transportation offered a "green channel" pass for truck drivers to help transport fresh produce and waived all toll fees. Logistics companies, farmer cooperatives, as well as e-commerce companies were organized to market agricultural products through the internet. For migrant workers, a "point-to-point" policy was implemented; "Notice on Doing a Good Job of "Point-to-Point" Service Guarantee for Returning to Work for Migrant Workers". Before trains and planes resumed operation, workers from other counties were transported together and directly to their working place in buses organized by the government. This increased the efficiency of work resumption and reduced the probability of cross infection, and as of March 6, 2020, 2.63 million migrant workers benefited through this policy (Pan et al., 2020).

To address labor shortages in farm production, the GoC differentiated the travel restrictions placed on municipalities based on the transmissibility of the virus and number of active cases. In areas deemed as low risk, enterprises and farms could fully resume production. At the same time, the agri-food system chain was targeted to provide more job opportunities and secure greater food supply at a local level where migrant workers faced travel restrictions. Local businesses, cooperatives, and family farms were encouraged to employ local workers. Counties were asked to encourage local enterprises to provide temporary and flexible job opportunities, build a communications platform between workers and businesses, and if necessary, create public service job opportunities to ensure local workers' employment (Pan et al., 2020). Migrant workers from the villages also had the opportunity to sell their farm products through new online sales platforms. For example, Pinduoduo, the largest agriculture-focused technology platform in mainland China, provided 500 million Yuan of special subsidies to purchase agricultural products at a price higher than the average market price (Luo et al., 2020; Zhan and Chen, 2021). E-commerce played a crucial role in helping the agricultural market to adjust to pandemic conditions and reform. Data from the Ministry of Commerce show that there was a 40% increase in total transactions online of agricultural products in the first half of 2020 (Jingdong Big Data Research Institute, 2020). Supported by national social media platforms with participation from government officials, celebrities, e-commerce promoters, and local farmers, various e-commerce platforms helped greatly in selling those agricultural products that had excess supply due to transportation restrictions. Furthermore, as lockdown measures led to a huge spike in demand for fresh groceries, e-commerce companies expanded the coverage of contactless delivery and pick-up options, similar to those observed in other countries (Zhan and Chen, 2021). The most popular e-commerce platform in China, Taobao, in coordination with Alibaba, set up a 1-billion-Yuan fund on February 12th, 2020, to help farmers throughout the supply chain: production, transportation, and marketing, referred to as the "Love and Help for Farmers Program", where farmers from eight provinces were able to sign up. In less than 40 days, 118,000 tons of fruits and vegetables were sold to consumers across China (Fei and Ni, 2020).

Impacts and Adaptive Responses of Farmers and Farm Organizations

1. The United States/California

In the United States, farms were considered "essential services" from the beginning of the pandemic so they were not subject to lockdowns. Most continued operating throughout the pandemic. For California the median age of the eight interviewed farmers was 54 years, ranging from 31 years to 83 years, with a 50/50 gender distribution of three men, three women, and two female-male pairs. Six were full-time and two were part-time farmers. The main negative impacts interviewed farmers reported were lost markets, lost income, and supply chain disruptions (**Figure 1**). Organization staff, referring to the larger number of farmers that they support, reported more widespread and severe impacts as compared to the sample

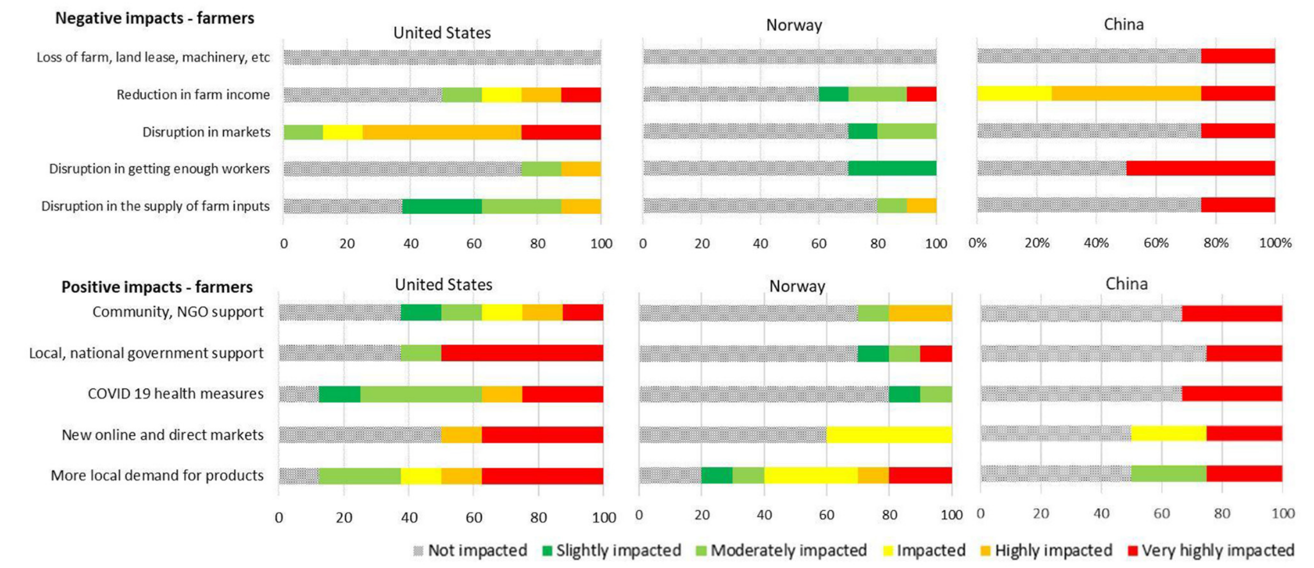

FIGURE 1 | Negative (top pains) and positive (bottom pains) impacts of the COVID-19 pandemic as perceived by the interviewed small-scale farmers and their farm operations, shown as percentage distributions over the six different impact categories (gray = not impacted, green = slightly impacted, light green = moderately impacted, yellow = impacted, orange = highly impacted, red = very highly impacted), in the United States, Norway and China (*n* = 23).

farmers, especially in lost income and market disruptions, as well as reduced labor due to sickness or fear of sickness (**Figure 2**). "*I've seen farmers making different decisions about what to grow, the timing, the size of their operations to be more efficient, dealing with having less labor and sales, those are things to manage risk*" (California government advisor). "*Missing a few markets for a small business is enough to put people into financial straits. These are incredibly small farms operating on razor thin profit margins, if they even have profit margins*" (NGO small farm advisor).

On lost markets we quote an advisor stating: "*...changing your entire business model takes time, takes effort, takes labor. Yes, they were able to pivot and pick up on the CSA boom, but at the same time to sell the same amount of produce they had to put in a lot more work and time*" (CAFF advisor). Concerning supply chain disruptions, a farmer reports: "*Product was delayed, materials were delayed because factories weren't up and running fully. We struggled a lot, especially early on when everyone got really scared*" (Mid-size vegetable farmer). Further, a support organization representative states: "*I think it's important to distinguish between what the market was doing and what income was doing, and where the fault lay... demand may be spiking but their income is not changing, and it's beyond their control due to limitations in supply chain and processing to respond to increased demand in grocery stores" (*UC Extension). On labor (deficit) a farmer responds: "*Labor was a problem in vegetables. It's a problem because we couldn't count on the people who used to help out*" (Small vegetable farmer). And on labor surplus a farmer reports: "*A lot of people were out of work, a lot of field guys, guys that worked in construction lost their jobs, so they came back to pick fruit because I have always left the door open...* " (Mid-size fruit farmer).

Many fruit and vegetable farmers, including those in the study sample, adapted their production, labor and marketing strategies quickly to mitigate pandemic-related closures and fluctuations and take advantage of a surge in direct and on-line consumer demand (**Figure 1**). Several NGOs (e.g., CAFF, KTA, Fresh Approach—see policy section above) were key for linking farmers with government programs aimed at supplying emergency food relief during the pandemic, partially compensating for the loss of other markets. A mid-size fruit farmer stated that: "*With COVID-19 people wanted low interaction shopping, direct market/delivery. We have a CSA program and e-commerce, and huge demand rose for those programs. 1500 CSA members compared to 600 last winter (maybe lower).*" With the help of Fresh Approach, this farm received a first-round grant from the USDA to participate in the 'Farmers to Families' program, supplying top quality organic produce to nearby schools and food banks. Several also applied and received payroll protection grants and funding from other support programs. As a result, only half of the study farmers experienced lost income, and only for a relatively short time (**Figure 1**). The nut farmers lost income from declining prices due to export market disruptions, especially to India and China, but partially made up the difference with their organic nuts that continued to sell well in the domestic market. A cannabis farmer interviewed remarked on how the price of his commodity increased by 10% and he was able to easily sell the whole crop at a high price, resulting in a good income year. Both the farmers and the organizations reported unprecedented cooperation among farmers, consumers, government and NGOs to help farmers weather the storm. "*It's been very rewarding to be a part of this very broad 'all hands on deck' effort to help the agriculture community weather this crisis.... and to see how many farms and ranches have navigated the waters on their own ... Just a tremendous amount*

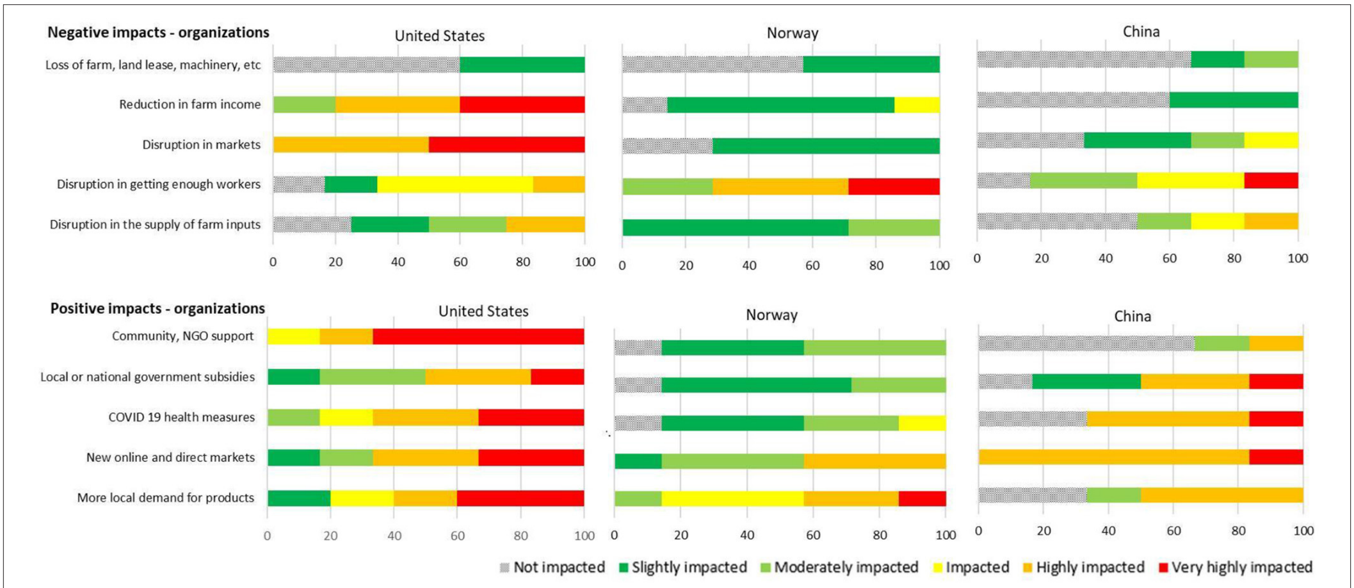

FIGURE 2 | Negative (top pains) and positive (bottom pains) impacts of the COVID-19 pandemic as perceived by interviewed support organizations on the farmers they serve or represent, shown as percentage distributions over the six different impact categories (gray = not impacted, green = slightly impacted, light green = moderately impacted, yellow = impacted, orange = highly impacted, red = very highly impacted), in the United States, Norway and China (n = 19).

of energy has been poured into the crisis response. I hope we can be a part of institutionalizing what good has come out of this so that it doesn't just sink back into the ground, like water after a short rain." (UC County Extension Officer). "*I don't know, but to the degree that there hasn't been more negative impacts on farmers to the point of having to sell their farms, is a combination between their own nimbleness and adaptation and government programs. Both were required.*" (CAFF staff member).

Not all farmers, however, had the same access to support: "*... for socially disadvantaged farmers and ranchers I'd say particularly for those who do not speak English as a first language, they had an extreme level of disruption earlier on primarily because they market mostly to either a wholesaler or an institutional market or farmers markets and they did not have the same access to information and resources about how to pivot or change those markets in a pandemic*". As an example, an indigenous woman small-scale farmer reports: "*Regarding the coronavirus, the real truth is that I don't look for help, someone like me, I only read a little Spanish, no English, I've heard about programs...but no, nothing, still I feel fortunate.*" In her case, the owner of the land she leases took an interest in her well-being at the outset of the pandemic and together they designed a website to offer excess produce through a Bay Area-based CSA. An emergency relief fund was created and funded by six support organizations to help fill this gap, distributing nearly one million $ in funds to 80 Black, Indigenous and People of Color (BIPOC) farmers during 2020 (BIPOC Steward of Land Relief Fund).

The post-pandemic future of e-commerce and direct marketing to consumers and needy families as a continued positive impact for small, medium and organic farmers is very much in question, as government programs terminate or shift to the advantage of large corporate farms (Bitker, 2020), and consumers decide to continue, reduce or halt their CSA subscriptions. Highly efficient corporations like Safeway, Amazon Fresh and Walmart will likely continue to dominate the e-commerce space, while the participation of small and medium farmers producing local foods for consumers of all income levels will depend upon continued lobbying by advocates, government support, farmer nimbleness, and consumer loyalty. "*At the beginning, yes, unfortunately it didn't last through the whole year. It only was at the beginning when there was nobody else open, and there was no produce in Safeway. It was very good. Unfortunately, it didn't sustain.*" (Small vegetable and fruit farmer). "*It's a very political, and unfortunate, reason for why it ended. ....we had a strong application—I mean we distributed so much local organic produce to our community. ...but when the USDA announced who they chose for their second round it was very clear they awarded the next contract round to huge distribution companies, like Cisco...They wanted to prioritize boxes that had meat and dairy in them. So yeah, for the second round of the grant, there were no small farmers*" (Mid-size fruit farmer).

2. Norway/Vestland

For Norway the median age of the 10 interviewed farmers was 53 years, with a 50/50 gender distribution. Seven of them were full-time farmers and three part-time farmers (30-50%). Most of interviewed the farmers, 60%, reported no impact or only slight impact on their farm operations over the course of the pandemic, and none had been severely impacted, as one of the farmers noted; "*I have experienced mostly positive impacts,* *as negative impacts are not noticeable on such a small-scale and diversified farm operation as mine*" (Farmer 1). Negative impacts were very limited; 70% of the farmers experienced no negative impacts or only slight negative impacts (**Figure 1**). None experienced loss of their farm, farmland, land lease, machinery or other property, and only one farmer was severely impacted by a reduction in farm income. Disruptions in the supply chain were also very limited. Lost markets were noted by several of the respondents. "*The farm restaurant has been negatively impacted, especially during the 2020 summer with max. 20 guests allowed, compared to the usual 50-60. The constant search for solutions and improvements has had a psychological impact. Cancellations, uncertainty, disappointment.*" (Farmer 6). Most of the farmers commented on the uncertainty; "*There has been more uncertainty, poor predictability and difficulties related to planning, and the psychological aspect is most prominent, not knowing if the customer base disappears. For example, the slaughterhouse was uncertain about delivery for a short period during the lockdown. Farming costs are high anyways, hence also my product prices, but can struggling restaurants afford to pay? To me this is an ethical dilemma as I have a sense of solidarity with my customers*". (Farmer 1).

In contrast, there were more positive impacts of the pandemic reported by the farmers. For example, 80% of the respondents saw an increase in the demand for locally produced foods, and 40% saw an increase in the use of new online and/or direct markets. Only 30% received government support. "*I noticed societal change in attitudes and interest in food origins, self-sufficiency, and other food matters. More people were helping each other in the community too, and there was a societal change in attitudes—the status of Norwegian agriculture has improved*" (Farmer 2). "*Private customers have become more interested in local food, and I have more direct inquiries (without active marketing), increased demand, and increased sales*" (Farmer 1). "*We experienced more sales through other channels than usual. We saw an increase in dairy demand and sales and a higher demand for Norwegian vs imported produce in general. We increased our direct sales and got compensated by increased overall demand through the cooperative.*" (Farmer 6). Many reported on impacts on work life due to lockdowns and restrictions; "*I have less vacation, but more time working from home (other jobs), and this is an advantage when you have livestock*" (Farmer 2). "*The pandemic has given me more time at home, and I get more work done. Fewer visitors mean less time 'wasted' on visits. I have increased sales, so I see only positive impacts*" (Farmer 4). However, some farmers did not notice much difference; "*Not much has changed; I have mostly worked like before. Only a bit more washing etc.*" (Farmer 7).

Most of the farmers had made only minor adaptations as they were not very impacted. One farmer reports; "*We have experienced slightly lower production due to the uncertainty in the restaurant market but we have high flexibility because of multiple income sources, so not very vulnerable. We are awaiting the situation and seeing how it develops. The waiting strategy is only possible due to other income sources*" (Farmer 1). Another farmer reports: "*We've not had to adapt much—we're used to fixing things ourselves. Small-scale farming and self-sufficiency are an advantage in a pandemic because it makes you much less vulnerable than the rest of the society*" (Farmer 2). Several farmers used social media more extensively in promoting their farm operation; "*From early in the pandemic (March 2020), I made a change in my professional social media activity—from occasional to daily updates (Instagram), focused on storytelling and sharing everyday life—marketing and entertainment value for others, as well as positive social value for us*" (Farmer 1).

Forty percent of the farmers had not received any form of support while the rest had received various types of limited support, like online courses and workshops arranged by various organizations, networks and labor unions, to develop professionally or provide professional support. The Farmers Union ("Norges Bondelag"), with 62 000 members and 500 local branches around Norway, helped with competence development and social needs. Norwegian Agricultural Counseling ("Norsk landbruksrådgivning"), with 24,000 members and 330 employees, provided courses, webinars, and professional development online. Cooperatives like "Prior" and the Norwegian Food Safety Authority provided professional support. Networks, such as Food Arena ("MatArena"), a network to inspire, develop and connect actors in sustainable local food production, played an important motivational role. The government was identified by 70% of the farmers to be most important in supporting farmers, along with NGOs, the local community and other farmers, and agricultural corporations. However, farmers noted "*The Norwegian compensation model is suitable for large operations; small farms don't 'fit' in the system. You also need an accountant to write applications, and this is not economically sustainable for small operations.*" (Farmer 6). "*Large-scale operations are more affected economically by the pandemic but can get more governmental financial support.*" (Farmer 2). Many commented on positive experiences with community support, "*Other farmers helped with labor during intense and critical parts of the season. The municipality also helped to some extent—as a conversation partner and bureaucratic support.*" (Farmer 2). "*Neighbors helped both socially and economically—we helped each other like back in the old days. You step across the fence and help your neighbor. That's why we have a different experience with the pandemic in rural areas than in urban areas—people are less psychologically affected in the countryside.*" (Farmer 10). "*The cooperatives ('Samvirkelagene') are important—their commitment to receive agricultural products anywhere in the country (in contrast to private enterprises) has proven robust during the pandemic* (Farmer 2).

In Norway, farmer organizations reported on slightly more negative impacts to the farming community than reflected in the responses from the interviewed farmers. Here, as in Kunshan and California, disruption of getting enough farm workers was reported as the biggest negative impact, with disruption in the supply of farm inputs to a lesser extent (**Figure 2**). There have been major challenges related to labor supply in the spring and summer of 2021 for vegetable and fruit growers and a good yield year resulted in a lot of waste. On the positive side, there were also more positive impacts than reported by the farmers themselves (**Figure 2**). Foremost, increased local demand for agricultural produce was noted. In particular, there has been an increased demand for locally produced meats in new marketplaces, but also increased production costs for these products. The dairy farmers increased their returns in 2021. Also, a boost in online and direct marketplaces, like home- or local delivery points, like the "REKO-ring", were registered. 'REKO' stands for 'REttferdig KOnsum' (fair consumption) and was founded in Finland by Thomas Snellman in 2013. The first REKO ring in Norway was established in 2017 and as of Oct 2020, there were 120 rings scattered around the country serving about 500,000 customers and 500 producers, supported by the Norwegian Farmers' and Smallholders' Association ('Bonde og Småbrukarlaget'). The REKO-ring offers producers direct contact with potential customers *via* a digital meeting place. Customers pre-order and pre-pay items *via* the ring's Facebook page which are then delivered by the producer at the ring's announced delivery location, date and time, for example the IKEA parking lot on Thursday nights in Bergen.

3. China/Kunshan

For China, the median age of the four interviewed farmworkers at Yue Feng Dao Farm (YFD) was 67 years, with a 50/50 gender distribution. They are all from the nearby village and grow food and raise animals for home consumption in addition to their employment at YFD. A fifth interview was carried out with the YFD marketing manager who lives in Shanghai. The interview information gathered at YFD overlaps with the pandemic- related disruptions seen throughout China in commercial farms. The major negative impacts were disruption in markets and/or supply chains, disruption in getting enough workers, and reduction or loss in farm income (**Figure 1**). "*In the early stage of the pandemic, farm workers were not permitted to come back out of concerns of pandemic prevention. To stop the crops and vegetables from completely rotting away, all employers and managers who remained in Kunshan were assigned to harvest.*" (YFD Marketing Supervisor). Due to the lockdowns, lost work and income were also the major impacts for YFD workers (**Figure 1**). All of the YFD employees/farm workers interviewed work at the farm primarily for additional income. YFD did not experience more severe impacts as it had an inventory of inputs and the agricultural technology bureau also offered supplies made scarce by the pandemic.

Farmworkers and the YFD marketing supervisor also spoke about the farm's sustainable farming philosophy and transmission of healthy farming ideas and practices to employees. Although organic products are very expensive for farm workers to afford, some have adopted practices such as less use of chemicals back in their own kitchen gardens. The pandemic set back the positive changes the farm workers were adopting. "*I experienced lockdowns in the early stages, so I didn't have my monthly income. But I have to feed my family. How can I afford sustainable agricultural products from YFD? And how can the sustainable planting mode supply the amount of food my family needs?*" (YFD farmworker). This quote points out the farm worker's perceived drawbacks of organic vegetable, rice and poultry production during crisis. On lost income, a representative of the Farmers Seed Network further explained: "*... remote communities that we have helped are mostly based on subsistence farming and remittances from migrant workers. Therefore, these communities are the source of migrant workers. When the pandemic started, the workers were unable to travel back to work after the Spring festival, so they lost some income at the beginning*". When asked what governmental support farm workers received during the worst period of the pandemic, whether national or local, they all replied in similar ways, commenting that they only got face masks and sanitary products rather than financial support: "*We don't know how the local government is compensating the loss of YFD, but we did not receive much support other than asking us to stay at home.*" (YFD farmworker).

There were also positive developments as farmers and managers adopted measures to reduce the losses under the pandemic (**Figures 1**, **2**). The new and expanded e-commerce and online platforms used by local farms showcased how local agricultural products might be the safest and most available option for residents under pandemic restrictions. Specifically, the pandemic opened up opportunities for YFD to invent new strategies to recoup its losses. According to the farm manager interviewed, "*YFD seized this opportunity to extend their market chain and unite three kinds of industries.*" In addition to sustainable farming, YFD diversified its agricultural products and value-added processing for e-commerce sales: "*We started to rely on social media platforms to do promotions. We use "wechat" mini programs to sell our organic products and use "wechat" public accounts to spread our sustainable farming philosophy.*" "wechat", an application that merges socializing and commerce functions, is now the most widely used app in China. Further, pandemic-related overseas travel restrictions gave rise to a surge of domestic traveling so YFD began to develop activities to attract tourists and offered educational immersive programs on sustainable agriculture. For example, "*We encouraged customers to learn how to prepare for, plant and harvest rice. By offering such an experience, customers will get to know the connotation of sustainable agriculture. It is a process of learning by doing.*" In this way, YFD successfully merged its long-term goal of educating the next generation to embrace sustainable agriculture with an income-generating opportunity associated with the rise in domestic travel and demand for extracurricular activities. With regards to direct markets, these quotes are illustrative: "*The Covid is actually a good thing for these small ecological farmers because everyone is cooking at home. For farmers that have a direct connection to their consumers, it's actually a good thing for them*" (Beijing Farmer's Market representative), and: "*... a turning point for family farms as people are willing to spend more money on vegetables during a crisis, thus starting to appreciate the quality of sustainable agriculture.*"

(Liangshumin Rural Reconstruction Center representative).

According to interviews with farmer support organizations, the largest negative impact was the disruption in getting enough workers (**Figure 2**). This was due to the block of transportation. When COVID-19 first spread massively in Feb 2020, it coincided with China's spring festival and many migrant workers went back to their hometowns in this period, hence migrant workers were not able to return to their workplaces after the holidays as they were asked to quarantine. However, this impact was relatively short-lived. For governmental-affiliated organizations like the YFD Farm and the Liangshumin Rural Reconstruction Centre, the local governments were able to respond quickly and opened up emergency channels to transport workers and farm products. For non-governmental organizations like Beijing Farmer's Market, they were able to find ways to get in touch with the farmers during lockdowns, for example driving to their village and getting the products themselves over the village gates. It was somewhat surprising that most of the respondents of the organizations indicated that the pandemic actually brought more positive than negative impacts, most importantly represented by the introduction of new online and direct marketing channels. Organizations like Beijing Farmer's Market and YFD Farm put their available products on online platforms like Wechat's mini program so that consumers could browse through and purchase directly. The products were either delivered to the consumer's house *via* logistics companies or were placed in a set location for consumers to pick up at a certain time. These methods were the safest and the most convenient ways for consumers to acquire their fruits and vegetables, thus boosting the total sales and income of the organizations.

Interviewed non-profit organizations did not receive any financial support from the government during the pandemic. Subsidies would mostly go to larger enterprises and governmental-affiliated organizations, according to the director of the Beijing Farmer's Market. Some individual farmers who are not government affiliated nor cooperate with bigger enterprises, were able to benefit from programs like Alibaba's 'One billion-Yuan fund' but were not direct beneficiaries of central government programs. According to China's Third National Agricultural Census, there are around 310 million people who work in China's agricultural sector, a majority of them 'scattered farmers' ("*Bulletin on Main…Census (No. 5)")*. The organizations suggested that the government could pay more attention to these farmers and release more targeted policies at a local level, as said by the director of Beijing Farmer's Market: "*You need to have a supporting market mechanism so that this farmer can connect with it when doing ecological agriculture. It's difficult now*".

DISCUSSION

Here we present a unique comparative and empirical based study, reflecting on pandemic-related impacts and responses on and by diversified farm operations, governments and non-governmental entities in three very different contexts, revealing fewer devastating impacts than anticipated in large part because of the breadth and depth of multi-level responses across sites. We are, however, aware that this represents just part of the global picture and that many other farms and communities (see e.g., Barrett et al., 2021; Lioutas and Charatsari, 2021; Lopez-Ridaura et al., 2021), especially in the global south (see e.g., Carreras et al., 2020; Morton, 2020; Gatto and Islam, 2021; Rasul et al., 2021), saw more severe impacts and fared worse, as evidenced by a growing literature (Abiral and Atalan-Helicke, 2020; Jámbor et al., 2020; Meuwissen et al., 2021). Our study is an important contribution for understanding both the vulnerabilities and resilience of different actors within the agri-food system during the global COVID-19 crisis, with clear policy recommendations toward a more inclusive, resilient and sustainable food system for the future.

Commonalities and Differences Across Countries; United States, Norway and China

We anticipated that—given the differences in socio-political systems, the pandemic impacts, and, especially, the policy responses, would mirror these differences, with impacts greatest in market-dominated US, and government playing a smaller role to mitigate negative impacts especially among smaller scale farmers, as compared to Norway and China where it was expected that government would step in to shore up the agri-food system. These expectations were largely met in Norway and China, where government policies to deal with curtailed transport, labor availability, lost markets, and input supply disruptions were quickly put into place to help agriculture, especially larger-scale farm enterprises and cooperatives. Surprising, however, was the extent to which the United States federal government also responded to the pandemic, albeit belatedly, with major infusions of money to support agriculture, early on making the decision to include all farms that employ workers in its signature Payroll Protection Plan, and under the Coronavirus Food Assistance Program, to fund farmers of all sizes to participate in USDA boxes (Bitker, 2020; USDA, 2020b). Thus, government policies were enormously important in all three cases in preventing more severe or long-lasting impacts on farmers, such as loss of land and equipment.

Nevertheless, the combined farmer and policy data reveal that in the three cases not all farmers benefited from the wide-ranging government programs, and that, benefits were hard to access for socially disadvantaged/non-English speaking farmers (Beatty et al., 2020; Committee on Agriculture, 2021; the US), small, diversified family farmers (Norway), and "scattered farmers" unassociated with government-backed enterprises (China). In their large survey study, the California Institute for Rural Studies revealed the disproportionate burden of COVID-19 illness and economic hardship on farmworkers of color in California (CIRS, 2021). For these farmers and farmworkers, to a significant extent the local community, non-governmental organizations, the private sector and concerned consumers stepped in to make up the difference. As such, a major finding is that across sites a constellation of actors worked in concert to help farmers and the agri-food sector weather the pandemic storm (see also Barrett et al., 2021; Meuwissen et al., 2021). In China, the major role of Alibaba's digital platform linking thousands of "scattered" farmers with excess produce to buyers throughout the country, facilitating marketing, transport and distribution was important. In Norway, direct markets and the Norwegian Farmers and Smallholders Association have been the driving force behind the fast growth of REKO-rings, digitally connecting small, diversified farmers with individual customers to make up for lost markets with restaurants and farmers markets. And in California, non- governmental organizations such as Fresh Approach, Community Alliance for Family Farmers, and Kitchen Table Advisors have focused on supporting socially disadvantaged farmers to gain access to the information and skills needed to participate in new opportunities (e.g., e-commerce, Farmers to Families), and generating emergency funds to tide them over periods of health and economic crises (Fresh Approach, 2020; Kitchen Table Advisors, 2021).

The strong policy response to the pandemic reinforced actions taken by farmers themselves to quickly adapt to an unprecedented situation, particularly regarding access to labor. As food providers they were considered "essential", however, the freedom to work as farmer-owners did not extend to foreign or migrant farmworkers in Norway and China, respectively, and the US, was also impacted, though less so, by closures at the Mexico border. Norway adopted policies to encourage Norwegian unemployed and laid-off workers to take the place of foreign labor barred from entering the country, while in China on-site managers and other personnel went into the fields to harvest until "point to point" policies provided emergency transport for migrant workers. In California, farmers reported adopting public health measures to prevent contagion (least successful in large, compact operations such as chicken and meat processing) and relying more on trusted long-term employees. Very small farms in all three countries relied intensely on non-paid family members and neighbors during the early months of the pandemic. This was an "all hands on deck" response to prevent more illness and keep food flowing to distribution points, near and far.

Also, strongly evident across the three sites, and somewhat surprising, across the three sites was the positive impact of the pandemic in expanding consumer demand and appreciation for healthy and locally grown food. Fruit and vegetable farmers, especially in California, quickly pivoted markets for their produce from closed restaurants and wholesalers to CSA boxes, farmers markets, and on-site stores, often pulling in a variety of products from other sources to add diversity and value to the boxes. As a result of initial support from USDA subsidies through Farmers to Families and intermediary organizations such as Fresh Approach and Kitchen Table Advisors, the benefits were more widely spread to include small and organic farmers, and needy families accessing boxes through their schools, food banks and churches. In Norway, although both pandemic-related negative and positive impacts were less frequent and dramatic, farmers had similar experiences with consumer interest in "food origins" and appreciation for Norwegian products above imports, where increased demand from cooperatives and direct markets more than made up for losses in sales. Both the policy data from China and the experience of YFD Farm show how farmers, consumers, government and the private sector cooperated *via* e-commerce platforms to ensure food distribution to urban centers across the country. In the case of YFD, the farm diversified its fresh and value-added products to meet increased Kunshan County/Shanghai demand for locally grown, high quality food, even at high prices, using the ubiquitous "wechat" social media platform to sell their organic products and promote their "sustainable farming philosophy".

Lessons Learned and Suggestions

Diversified, small and mid-size farms were able to survive and even prosper during the pandemic because of their "nimbleness" in quickly pivoting to direct marketing as demand increased. Organic farmers did especially well as healthy food during a health pandemic was at a premium in all three countries, as did cannabis and wine producers in the United States. In China, subsistence farmers linked to local seed supplies were able to plant where farmers reliant on purchased seed delayed their spring planting, linking seed access to resilience. Villages able to store their own seeds using traditional knowledge suffered less from supply chain disruptions.

The necessity of community solidarity together with institutional support for surviving a health crisis affecting the entire planet became apparent. In the United States, hard lessons were learned from the lack of solidarity at the federal level during 2020, to a significant extent made up for at local levels and by NGOs until federal policies kicked in. Institutional support in the EU and Norway was stable from the start because of the long-term social contract with a high degree of trust among citizens with their governments. In addition, active Farmers Unions, cooperatives and member organizations and networks mobilized to break farmer isolation and uncertainty during the pandemic. In China, the government pressured the private sector to mobilize its assets to support farmers and distribute food, and local governments helped smooth supply and labor disruptions, while consumer-driven food e-commerce exploded around urban centers as a result of the lockdowns. Non-governmental organizations played a minor role in China, however, groups like the Farmers Seed Network and Beijing Farmers Market had been working for a long time on behalf of sustainable small farms and this support proved crucial for some of these unorganized or "scattered" farmers during the early months of the pandemic.

The big question remains as to whether these positive lessons will endure after the pandemic is over. Below we summarize the main categories of suggestions for building a more socially, ecologically and economically resilient agri-food system post-pandemic, bringing together responses from the three sites.

Diversify Markets

Nearly all farmers and support organizations concur that diversified crops and markets are essential for coping with shocks like the global health pandemic, and similarly with the weather shocks they face with increasing frequency. With the pandemic, markets were hit directly, so farmers able to pivot quickly to direct marketing did relatively well, and farmers with a diversity of fresh and processed products to offer sheltering-at-home consumers did even better. In addition, several farmers benefited from a break in perceived unfair competition with imported food, especially from Mexico in the case of California, and other EU countries in the case of Norway. Even YFD Farm benefited from closed regional borders adding a new source of local tourism income. Finally, farmers noted that in times of crisis, and reduced demand, more markets are needed for second quality produce. Several of the policies sustained during the pandemic address these marketing issues and could be kept in place as stable support for small and mid-size farms, especially organic farmers that typically incur higher costs of production: (1) on-going government funding for fresh produce farmers to supply local foods to needy families year-round, with a sizeable proportion of contracts going to small and organic farmers; (2) public support for organizations, such as Fresh Approach, Norwegian Farmers' and Smallholders' Association ('Bonde og Småbrukar-laget'), and Beijing Farmers Market, among many others, as partners for connecting and aggregating produce from smaller farmers to supply a range of customers; (3) place tariffs on imported foods from countries with lower environmental, labor and food safety standards to bring up prices to cover the costs of sustainably grown foods; and (4) fund research and training through such organizations as Farmers Seed Network and CAFF to build a more diversified agri-food system.

Retain Positive Changes in Social Norms

This global pandemic put a spotlight on peoples' essential connections to food and food providers while lockdown restrictions increased demand for locally produced foods that were perceived as safer and more readily available. Further, in all three contexts, although less so in China where e-commerce of processed foods is highly popular in urban areas, sheltering-in-place led to renewed interest in home cooking and family mealtime, particularly among affluent households. Farmers involved in direct marketing perceive this as a positive change in social norms that they hope will continue post-pandemic. In Norway, most farmers identified the need for continued food knowledge promotion amongst consumers. In California, farmers are cautiously optimistic that consumers will continue to appreciate locally grown food. Similarly, farmers and organizations referred to a positive cultural shift from the individual to the collective. One example was the partnering among farmers to add products to boxes to add more variety and value for consumers. Another was the wide sharing of information through webinars and social media on accessing personal protection equipment, new markets, and government and emergency funding in a spirit of solidarity more than competition. In Norway, communities re-kindled some of the traditional social structures of helping each other, and society supported farmers as essential workers by keeping their schools and kindergartens open during lockdown.

Prioritize Socially Disadvantaged and Small to Midsize Farmers

Whereas this study has highlighted the resilience of many small and mid-size farmers in a global health pandemic, supported by multiple levels of institutions, the findings also indicate inequities in impacts, leaning more negative than positive for immigrant farmers (California) and "scattered" subsistence farmers (China) lacking adequate access to information, funding and alternative markets. In Norway, however, even small semi-subsistence farmers did not fare badly because of government subsidies and other sources of income. Negative impacts were minimized where NGOs and selected government programs actively targeted socially disadvantaged farmers, but only to an extent. Furthermore, farmworkers across the three sites faced serious negative impacts. As a result, one of the key recommendations for "building back better" post-pandemic is to prioritize socially disadvantaged farmers and farmworker conditions, however these may be defined locally. Specifically, in California, respondents are eager for programs to continue that included small, organic and immigrant farmers, such as Farmers to Families Round 1, and for NGOs operating on a shoestring to be recognized for their immense importance during the pandemic with more sustainable financial support. They urge provisions in the 2023 Farm Bill that prioritize new, beginning and historically disadvantaged farmers, building their capacities to weather future crises. In both California and Norway, farmers recommend relaxation of regulatory barriers, such as the Good Agricultural Practices (GAP) certification requirement on USDA boxes, which discriminate against organic practices. Further, the pandemic revealed major breakdowns in large food processing capacity, highlighting the need for more local processing, especially in meat and dairy, currently stymied by regulatory and capital requirements (Altieri and Nicholls, 2020; Hobbs, 2020; Lioutas and Charatsari, 2021).

In Norway, the progressive social contract between citizens and their government is nonetheless focused on large operations, and consumers rely heavily on cheaper imported food. Also in China, pandemic policies favored larger private and government-affiliated enterprises, with millions of "scattered" subsistence farmers and migrant workers left to fend for themselves during lockdowns. Several organizations recommended that in the future more attention be paid to these farmers with targeted policies on a local level. Village farmers that did better during the pandemic were those who lived in self-reliant communities, sharing seeds and other inputs, and marketing products among themselves, a long-term resilience strategy supported by the Farmers Seed Network.

"Hybrid" Agri-Food System?

In addition to the country-specific lessons learned from the pandemic, this study has enabled an examination of what we can learn from each other in terms of effective responses to a major crisis. For instance, whereas the European Union/Norway and China had a unified rapid response to the pandemic to prevent its spread and worsening health and economic impacts, the United States' federal response was delayed leaving much of the heavy lifting to individual states with heavy costs in lives and economic harm. China was able to quickly mobilize its government apparatus, private sector and citizens to distribute food to urban areas throughout the country, and to favor farm products from badly hit localities such as Hubei Province, minimizing food insecurity. In the United States, high unemployment and delays in getting cash and food stamps to needy families resulted in huge lines at food banks, continuing at a more modest level into the third year of the pandemic. Norwegians prevented such impacts through continued employment guarantees and support to handle lost workers and output in the farm sector, combined with community solidarity, farmers' unions and well-functioning cooperatives. In the United States, and California in particular, despite and partially because of the federal delays, there was a spectacular non-governmental response to the market and supply disruptions—both by farmers and support organizations, reducing harm to small commercial farms and socially disadvantaged farmers and farmworkers. These crisis-driven innovations were less apparent in Europe and China. In the end, the United States government did not let market-driven forces go unchecked, providing significant relief by the second year of the pandemic. Given these major strengths and weaknesses across three very different societies, it is interesting to contemplate building a "hybrid" crisis response structure that takes the best from each system. Indeed, this comparative study suggests a strong need for such an exercise by policymakers, NGOs and citizens across the world in their deliberations and planning for the next global crisis.

CONCLUSIONS

This paper presents a novel assessment of impacts and adaptive responses to the COVID-19 pandemic in diversified farming systems in the United States/California, EU/Norway and China. We show commonalities for several of the adaptive responses despite very distinct socio-political systems, most importantly:

- Sharp rise in e-commerce;
- Increased direct and diversified markets to consumers;
- Changes in social norms toward collaboration and re-kindling of community traditions;
- Crucial designation of farmers and farmworkers as "essential";
- Crucial government emergency and recovery support; and
- Complementary training and logistics support by NGOs and/or the private sector to farmers where government support was lacking.

Overall, different actors responded in manifold new ways, which in concert resulted in the resilience reported above. Examples include the use of new sources of labor, new sanitary measures, innovative adaptations to shifts in consumer demand, and the expansion of food deliveries at home (Lusk and Anderson, 2020; Wieck et al., 2021), just to mention a few. How to leverage Internet-enabled food supply and distribution for enhanced food system resilience deserves further attention. A key question is how online grocery-shopping will evolve after the pandemic. Will this have ramifications on the infrastructure of the supply chain, food safety and public health? Will the large corporate e-commerce platforms and food distribution networks dominate the market and squeeze out individual farmers, or will there be a continued demand for locally and sustainably produced foods? Scaling up this study to include more farmers and support organizations spanning the whole spectrum of the food system would allow for a wider scope as well as more in-depth analysis and knowledge generation on the evolution of mechanisms and adaptive responses in the wake of disaster.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Office for the Protection of Human Subjects at UC Berkeley and Duke Kunshan University, and by the Norwegian Center for Research Data (NSD). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

IM and RM designed the overall project, wrote the grant proposal for funding, provided guidance on methods, analysis, and our collaborative process. IM, RM, KM, SW, SZ, and RC collected, analyzed, and summarized qualitative data. HW, RM, KM, SW, SZ, RC, and KF contributed to policy mapping. IM and RM led writing and revision. HW and KF contributed to writing and editing. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

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REFERENCES

Abiral, B., and Atalan-Helicke, N. (2020). Trusting food supply chains during the pandemic: reflections from Turkey and the U.S. *Food Foodways*. 28, 226–236. doi: 10.1080/07409710.2020.1790147

Adger, N. A., Arnell, N. W., and Tompkins, E. L. (2005). Successful adaptation to climate change across scales. *Global Environ. Scales*. 15, 77–86. doi: 10.1016/j.gloenvcha.2004.12.005

Altieri, M., Nicholls-Estrada, C. I., Henao-Salazar, A., Galvis-Marta?nez, A. C., and Rog, P. (2015). *Didactic Toolkit for Assessment of Resilient Farming*

Systems. Third World Network, Penang, Malaysia, Sociedad Cienta?fica Latinoamericana de Agroecolog?a (SOCLA), Berkeley, California, USA, and REDAGRES, Berkeley, California, USA.

Altieri, M. A., and Nicholls, C. I. (2020). Agroecology and the emergence of a post COVID-19 agriculture. *Agric. Hum. Values*. 37, 525–526. doi: 10.1007/s10460-020-10043-7

Bacon, C. (2021). *A Food Justice Response to COVID-19*. Santa Clara University. Available online at: https://www.scu.edu/ej/events/ej-and-cg-initiative-news/a-food-justice-response-to-COVID-19/

Bacon, C. M., Getz, C., Kraus, S., Montenegro, M., and Holland, K. (2012). The social dimensions of sustainability and change in diversified farming systems. *Ecol. Soc.* 17, 41. doi: 10.5751/ES-05226-170441

Barrett, C. B., Fanzo, J., Herrero, M., Mason-D'Croz, D., Mathys, A., Thornton, P., et al. (2021). COVID-19 pandemic lessons for agri-food systems innovation. *Environ. Res. Lett*. 16, 101001. doi: 10.1088/1748-9326/ac25b9

Beatty, T., Hill, M. A., and Rutledge, Z. (2020). *COVID-19 and Farm Workers: Challenges Facing California Agriculture*. ARE Update 23, 2–4. University of California Giannini Foundation of Agricultural Economics

Bitker, J. (2020). Federal funding, lifeline for Bay Area farms, redirected to big corporations. *San Francisco Chronicle* (accessed October 20, 2020).

Bjørkhaug, H., and Richards, C. A. (2008). Multifunctional agriculture in policy and practice? A comparative analysis of Norway and Australia. *J. Rural Stud.* 24–1, 98–111. doi: 10.1016/j.jrurstud.2007.06.003

CAFF (2021). *California COVID-19 Responses and Resources for California Farmers*. Available online at: https://caff.org/covid19/

CalFresh Data Dashboard. Available online at: https://www.cdss.ca.gov/inforesources/data-portal/research-and-data/calfresh-data-dashboard

California Farm Bureau Federation (2020). Available online at: https://www.cfbf.com/wp-content/uploads/2020/05/2020-Coronavirus-farmer-survey-report.pdf

Carlisle, L., Montenegro de Wit, M., DeLonge, M. S., Calo, A., Getz, C., Munden-Doixon, K., et al. (2019). Securing the future of US agriculture: the case for investing in new entry sustainable farmers. *Elem. Sci. Anth.* 17. doi: 10.1525/elementa.356

Carreras, M., Saha, A., and Thompson, J. (2020). *Rapid Assessment of the Impact of COVID-19 on Food Systems and Rural Livelihoods in Sub-Saharan Africa. APRA COVID-19 Synthesis Report 2*.

CDFA (2020). *2020 Report to the California Legislature on the Farmer Equity Act*. California Department of Food and Agriculture

CIRS (2021). *Always Essential, Perpetually Disposable: California Farmworkers and the COVID-19 Pandemic. A Report on Phase Two of the COVID-19 Farmworker Study, prepared by Bonnie Bade, Sarah Ramirez and Dvera Saxton*. California Institute for Rural Studies.

Committee on Agriculture (2021). *INFORMATIONAL HEARING Wednesday, March 17, 9, 30. a.m. to 11:30 a.m. State Capitol, Room 4202 SUBJECT: Farmer Equity Act Assembly California Legislature*.

Congressional Research Service (2020). COVID-19: Supply Chain Disruptions in the U.S. Fruit and Vegetable Industry. In: *Brief*. Available online at: https://crsreports.congress.gov/product/pdf/R/R46348

Crowe, S., Cresswell, K., Robertson, A., Huby, G., and Avery, A. (2011). The case study approach. *BMC Med. Res. Methodol.* 11, 100. doi: 10.1186/1471-2288-11-100

Cutter, S. L., Barnes, L., and Berry, M. (2008). Community and regional resilience: perspectives from hazards, disasters, and emergency management. *Geography*. 1, 2301–2306.

DiCarlo, J., Epstein, K., Marsh, R., and Måren, I. E. (2018). Post-disaster agricultural transitions in Nepal. *AMBIO*. 47, 794–805. doi: 10.1007/s13280-018-1021-3

Du, Y., Park, A., and Wang, S. (2005). Migration and rural poverty in China. *J. Compar. Econ.* 33, 688–709. doi: 10.1016/j.jce.2005.09.001

Eklund, L., Persson, A., and Pilesjo, P. (2016). Cropland changes in times of conflict, reconstruction, and economic development in Iraqi Kurdistan. *Ambio*. 45, 78–88. doi: 10.1007/s13280-015-0686-0

Elias, M., and Marsh, R. (2019). Innovations in agricultural and food systems sustainability in California. *Case Stud. Environ.* 1–14. doi: 10.1525/cse.2019.002170

Epstein, K., DiCarlo, J., Marsh, R., Adhikari, B., Paudel, D., Ray, I., et al. (2018). Adaptation and recovery after the 2015 Nepal earthquakes: a smallholder household perspective. *Ecol. Soc*. 23, 29. doi: 10.5751/ES-09909-230129

Epstein, K., DiCarlo, J., Marsh, R., Ray, I., and Måren, I. E. (2017). *Coping Strategies of Smallholder Farming Communities after the 2015 Nepal Earthquake: Insights into Post-Disaster Resilience and Social–Ecological Change*. Case Studies in the Environment, University of California Press.

ERA Economics (2020). *Final Report: Economic Impacts of the COVID-19 Pandemic on California Agriculture*. ERA Economics LLC.

Fei, S., and Ni, J. (2020). *Local food systems and COVID-19: A look into China's responses. Food and Agriculture Organization of the United Nations*. Available online at: http://www.fao.org/in-action/food-for-cities-programme/news/detail/en/c/1270350/ (accessed January 20, 2021).

Folke, C. (2006). Resilience: the emergence of a perspective for social-ecological systems analyses. *Global Environ. Change*. 16, 253–267. doi: 10.1016/j.gloenvcha.2006.04.002

Folke, C., Biggs, R., Norström, A. V., Reyers, B., and Rockström, J. (2016). Social-ecological resilience and biosphere-based sustainability science. *Ecol. Soc.* 21, 41. doi: 10.5751/ES-08748-210341

Forbord, M., Bjørkhaug, H., and Burton, R. J. F. (2014). Drivers of change in Norwegian agricultural land control and the emergence of rental farming. *J. Rural Stud.* 33, 9e19. doi: 10.1016/j.jrurstud.2013.10.009

Fresh Approach (2020). *Farm Fresh Relief Program*. Available online at: https://www.farmfreshfoodrelief.org/about/

Gatto, M., and Islam, A. H. M. S. (2021). Impacts of COVID-19 on rural livelihoods in Bangladesh: Evidence using panel data. *PLoS ONE*. 16, e0259264. doi: 10.1371/journal.pone.0259264

Gautam, Y., and Andersen, P. (2016). Rural livelihood diversification and household well-being: Insight from Humla, Nepal. *J. Rural Stud*. 44, 239–249. doi: 10.1016/j.jrurstud.2016.02.001

Hazell, P., Poulton, C., Wiggins, S., and Dorward, A. (2010). The future of small farms: Trajectories and policy priorities. *World Develop.* 38, 1349–1361. doi: 10.1016/j.worlddev.2009.06.012

Hobbs, J. E. (2020). Food supply chains during the COVID-19 pandemic. *Can. J. Agric. Econ.* 68, 171–176. doi: 10.1111/cjag.12237

Holgersen, H., Jia, Z., and Svenkerud, S. (2020). *Labor Demand During the COVID-19 Crisis in Norway: Evidence from Vacancy Posting Data*. Available at SSRN 3663479

Holt-Giménez, E. (2002). Measuring farmers' agroecological resistance after Hurricane Mitch in Nicaragua: a case study in participatory, sustainable land management impact. *Agricult. Ecosyst. Environ.* 93, 87–105. doi: 10.1016/S0167-8809(02)00006-3

Iles, A., Graddy-Lovelace, G., Montenegro, M., and Galt, R. (2016). Agricultural systems: co-producing knowledge and food. In: *The Handbook of Science and Technology Studies*, 4th edition. U. Felt, R. Fouché, C. Miller, and L. Smith-Doerr, eds, Ch. 33. Cambridge, MA: MIT Press.

Iles, A., and Marsh, R. (2012). Nurturing diversified farming systems in industrialized countries: how public policy can contribute. *Ecol. Soc*. 17–42. doi: 10.5751/ES-05041-170442

IPBES (2019). *Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. IPBES Secretariat.

IPBES (2020). *Workshop Report on Biodiversity and Pandemics of the Intergovernmental Platform on Biodiversity and Ecosystem Services*. Daszak, P., das Neves, C., Amuasi, J., Hayman, D., Kuiken, T., Roche, B., Zambrana-Torrelio, C., Buss, P., Dundarova, H., Feferholtz, Y., Foldvari, G., Igbinosa, E., Junglen, S., Liu, Q., Suzan, G., Uhart, M., Wannous, C., Woolaston, K., Mosig Reidl, P., O'Brien, K., Pascual, U., Stoett, P., Li, H., Ngo, H. T., IPBES secretariat, Bonn, Germany.

IPCC (2019). *Special Report on Climate Change and Land*. Available online at: https://www.ipcc.ch/srccl/ (accessed December 7, 2021).

Jámbor, A., Czine, P., and Balogh, P. (2020). The Impact of the Coronavirus on Agriculture: First Evidence Based on Global Newspapers. *Sustainability*. 12, 4535. doi: 10.3390/su12114535

Jayne, T. S., Mather, D., and Mghenyi, E. (2010). Principal challenges confronting smallholder agriculture in Sub-Saharan Africa. *World Develop*. 38, 1384–1398. doi: 10.1016/j.worlddev.2010.06.002

Jingdong Big Data Research Institute (2020). *Online Agricultural Products Consumption Trend Report (with download) | Internet Data Information Network-199IT | Chinese Internet Data Research Information Center-199IT*. Available online at: http://www.199it.com/archives/1124282.html (accessed January 18 2022)

Kaland, P. E., Abrahamsen, A., Barlaup, B. T., Bjørge, L., Brattegard, T., Breistøl, A., et al. (2018). *Nordhordland Biosphere Reserve—UNESCO Application*. The Norwegian Environment Agency [Miljødirektoratet]. ISBN 978-82-8284-200-6.

Kitchen Table Advisors (2021). *2020–2021 Impact Report*. Available online at: https://www.kitchentableadvisors.org/

Klein, R. J. T., and Nicholls, R. J., and Thomalla,. F. (2003). Resilience to natural hazards: How useful is the concept? *Environ. Hazards*. 5, 35–45. doi: 10.1016/j.hazards.2004.02.001

Kremen, C., Iles, A., and Bacon, C. (2013). Diversified farming systems: an agroecological, systems-based alternative to modern industrial agriculture. *Ecol. Soc.* 17, 42. doi: 10.5751/ES-05103-170444

Kremen, C., and Merenlender, A. M. (2018). Landscapes that work for biodiversity and people. *Science*. 362, aau6020. doi: 10.1126/science.aau6020

Lin, B. (2011). Resilience in agriculture through crop diversification: adaptive management for environmental change. *BioScience*. 61, 183–93. doi: 10.1525/bio.2011.61.3.4

Lioutas, E. D., and Charatsari, C. (2021). Enhancing the ability of agriculture to cope with major crises or disasters: What the experience of COVID-19 teaches us. *Agricult. Syst.* 187, 103023. doi: 10.1016/j.agsy.2020.103023

Lopez-Ridaura, S., Sanders, A., Barba-Escotoa, L., Wiegel, J., Mayorga-Cortes, M., Gonzalez-Esquivel C., et al. (2021). Immediate impact of COVID-19 pandemic on farming systems in Central America and Mexico. *Agricult. Syst.* 192, 103178. doi: 10.1016/j.agsy.2021.103178

Luo, R., Liu, C., Gao, J., Wang, T., Zhi, H., Shi, P., et al. (2020). Impacts of the COVID-19 pandemic on rural poverty and policy responses in China. *J. Integr. Agricult.* 19, 2946–2964. doi: 10.1016/S2095-3119(20)63426-8

Lusk, J. and Anderson, J. D. (2020). *Economic Impacts of COVID-19 on Food and Agricultural Markets, Cast Commentary, Council for Agricultural Science and Technology (CAST), Ames IA*. Available online at: https://www.cast-science.org/publication/economic-impacts-of-COVID-19-on-food-and-agricultural-markets/

Marín, A., Gelcich, S., and Castilla, J. C. (2014). Ecosystem services and abrupt transformations in a coastal wetland social-ecological system: Tubul-Raqui after the 2010 Earthquake in Chile. *Ecol. Soc.* 19, 22. doi: 10.5751/ES-05633-190122

Meuwissen, M. P. M., Feindt, P. H. S. Y.,Paas, W., Termeer, K. J. A. M., Poortvliet, P. M., Peneva, M., et al. (2021). Impact of COVID-19 on farming systems in Europe through the lens of resilience thinking. *Agricult. Syst.* 191, 103152. doi: 10.1016/j.agsy.2021.103152

Ministry of Finance, Norway (2020). Prop 52 S (2019-2020). Endringer i statsbudsjettet 2020 under Kommunal- og moderniseringsdepartementet, Arbeids- og sosialdepartementet, Helse- og omsorgsdepartementet og Finansdepartementet (økonomiske tiltak i møte med virusutbruddet).

Morton, J. (2020). On the susceptibility and vulnerability of agricultural value chains to COVID-19. *World Develop.* 136, 105132. doi: 10.1016/j.worlddev.2020.105132

NSAC (2020). *More Money Now Available to Farmers Impacted by the Pandemic*. National Sustainable Agriculture

OECD (2017). *Evaluation of Agricultural Policy Reforms in the European Union: The Common Agricultural Policy 2014-20.* Paris: OECD Publishing.

OECD (2021a). *Policy brief Keep calm and carry on feeding: Agriculture and food policy responses to the COVID-19 crisis.*

OECD (2021b). *Agricultural Policy Monitoring and Evaluation 2021*. Addressing the Challenges Facing Food Systems.

OECD (2021c). *Developments in Agricultural Policy and Support, in Agricultural Policy Monitoring and Evaluation 2021: Addressing the Challenges Facing Food Systems.* Paris: OECD Publishing.

Pan, D., Yang, J., Zhou, G., and Kong, F. (2020). The influence of COVID-19 on agricultural economy and emergency mitigation measures in China: a text mining analysis. *PloS One.* 15, e0241167. doi: 10.1371/journal.pone.0241167

Petersen-Rockney, M., Baur, P., Guzman, A., Bender, S. F., Calo, A., Castillo, F., et al. (2021). Narrow and Brittle or Broad and Nimble? Comparing Adaptive Capacity in Simplifying and Diversifying Farming Systems. *Front. Sustain. Food Syst.* 5, 564900. doi: 10.3389/fsufs.2021.564900

Pu, M., and Zhong, Y. (2020). Rising concerns over agricultural production as COVID-19 spreads: Lessons from China. *Global Food Secur.* 26, 100409. doi: 10.1016/j.gfs.2020.100409

Rasul, G., Nepal, A. K., Hussain, A., Maharjan, A., Joshi, S., Lama, A., et al. (2021). Socio-Economic Implications of COVID-19 Pandemic in South Asia: Emerging Risks and Growing Challenges. *Front. Sociol.* 6, 629693. doi: 10.3389/fsoc.2021.629693

Reuters News (2020). Immediate Point of View: Food price surge supports China's CPI to maintain above 5% in February, falling oil prices intensify PPI deflationary pressure (updated version). Reuters. Available online at: https://www.reuters.com/article/instant-view-china-feb-inflation-0310-idCNKBS20X07X

Scheffer, M., and Carpenter, S. F. (2001). Catastrophic shifts in ecosystems. *Nature.* 413, 591–596. doi: 10.1038/35098000

Scheffer, M., Carpenter, S. R., Lenton, T. M., Bascompte, J., Brock, W., and Dakos, V. (2012). Anticipating critical transitions. *Science*. 338, 344–348. doi: 10.1126/science.1225244

Scheitrum, D. (2020). *Examining Agricultural Support and Subsidies in the U.S.* and Mexico. University of Arizona. Prepared for: Fresh Produce Association of the Americas.

Schumilas, T., and Scott, S. (2015). Characterizing alternative food networks in China. *Agricult. Human Values*. 32, 299–313. doi: 10.1007/s10460-014-9530-6

Shi, Y., Cheng, C., Lei, P., Wen, T., and Merrifield, C. (2011). Safe food, green food, good food: Chinese Community Supported Agriculture and the rising middle class. *Int. J. Agricult. Sustain.* 9, 551–558. doi: 10.1080/14735903.2011.619327

Shivakumar, M. V. K., Motha, R. P., and Das, H. P. (eds.). (2005). Impacts of natural disasters in agriculture, rangeland and forestry: an overview. In: *Natural Disasters and Extreme Events in Agriculture.* Berlin: Springer. doi: 10.1007/3-540-28307-2

Steffen, W., Persson, A., Deutsch, L., Zalasiewicz, J., Williams, M., Richardson, K., et al. (2011). The anthropocene: from global change to planetary stewardship. *Ambio*. 40, 739–761. doi: 10.1007/s13280-011-0185-x

Tendall, D. M., Joerin, J., Kopainsky, B., Edwards, P., Shreck, A., and Le, Q. B. (2015). Food system resilience: defining the concept. *Glob. Food Secur*. 6, 17–23. doi: 10.1016/j.gfs.2015.08.001

The Financial Times (2020). Available online at: https://www.ft.com/content/10d8f5e8-74eb-11ea-95fe-fcd274e920ca (accessed December 8, 2021).

UNESCO (2017). A New Roadmap for the Man and the Biosphere (MAB) Programme and its World Network of Biosphere Reserves. UNESCO.

USDA (2020a). *Announcement of Contract Awards for the Farmers to Families Food Box Program, Rounds 1* (accessed May 8, 2020).

USDA (2020b). *Coronavirus Food Assistance Program 1 Data*. United States Department of Agriculture. Available online at: https://www.farmers.gov/cfap1/data

USDA-AMS (2020). *USDA Farmers to Families Food Box*. United States Department of Agriculture—Agricultural Marketing Service, Washington, D.C., USA.

Valdés, A., and Foster, W. (2010). Reflections on the role of agriculture in pro-poor growth. *World Develop.* 38, 1362–1374. doi: 10.1016/j.worlddev.2010.06.003

Wieck, C., Dries, L., Martinez-Gomez, V., Kareem, O. I., Rudloff, B., Santeramo, F. G., et al. (2021). *European and Member State Policy Responses and Economic Impacts on Agri-Food Markets due to the COVID-19 Pandemic, IATRC Commissioned Paper 26, International Agricultural Trade Research Consortium, St Paul, MN*. Available online at: https://iatrc.umn.edu/european-and-member-state-policy-responses-and-economicimpacts-on-agri-food-markets-due-to-the-COVID-19-pandemic/

Woods, T., and Zare, M. (2021). *National Farm Market Impacts from Covid. Economic and Policy Update (21)*, vol. 4. Department of Agricultural Economics, University of Kentucky.

Wu, Z., and McGoogan, J. M. (2020). *Characteristics of and important lessons from the coronavirus disease 2019 (COVID-19) outbreak in China: summary* *of a report of 72 314 cases from the Chinese Center for Disease Control and Prevention*. *JAMA*. 323, 1239–1242. doi: 10.1001/jama.2020.2648

Zhan, Y., and Chen, K. (2021). Building Resilient Food System Amidst COVID-19: Responses and Lessons from China. *Agricult. Syst.* 190, 1–7. doi: 10.1016/j.agsy.2021.103102

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Changing Conditions for Local Food Actors to Operate Towards Agroecology During the COVID-19 Pandemic

Markus Frank[1,2]*, Brigitte Kaufmann[1,2], Mercedes Ejarque[3], María Guadalupe Lamaison[4], María Virginia Nessi[4] and Mariano Martin Amoroso[5,6]

[1] German Institute for Tropical and Subtropical Agriculture (DITSL), Witzenhausen, Germany, [2] Social Ecology of Tropical and Subtropical Land-Use Systems, Institute of Agricultural Sciences in the Tropics (Hans-Ruthenberg-Institute), University of Hohenheim, Stuttgart, Germany, [3] Instituto Nacional de Tecnología Agropecuaria (INTA), Instituto de Investigación y Desarrollo Tecnológico para la Agricultura Familiar, Región Patagonia, Plottier, Argentina, [4] Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Universidad de Buenos Aires, Instituto de Investigaciones Gino Germani (IIGG), Buenos Aires, Argentina, [5] Instituto de Investigaciones en Recursos Naturales, Universidad Nacional de Rio Negro, Agroecología y Desarrollo Rural (IRNAD), El Bolsón, Argentina, [6] Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), El Bolsón, Argentina

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Correspondence:
Markus Frank
m.frank@ditsl.org

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Given the novel character of disturbances caused by the pandemic in food systems, initial studies have been conducted to stress the reinforced urgent need for food systems' transformation toward sustainability. First assessments, conducted in the early months of the pandemic, found that local food actors responded to changing production and marketing conditions by implementing alternative practices under the umbrella of agroecology. However, given the unprecedented and dynamic character of the pandemic in regional situations, and related context-specific changes caused in food system actors' operations, case studies are needed to assess in more detail under which changing conditions food actors implemented alternative practices. Moreover, the maintenance of practices as conditions normalize, and food actors' transformative potential in relation to the principles of agroecology, need further assessment. In response to these emerging issues, we provide insights into our case study research conducted during 2021 in a local food system in Argentina. The aim of this research was to study how changing conditions triggered local food actors to (re-)frame their objectives and activities regarding marketing, and to assess the relevance of agroecological principles as a means of responding to changing conditions and to unfold longer-term transitions. We identified local producer shops ($n = 5$) and markets ($n = 4$) that were established or consolidated by self-organized producer groups (SOPGs) during the first months of the pandemic. Using semi-structured interviews with SOPG members ($n = 12$) and qualitative content analysis, we found that alternative practices were adopted in response to different changing conditions, and new needs and opportunities for producers and consumers brought about by the pandemic. Objectives pursued, and activities undertaken by the groups revealed reactive short-term mitigation strategies, and proactive longer-term transformative objectives. The relational analysis between practices and agroecological principles showed that the principles became important means of responding to changing conditions and to unfold longer-term transitions. The cases illustrate how local food actors operationalized agroecological principles, and in turn how principles can be used to investigate the nature and potentials of food actors' alternative practices, highlighting the relevance of agroecology to co-design sustainability transitions in local food systems and to mitigate possible future crisis.

Keywords: agroecological principles, agroecological transitions, shock-mitigation responses, transformative potential of local food actors, Argentina

INTRODUCTION

The COVID-19 pandemic and measures implemented by governments at the global level to manage the pandemic have caused a systemic crisis, affecting food systems' performance, and processes along global and local agri-food supply chains. Negative consequences for established global chains highlight weaknesses of prevalent food production, distribution and consumption practices, and threaten sustainable human development (van der Ploeg, 2020; Rivera-Ferre et al., 2021). Impacts caused by the pandemic unfold in multiple areas, and through complex interrelations between social, economic, ecological, and human health factors. A distinction is made between direct impacts (the virus on human health) and indirect impacts, as a consequence of measures implemented to control the pandemic or through the effect of fear in the population (UNICEF, 2020; Rivera-Ferre et al., 2021). In response to these impacts, actions have been taken by groups or individuals in society or governments to prevent, compensate for, or adapt to emerging changes. There are hints that local food actors have responded to the consequences and impacts by developing immediate decentralized collective strategies, and by implementing alternative practices under the umbrella of agroecology (Tittonell et al., 2021; Zollet et al., 2021). However, the particular changing conditions under which such practices have been implemented and what potentials they unfold within local food systems' sustainability transitions in time and in relation to the principles of agroecology (Wezel et al., 2020) remain to be further explored.

Given the novel character of the pandemic and induced disruptions in prevalent global food systems, studies have been conducted and expert opinions published to understand the new situations, to reveal impacts, and to stress the hitherto known and, through the pandemic, reinforced urgent need for a transformation of food systems toward sustainability (IAASTD, 2009; IPES Food, 2016; HLPE, 2019). The studies have focused on a wide range of phenomena associated with the diverse food system actors impacted, including farmers, processors, retailers, consumers, as well as regulatory and policy-making entities and wage workers involved in agri-food sectors. For instance, disruptions in supply chains were assessed with regard to decreasing food security (e.g., Savary et al., 2020; Workie et al., 2020), to impacts on different food supply chain components and commodity groups in developing countries (Vyas et al., 2021), to labor availability, food systems' connectivity and international trade (Stephens et al., 2020; van der Ploeg, 2020), and to increasing inequality experienced by small scale food producers (Paganini et al., 2020). A review by Béné (2020) shows that by June 2020, indirect impacts caused by lockdowns and mobility restrictions led to loss of income, purchase power, and in consequence to a decrease of food security for poorer segments of populations in low and middle income countries.

These suddenly arising and challenging impacts have pushed local food system actors to immediately respond to the changing conditions within their specific context of operation (Zollet et al., 2021; Frank and Amoroso, in press). Studies looking into such local responses were mainly conducted during the initial phase of the pandemic (March-June 2020), providing 'snapshots' of responses in the context of early lockdowns. For instance, studies on local and regional food systems in different countries around the globe, characterized by short supply chains and producer-consumer proximity, indicate high flexibility and adaptability of local actors to operate under changing conditions, by building on strong local relationships (Thilmany et al., 2020; Prosser et al., 2021), by taking advantage of (temporal) changes in consumption patterns (Lal, 2020; Bisoffi et al., 2021; Zollet et al., 2021), and by showing their growth potential (Nemes et al., 2021). In a cross-national study in the Latin American region, Tittonell et al. (2021) characterized initial responses of family farming and agroecology movements in the early months of the pandemic regarding their potential to mitigate threats toward food security. The study provides first indications of high resilience and potential for reconstruction of local actors in developing and implementing immediate strategies under lockdowns, based on producer-consumer links, short value chains, local and solidary economy, collective capacity, and cooperation within networks. Mostly, answers from development projects/initiatives were analyzed, hence direct farmer perceptions were not considered (Tittonell et al., 2021).

These first findings, based mostly on large online surveys, from the initial phase of the pandemic, support the general narrative by advocates for agroecology. The narrative uses the argumentation that reinforced and evidenced weaknesses of prevalent food systems and observed "agroecological" responses of local food actors confirm that agroecology is the appropriate pathway for sustainability transitions in food systems (Altieri and Nicholls, 2020; Gliessman, 2020; Bisoffi et al., 2021; Gras and Hernández, 2021). However, given the unprecedented and dynamic character of the current pandemic, its varying implications in different regional situations, and related context-specific changes caused in food system actors operations, the above argumentation for agroecological food practices as appropriate responses to systemic shocks requires further, case study based, empirical evidence. Moreover, the maintenance and evolution of responses as conditions normalize, and the longer-term transformative potentials of practices implemented in relation to sustainability issues, such as consolidated in the principles of agroecology, need further assessment (Nemes et al., 2021).

Longer-term food system transitions might be explainable by the consolidated principles of agroecology, proposed as a general framework to guide and monitor transitions at the plot, farm, and food system level (Wezel et al., 2020). Using the generically formulated principles for in-depth analysis of local responses by food actors under changing conditions may lead to better understanding of how suddenly changing conditions for producing, marketing and consuming food may trigger actors to develop and implement agroecological practices. By studying how actors (re-)frame their objectives under changing conditions and how the statements of agroecological principles are translated into concrete local action, the potential of agroecology for local transitions in the context of a systemic crisis and beyond can be approached. In turn, this knowledge can help to define the relevance of specific principles for actors to operate under changing conditions, and to better inform policy interventions to support local food actors. Appropriate support measures can help actors to potentialize their capacity to mitigate shocks through increased resilience and to use this crisis as an opportunity to unfold their longer-term transformative potential (Folke et al., 2010), by contributing to food security, sovereignty and reduction of vulnerability of smallholder food actors (Tittonell, 2019).

Conceptually, such analysis responds to the dynamic and unpredictable character of agroecological transitions, and the need for more inductive and constructivist research (Ollivier et al., 2018). It can be approached through the understanding of agri-food systems as purposeful human activity systems (Kaufmann and Hülsebusch, 2015), where actors operate within their frame of reference (knowledge, objectives, values, attitudes etc.) toward their specific objectives, influenced by constraining or enhancing context conditions (Mezirow, 2000). For instance, at the farm decision-making level, Sutherland (2011) conceptualized that major change processes toward sustainable management are often initiated in response to major trigger events. From this perspective, studying the diverse changing conditions caused by the pandemic that frame the individual and collective room to maneuver of local food actors for (re-)framing their objectives and actions is promising to understand what pushes actors to change from the usual.

Against this background, this study emphasized the Argentinean case, where in recent years agroecology is gaining momentum, and where the pandemic and the prevention measures have had severe impacts. The worldwide calculated COVID-19 Stringency Index shows that in a global comparison, Argentina was one of the countries with the strictest and longest lock-down and prevention measures implemented (Hale et al., 2021). National lockdown measures included strict local mobility restrictions, mandatory social isolation, distancing and closure of local markets and shops (put into force by the national decree N° 260 in March 2020). Although agricultural production and marketing activities where officially exempt from lockdown, difficulties in obtaining circulation permits for local food actors where widely reported all over the country (Urcola and Nogueira, 2020).

Within our ongoing case study research on agroecological transition pathways in a local food system in Argentina, in April 2020 we responded to the sudden lockdown and its impacts on the local food system by starting a stepwise study. In a first step, we conducted an online-survey to assess how local farmers and processors in a local food system in Northern Patagonia perceived disruptions and impacts in the early stage of the pandemic (March-June 2020) to carry out activities for producing and marketing food, and what immediate strategies they proposed and implemented to cope with the restrictions and perceived impacts (Frank and Amoroso, in press). We found that ninety percent of the respondents were affected in their farming and/or processing activities. In relation to specific impacts, among others, sale of products appeared as the most affected process and farmers and food processors stated their interests in establishing agroecological practices within civic food networks (c.f. Renting et al., 2012).

Based on these findings, in the second step of our study, we identified local producer shops and markets that were established or reinforced during the pandemic, for an in-depth case study. The overall aim was to study changing conditions, how they triggered actors to (re-)frame their objectives and activities regarding local marketing, and to assess the relevance of agroecological principles as a means of responding to changing conditions and to unfold longer-term transitions. The specific objectives were to (i) reveal marketing conditions that changed during the pandemic for local food actors to operate; (ii) identify objectives of, and activities conducted by, local producer groups to establish producer shops and markets; and to (iii) understand how the objectives and activities carried out reflect agroecological principles as articulated by Wezel et al. (2020).

This study reports on an exemplary case 'in the making', providing insights into particular changing conditions under which alternative practices are implemented, and into how agroecological principles can be used as a lens to investigate characteristics and potentials of these practices regarding immediate shock mitigation aspects, and longer-term agroecological transitions. Thereby this study contributes with case study-based knowledge to better situate general narratives for agroecology as sustainability pathway in response to food systems' crisis.

In the following, we first present materials and methods used to approach the above objectives. In the results we give a brief characterization of the assessed producer shops and markets and present our analysis of changing conditions for market actors, objectives and activities conducted by the self-organized producer groups (SOPGs) who implemented the producer shops and markets, and the linkages of their objectives and activities with the agroecological principles. Finally, we discuss our findings in the light of learning opportunities from disruptions caused by the pandemic and from the responses by food actors regarding potentials of agroecology approaches to build alternative local food systems in context of crisis and beyond.

MATERIALS AND METHODS

Study Location

The case study was conducted in the Andean valley region *Comarca Andina del Paralelo 42*, comprising territories between parallels 41°30′ and 44°55′ South, and 71°20′ and 71°42′ West of the provinces of Río Negro and Chubut, Argentina (**Figure 1**). The region is characterized by a cold temperate mountain climate (average precipitation 750 mm/a, average annual temp. 9,8°C) (Madariaga, 2009). The human population has been growing rapidly in the region over the last decades, due to high national and international migration fluxes.[1] The territory counts several dispersed and rapidly growing urban and peri-urban centers, connected by a strong flow of labor, goods and capital across the province border that divides the region. In socio-economic terms, tourism, the public sector, agricultural and forestry production, and a diversity of handcrafts are the main sources of income for the local population.

Surrounded by mountainous forest landscapes, diversified agricultural production takes place in the productive valleys and on terraces (fruits, vegetables, hops, cereals, and small to medium scale animal production with varying intensities). The main growing season is from November to March. Local food provision relies to a large amount on imports from other regions of the country, although parts of the population choose local products and thereby engage in sustainable consumption practices. To our knowledge, there is no data available that quantifies the amounts and types of food imports or the share of local production necessary to cover local food demands.

According to data estimated by the National Institute for Agricultural Technology (Cardozo et al., 2022), there are 2619 farmers in the study region, out of which 96% work on a small scale for family consumption and/or selling of small volumes. Vegetable production is estimated to take place on 101 ha in greenhouses and outdoors. Farms are characterized by mixed small and medium scale production systems, under conventional management and a growing number under agroecological-based management approaches, such as organic farming, market gardening, community supported agriculture, community gardening and small farms for self-consumption (Frank et al., 2020). Local products are usually sold *via* direct marketing (on-farm, social media, home delivery and farmer markets), local retailers and informal bartering.

Data Collection and Analysis

Based on our findings on emerging local marketing strategies in response to indirect impacts perceived by local farmers and processors (Frank and Amoroso, in press), in March 2021 we mapped local producer shops (locally used term in Spanish: *mercados*) and markets (locally used term in Spanish: *ferias*) in the study region. In consultation with local

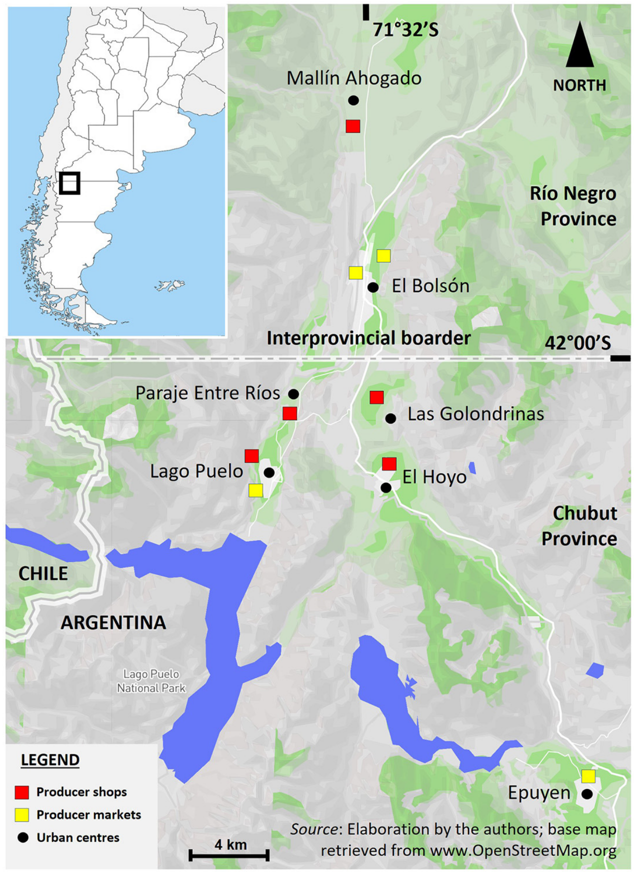

FIGURE 1 | Map of the study region and assessed cases.

experts (extension service, advisors, researchers, farmers, and consumers) we identified all the shops and markets ($n = 14$) that fulfilled our defined criteria (farmer/processor-led; food or mixed food/no-food; focus on direct marketing). Subsequently, we selected those cases ($n = 9$) that were functioning during lockdown/restrictions between March and December 2020, or at least during some months in this period, in order to be able to observe effects of changing conditions for the market actors. Out of the selected cases, 6 (5 shops and 1 on-farm market) were established after March 2020 (i.e., during the pandemic), and 3 (markets) existed before that date. The distinguishing characteristics of producer shops and markets is detailed in the results (Section Characteristics of Producer Shops and Markets). The identified shops and markets were visited to familiarize with the organizing groups (hereinafter referred to as *self-organized producer groups*: SOPGs), to learn from informal interactions how the shops/markets function, what motivates participating producers,[2] their objectives, and the challenges they face. The visits were conducted by the authors in collaboration with the local state extension service. Finally, during the visits we

[1] The last official census in 2010 reported a total of 23392 inhabitants (INDEC, 2010).

[2] In this article we adopt the term *producer* to refer to *farmers* (primary production) and *processors* (elaboration).

determined with the SOPGs their interest in participating in the consultative research through individual and group interviews.

Given the exploratory character of the study, a semi-structured interview method was chosen to capture and understand the interviewees' perceptions within the scope of the research objectives (Kvale, 2012), such as the history of the producer shops and markets, effects of the pandemic, objectives, activities, experiences, and future expectations of interviewees. Further, an open interview flow was used to provide space for the interview partners to also bring forward those relevant aspects that were not previously thought of by the researchers, and therefore to enrich the data and to reduce possible bias of the results. Where possible, group interviews were conducted with various members of the respective SOPG, to capture perceptions and knowledge of different individuals. This approach facilitated gaining insights into the representations, motivations, and interpretations of the participants in a situation of interaction not only with the interviewers, but also with other SOPG members. The dynamic interaction among group members recreates the social representations of the group on the issues under study, based on the discursive confrontation among participants. It is from this group interaction that the answers to the questions were further discussed, enhancing the richness of obtained data (Merton, 1987). Further, it provided the participants with greater cohesion and confidence at the time of answering in the dialogical mode proposed by the researchers (Kamberelis and Dimitriadis, 2011). For this study, the selection of interview partners was carried out by the consulted SOPGs themselves, respecting their organizational dynamics (Beitin, 2002).

Based on insights from the first interactions with the SOPGs and the defined research objectives, a first guide for the semi-structured interviews was drafted. The draft guide was used for the first three interviews (February 2021) and adjusted based on a preliminary revision of transcripts. Then, the remaining interviews were conducted by the authors (see Section Author Contributions) between August and October 2021. In total, 12 interviews were conducted, 8 with participants of the 6 producer shops that were established after March 2020, and 4 with participants of identified producer markets that were established before the pandemic started. In total, 5 group interviews and 8 individual interviews were conducted, with an average duration of 70 mins (range from 30 to 90 mins).

All interview material (Spanish language) was transcribed using a basic transcription mode to completely transcribe the literal content. Transcripts were then introduced into a qualitative data analysis software (ATLAS.ti) for qualitative content analysis. Qualitative content analysis is a flexible but structured method for qualitative-interpretative analysis of (text) material. It is the systematic analysis of documented communication, based on certain rules and led by theory (Mayring and Fenzl, 2014). The structured analytical-interpretative process was guided by the development of concepts and categories (codes) that were applied to the text in order to sort the material with regard to content (coding), and to increase information density by reducing text volume. **Figure 2** gives an overview of the qualitative data analysis framework, as employed in this study. The (sub-)categories and coding themes were developed by using a hybrid approach. The main analytical categories (1–5) were derived from the research objectives (deductive). Then, the sub-categories within the main categories 1–4 were developed based on the transcripts (inductive). For the analysis of linkages of objectives and activities with agroecological principles (category 5), the principles of agroecology that apply to the (local) food system level (as defined by Wezel et al., 2020) were taken as sub-categories and their definition (coding themes) were then used to reveal connections to objectives and activities conducted. Direct quotes of interview partners presented in the results are coded by the interview ID, differentiating between group or individual interview (gr/ind).

RESULTS

Characteristics of Producer Shops and Markets

Among the studied cases, two operational types of physical marketplaces were identified, where self-organized producer groups (SOPGs) and consumers, residents of the region or tourists, come together. The first type were the *producer markets* ($n = 3$), which preexisted the pandemic and were characterized by open-air spaces where producers offered their products at individual stalls. Producers participating in the markets organized to perform common tasks, such as communication, maintenance, or improvement of the markets' infrastructure. The second type were the *producer shops* ($n = 6$) that were closed spaces, implementing a rotational shift-work scheme for selling products of all the participating producers.

In both operational types, responding to the principle of self-organization, most SOPGs established assembly structures and decisions were made by consensus. The type of products offered were similar in all assessed SOPGs. A variety of local food products, such as vegetables, fruits, marmalade, honey, sweets, juices and bakery goods, seeds and seedlings, as well as handmade cosmetics, clothing, and other handicrafts were offered. In some cases, the product range was supplemented with products from other regions (community-based purchase), as availability of local fresh produce is seasonal.

Shops and markets were composed on average by 35 members (min = 5/max = 88), with seasonal fluctuation. Participant profiles were heterogeneous in terms of age and socioeconomic level, including a high number of producers with an urban-rural migration background and a predominance of female participants in the SOPGs. Most of the producers had other sources of "off-farm income," and only a few relied solely on the economic revenue from the shops and markets. Participating producers were farmers, some of them integrating processing of their crop and livestock products, and processors who bought raw materials mostly from within the SOPGs or from other local producers. Only in one case, pure re-sellers (traders) were represented within the SOPG.

Changing Conditions for Market Actors to Operate

Locally implemented lockdown measures in the study region came into force by 17th of March 2020, and were extended

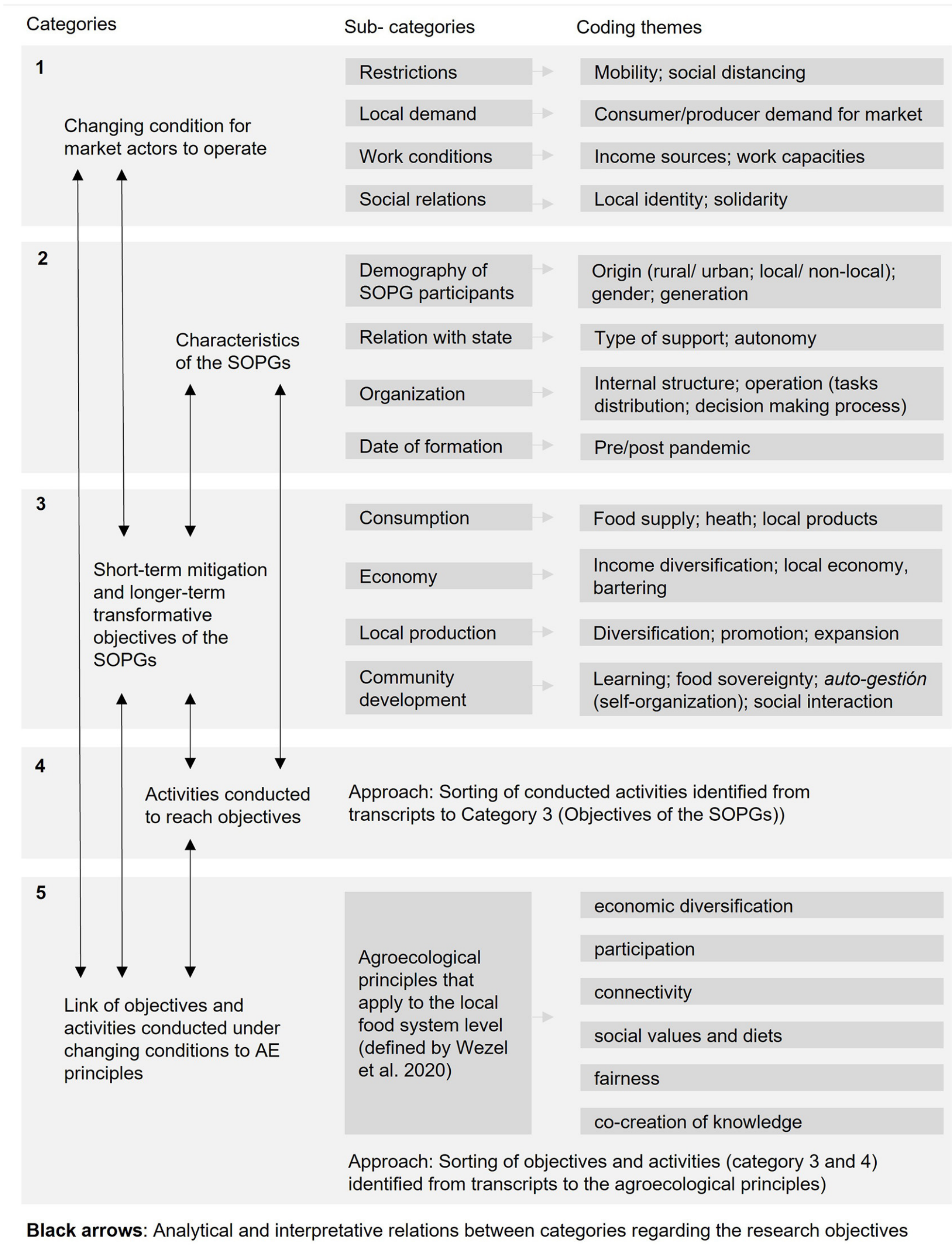

FIGURE 2 | Qualitative content analysis framework.

and modified in the subsequent months, legally justified by a high number of frequently changing national and provincial decrees.[3] Most restrictions were implemented by law nearly until the end of 2020, such as the closure of the province borders between the Provinces of Rio Negro and Chubut (dividing the highly connected urban centers within the study region), strict curfews and later on, social distancing measures for the general population. Formally, agricultural activities were exempt from restrictions, while some established mixed farmer and handicraft markets were closed. Small-scale producers, including the participants of the SOPGs, were restricted in their mobility to cross provincial borders. The beginning of lockdowns coincided with the ending of the main agricultural production season in the region, affecting marketing of the local production.

[3]National decrees: https://www.boletinoficial.gob.ar/busquedaAvanzada/busquedaEspecial; Chubut Province: https://boletin.chubut.gov.ar/; Rio Negro Province https://defensoriarionegro.gov.ar/drn/normativas-provinciales/.

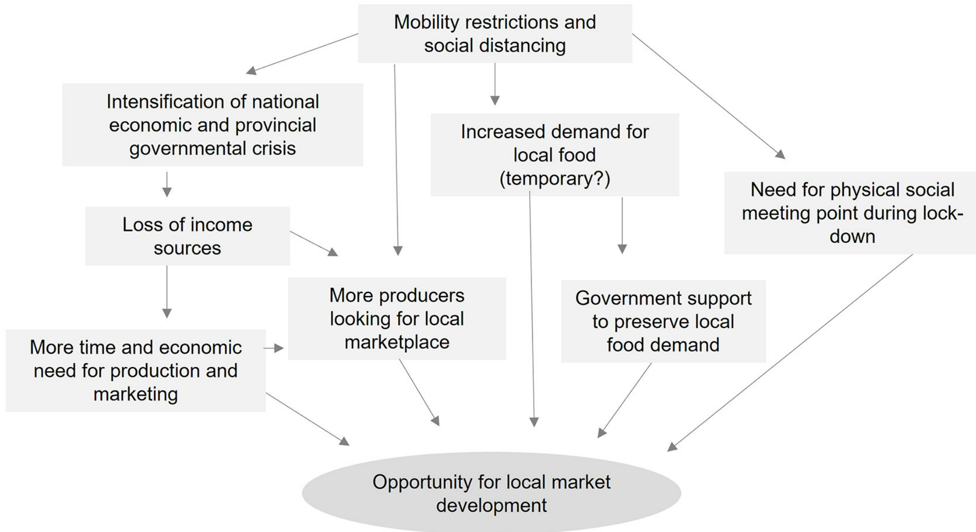

FIGURE 3 | Relational chart of changing conditions for local market development, based on the interview partners' perceptions.

Interview partners particularly perceived mobility restrictions and mandatory isolation as initial factors disrupting their operations. The relational analysis conducted by linking the other factors mentioned by the interview partners therefore starts with these two important new conditions (**Figure 3**).

The general context for the producer markets and shops to evolve during the pandemic was described by one interview partner as follows:

> *Having the borders closed made us look a little more inward, and an economic crisis began to emerge from which you know that in this region most of the people ask for some jobs in the public sector or some private jobs, but most of them are self-supporting, artisans (...). It was this situation that made appear these markets (. . .). In some places they began to work as an economic alternative, let's say, for the crisis (I2-ind).*

Although the implementation of the markets was apparently conducted within a crisis situation, and, as we show in the following, aimed at satisfying basic needs of the local population, the notion of *new opportunities* with a positive connotation brought by the changing conditions was revealed from the market participants' narrations.

> *The truth is that it [the pandemic] does not worry me much, on the contrary, I really like what we are doing here. We generated a link and very interesting discussions with the colleagues of the market group. And well, I see this as an opportunity, not as a problem. For me this was an opportunity (I4-gr).*

When explaining the above context of restrictions (**Figure 3**), local producers also reported experiences from their role as consumers. On the consumer side, the lockdown led to increased demand of consumers to access food in the direct neighborhood during strict curfews.

From the producer perspective, it was reported that loss of off-farm income due to the national economic crisis, before the pandemic and its further deterioration caused by the pandemic, led to an increased need to earn income from farming/processing and local marketing activities. In this regard, producers living and working in the Province of Chubut also referred to the ongoing provincial government crisis (e.g., leading to very long payment delays for public employees and strikes). Furthermore, in the entire study region, some producers were affected by severe fires that hit the region and burned 19,605 hectares[4] of forest and agricultural land between February and March 2021. Moreover, mobility restrictions, inhibiting other businesses (e.g., tourism and wage work), and hindering marketing of products in other closed local or inter-regional markets, led to more available work time, to increased need to redirect produce to very local market channels, to innovate and to change habits:

> *(. . .) because habits changed, although we lived in a certain rural environment, there was more time (...) that is to say, in the previous daily life there was not so much time to take advantage of all the apples, all the walnuts, everything, or to start cooking cakes or making bread (...). Someone who was an artisan became a baker, started making salads or sweets.* (I4-gr).

Given these circumstances, interview partners reported an increased demand of local producers for alternative physical marketplaces in the different residential locations (span. *parajes*). Furthermore, emergency support of the local municipal governments to establish (temporary) local markets was highlighted as a new and favorable condition in some of the markets. This was explained in the context of temporary closures of some established mixed food and handcraft markets during

[4]Personal communication: Servicio Nacional de Manejo del Fuego, Government of Argentina.

the lockdown. Here the municipalities responded with support to provide alternative market options for local (food) producers. In some cases, local authorities provided plots for outdoor markets and buildings for indoor shops, mostly in community or municipality centers, which were closed during the lockdown. In other cases, public support was provided to cover expenses for the daily functioning of markets (i.e., gas or electricity) or to adjust sanitary requirements to the market demands.

Restrictions that affected the opening of local markets were the established distancing protocols for physical markets, in particular regarding the restricted number of people allowed in closed marketplaces. This led to the development of organizational schemes for the rotational attendance of the markets to adjust to the sanitary protocols and a distribution of tasks also considering personal situations of the participants, i.e., high risk groups were excluded from serving the public as sales personnel.

All assessed SOPGs reported that during the strict lockdown, the demand in the local markets, both regarding consumers and producers, was very high and dropped gradually as restrictions were lifted. However, this was also attributed to two seasonal particularities in the region. First, the decline of local fresh products offered in the off-season, and second, the pronounced seasonality of tourism as an important economic factor for the local economy.

Finally, interview partners' narratives emphasize that the exceptional emergency, and changes caused in the individual routines, stimulated critical personal and societal reflections, such as the need for strengthening and revaluing grassroots initiatives for developing and transforming the local food system toward increased food sovereignty.

Objectives of the SOPGs and Activities Conducted

The analysis of objectives pursued by the different SOPGs under the changing conditions during the pandemic revealed three overall aims. These were: (i) to permanently establish producer shops in the different residential areas within the study region, also beyond the pandemic, and/or to reinforce already existing producer markets; (ii) to utilize the producer shops and markets as places of community development, and peer-learning through knowledge co-creation and exchange; and (iii) to articulate and potentialize political concerns of food sovereignty through collective action.

These overarching and general aims were approached by the SOPGs through specific objectives and activities (**Table 1**). Objectives and activities conducted were found to be similar between cases, except for some obvious organizational objectives typical for the producer shop organization. Therefore, no comparative analysis was conducted, and differences highlighted only where they applied. The objectives showed a principal divide regarding their nature. There are *reactive, short-term mitigation objectives* of the SOPGs to provide emergency relief in direct response to conditions changed by the pandemic and immediate needs, and *proactive, longer-term transformative objectives* to work on post-pandemic growth of the producer shops and markets and on broader local food system development. Short-term mitigation objectives directly responded to the changing conditions (cf. Section Changing Conditions for Market Actors to Operate), both in terms of economic needs to generate alternative household income, to sustain local food supply, and to provide physical places for social interaction and solidarity-based peer-to-peer aid for the local population during lockdown. Therefore, they can be classified as *reactive*, as they directly *respond to changed conditions*. In contrast, longer-term transformative objectives have a more *proactive* notion, hence they reflect actors' objectives of *initiating change* to transform the local food system.

Further, based on the analytical categories (see **Figure 2**), it was revealed that the SOPGs' overall aims, specific objectives and activities conducted addressed different aspects of the local food system, i.e., *economy*, *production*, *consumption*, and *community development*. This distinction is used to group objectives in **Table 1**. It constitutes the first analytical step to highlight the diversity of objectives and activities conducted, subject to further analysis of linkages with the agroecological principles (Section Linkages of Objectives and Activities With Agroecological Principles). The diversity reveals the holistic and transformative approach pursued by the SOPGs; not only to mitigate impacts of the pandemic on local producers and consumers, but also to actively contribute to the development of local agroecological production, local and solidary economy, convergence and relation-building between local consumers and producers, and broader community development.

The heterogenous character of objectives and activities indicates that motivations of participating producers went beyond the individual purpose of generating and diversifying income (*economy*) and pointed to more community-oriented social and environmental concerns, for instance classified under *community development*, *consumption*, and *local production*.

There were different motivations for objectives represented in the different SOPGs, explained by one interview partner as follows:

> *Until today we are thinking and rethinking what we want to be as a market, if we want to be a market with certain characteristics, or a simply commercial market. (...) there is a group of colleagues who have a beautiful and harmonious commercial vision, I say harmonious because it is not within the framework of capitalist commerce, that is, just to make money, but it is thought from a more communitarian point of view, but it is still a commercial vision. Then there is another group that is more interested in being there for community reasons, without looking so much at the commercial aspect, which is the case of many people who participate and do not sell much (...). Then there is another group of colleagues who are thinking about "how can we organize it so that we can fulfill both needs, let's say?" (I2-ind).*

By analyzing the nature of the activities that the SOPGs prompted (**Table 1**), it was revealed that only some activities were carried out by individuals at the farm- or processing-activity level, such as to produce more, to diversify production based preferentially on local resources (brought in or bartered from peers), and to start selling through different marketing channels. All other actions were taken at the shop/market activity system level (e.g.,

TABLE 1 | Objectives and activities of the SOPGs.

Analytical categories		Specific objectives	Activities* conducted to reach objectives
Reactive short-term mitigation	Economy; Production; Consumption; Community development	Generate alternative income sources in response to income losses caused by the pandemic crisis. Sustain local food offer supply during lockdown. Establish meeting points for social interaction and collective action during lockdown. Solidary peer-to-peer support to cope with socio-economic challenges.	- Collaborate with municipalities to open markets. (g) - Implement COVID protocols in the markets. (g) - Improve markets' physical infrastructure. (g) - Provide material/labor support by peers/consumers. (g) - Establish social media to organize/promote shops/markets. (g) - Ask peers to start farming/processing business. (i) - Exchange knowledge on farming/processing practices. (g) - Start producing beyond self-consumption. (i) - Implement bartering practices. (g) - Work voluntarily in market organization. (g) - Purchase staple food as community (food coops). (g)
	Economy; consumption	Generate alternative and diversified income sources beyond shock mitigation. Create consumer-producer proximity without intermediaries. Expand and diversify markets in support of the local economy. Incentivize local/healthy/diversified consumption.	- Negotiate with municipalities for continuing support (physical places, food safety protocols, permits). (g) - Offer products on different local markets. (i) - Collectively define fair prices. (g) - Implement bartering practices. (g) - Purchase primary products from local peers. (i) - Use social media to attract more consumers. (g) - Share knowledge among producers and consumers (consumption and farming practices). (g) - Organize seed/seedling exchange events. (g) - Generate networks between markets to complement product ranges to attract consumers. (g)
Proactive longer-term transformative	Production	Expand and diversify markets based on local farming and processing practices. Strengthen local/agroecological production.	- Prioritize local (agroecological) products offered. (g) - Promote agroecological practices within the marketing groups. (g) - Ask peers to start farming/processing business. (i) - Purchase primary products from local peers. (i) - Organize seed exchange events. (g) - Start producing beyond self-consumption for sale. (i) - Offer trainings and workshops on agroecological practices. (g)
	Community development	Markets as social meeting points, and places of learning. Strengthen local and solidary social networks for collective action.	- Develop group-based and participatory organizational structures and tools for producer shops. (g) - Train participants in relevant organizational topics. (g) - Implement remuneration schemes for rotational attendance by market participants. (g) - Implement social media platforms to organize and promote markets. (g) - Exchange knowledge between peers and with other local markets (processing, market organization). (g) - Link market spaces with other community activities (workshops, trainings, events). (g) - Conduct solidarity peer activities to overcome economic crisis. (g) - Purchase staple food as community (food coops). (g)

**Conducted by individuals at the farm and processing level (i); at the SOPG level (g).*

organizational and training activities) and done to reinforce linkages between shops and markets with the local communities (cultural events, workshops, fundraising, etc.). Remarkably, these activities reflect important investments of human and social capital by the SOPGs to reach their objectives. Most of the activities which were directly related to the producer shop organization were conducted by participants *ad honorem*.

Moreover, activities were identified that aimed at the increase of human and social capitals through changes in relationships between actors and co-learning within the SOPGs (e.g., through participatory and group-based organization of the producer shops, trainings and knowledge co-creation and exchange activities), and with the local communities (e.g., through raising consumer awareness of local production and consumption practices and through consumer involvement in the producer shops and markets). In this context, *knowledge exchange*, *participation*, *togetherness*, *empathy*, *solidarity*, *tolerance*, *trust*, *commitment*, *awareness*, and *autonomy* were frequently used in the interview partners' descriptions of the SOPGs' relations, their objectives and activities, their engagement with the local community, and their values and future aspirations. The groups pursued a combination of direct marketing-related and socio-cultural and political objectives and activities. However, the analysis of activities showed that the marketing-related objectives where emphasized, while community development was less represented in concrete activities.

Reported challenges encountered in the autonomous, participatory and solidarity-based approach implemented by the SOPGs were the high amount of time to be invested by individuals *ad honorem*; managing group conflicts and decision-making in the organization of activities, assuring continuous participation of producers, particularly during normalization of conditions after lockdown ended, and seasonal decrease of economic revenues from selling in the markets. In this regard, the SOPGs that implemented the producer shops reported that some producers stopped participating after lockdown ended and when the high selling season was over. However, those SOPG members who kept up with the shop or market activities

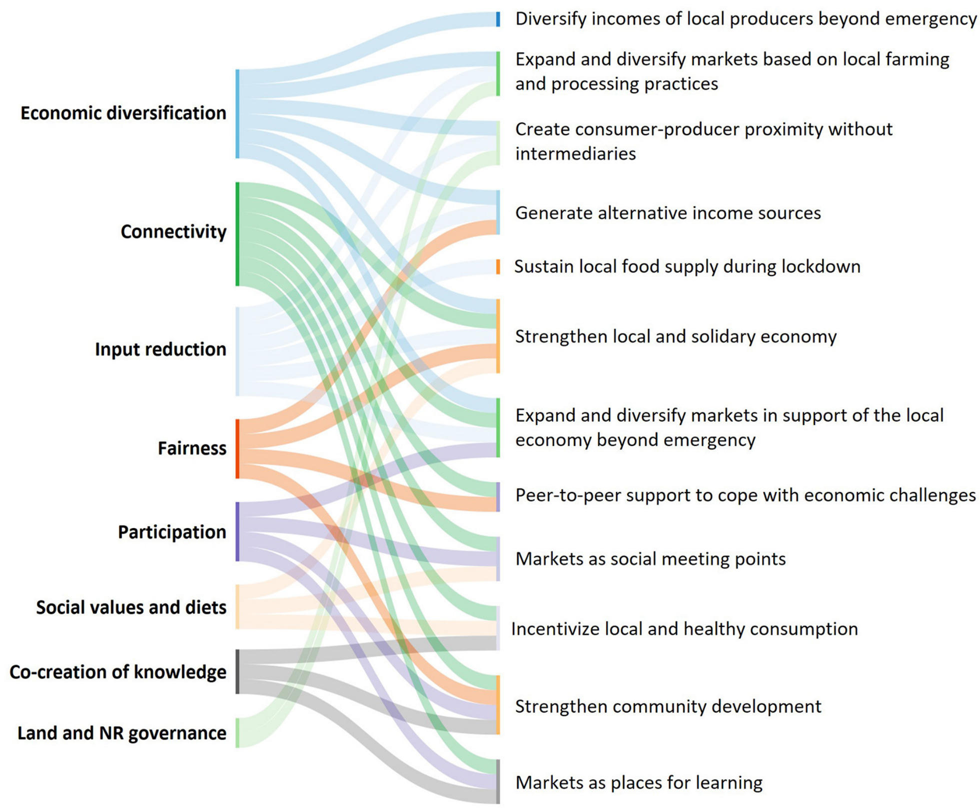

FIGURE 4 | Assignment of SOPGs' objectives and agroecological principles.

stated a pronounced commitment to continue in the collective construction process, pointing at the long-term establishment of producer shops and markets as instruments for local food system transition toward food sovereignty.

Linkages of Objectives and Activities With Agroecological Principles and How They Respond to Changing Conditions

Figure 4 shows the multiple linkages between the objectives of the SOPGs and the agroecological principles. These linkages are explained in the following for each principle also regarding how they respond to the changing conditions (see Section Changing Conditions for Market Actors to Operate). In order to give more meaning to the principles, each of them is introduced by citing its definition according to Wezel et al. (2020).

Economic Diversification

"Diversify on-farm incomes by ensuring that small-scale farmers have greater financial independence and value addition opportunities while enabling them to respond to demand from consumers." One key objective of the SOPGs was to generate new income sources for local producers, based on local and solidarity marketing approaches, and direct consumer-producer relations without intermediaries. Although the assessed producer markets existed before the pandemic, and most producers who participated in the new producer shops had produced and marketed locally before, it became clear that by having a growing number of producer shops to market their products, they were incentivized to conduct activities to increase and/or diversify their production and marketing during the pandemic. Thereby, they were able to partially serve the (temporary) increased demand of local consumers. However, it needs to be underlined that most of the producers in the assessed SOPGs did not make their living from on-farm or processing income alone. In this sense the markets provided a platform to generate additional income to increase financial independence of the households by combining on-farm or processing income with other off-farm incomes. Further, the objective of supporting the development of local and agroecological production practices showed the motivation to incentivize local farm-level transitions beyond the individual production horizon and through collective marketing. In this regard, interview partners highlighted the need to diversify product ranges offered in the shops and markets to attract consumers and to respond to consumer demands.

Input Reduction

"Reduce or eliminate dependency on purchased inputs and increase self-sufficiency." The high relevance of this principle during times of mobility restrictions, temporary input-supply disruptions for producers and consumers, and mandatory social isolation of consumers was shown by the response of local

actors who established producer shops and markets to sustain local food supply during lockdown, responding to increased demand to produce, market and consume locally. Further, the articulated reliance on preferably local resources (such as flour, fruits and vegetables) by processors, and local seed production and exchange by farmers, directly responded to this principle. However, the principle was not fully applied. This was explained by the problem of (temporarily) limited local availability of certain products for production and consumption. Here, the SOPGs worked in collaboration with national farmer organizations, organic retailers, and food coops to obtain inputs needed in processing, such as sugar, coconut oil, etc., and products to increase product ranges for consumers in the markets (sugar, fruits, vegetables, yerba mate, etc.).

Fairness

"Support dignified and robust livelihoods for all actors engaged in food systems, especially small-scale food producers, based on fair trade, fair employment and fair treatment of intellectual property rights." The support of robust livelihoods by producers and local consumers participating in the markets became evident through the objectives and related activities to sustain local food supply during lockdown, to provide solidary-based peer-to-peer support to cope with economic challenges in times of economic crisis (and other catastrophes, such as the fires). Fair trade was encouraged through direct producer-consumer marketing without intermediaries, in some SOPGs through definition of prices based on production cost. Aiming to establish producer shops and markets as places of social interaction and learning, the SOPGs encouraged transparent communication of price structures to consumers, coupled with awareness-raising activities related to local and agroecological production. Whereas the groups' motivations to establish and operate the producer shops were principally based on volunteering, some groups made use of remuneration schemes for worktime provided by group members to serve the public. Thereby, where remuneration schemes were implemented, the groups developed mechanisms to approach issues of fair employment, within a context of economic need for income, to operate the shops.

Social Values and Diets

"Build food systems based on the culture, identity, tradition, social and gender equity of local communities that provide healthy, diversified, seasonally and culturally appropriate diets." Identified objectives and activities of the SOPGs are related to this principle, particularly with respect to facilitation of exchange of local knowledge on agroecological production, marketing, and consumption practices. Motivations expressed by interview partners in this regard were to incentivize local and healthy consumption, and to enhance the implementation of agroecological farming practices. Diversification of diets was directly addressed by the SOPGs through the ambition to expand the range of products available in the shops and markets for local consumers, and by offering different types of healthy products, partly little known to local consumers. This principle also reflects cultural practices of parts of the local population who follow alternative and healthy lifestyles and emphasize solidarity and autonomy aspirations. Interview partners reported that local identity-building was encouraged through the shops and markets as social meeting points for collective action during social isolation, an example of how activities responded to the changing conditions.

Land and Natural Resource Governance

"Strengthen institutional arrangements to improve, including the recognition and support of family farmers, smallholders and peasant food producers as sustainable managers of natural and genetic resources." The SOPGs constitute new community-based institutional arrangements to form producer shops and markets. Interview partners characterized the shops and markets as places of institutional and organizational innovation to build an alternative local food system based on food sovereignty. Indeed, the new institutional arrangements adopted by the groups did not directly refer to land and natural resource governance. However, the SOPGs geared their objectives toward building a platform to facilitate broader institutional innovation within the local food system, also regarding management of natural and genetic resources (e.g., land rights and local seed production). Solidarity-based objectives and activities within the SOPGs were reinforced by the changing conditions: for instance, through peer-to-peer support to cope with economic challenges at the household level, through establishment of bartering systems, and through the objective to strengthen social community interaction (for example, through fundraising and campaigns to collaborate with the victims of the fires). Further, the emergency support provided by local governments was explained as a result of the new situation caused by the pandemic. However, in most cases, this support was temporarily limited to the emergency situation. Only in the case of pre-existing markets and in the case of one producer shop, did the government prove continued support through longer-term contracts to sustain the shop beyond the emergency situation. Hence, in these cases, the new situation helped to encourage local governments to support the new institutional arrangements that were created by the SOPGs. However, interview partners underlined the rather conflicting relation between the SOPGs and local authorities, and the lack of support for local agricultural development in general. Reference was made to the absence of territorial land-use regulations, pressure by the real estate sector, and missing recognition by local governments of local (smallholder) farmers as capable and sustainable managers of locally limited agricultural lands.

Connectivity

"Ensure proximity and confidence between producers and consumers through promotion of fair and short distribution networks and by re-embedding food systems into local economies." Connectivity was most obviously reflected in the objectives and activities of the SOPGs. This principle is inherent to the main objectives of the groups as they emphasized consumer-producer and producer-producer proximity through short distribution networks and strengthening local economies. Furthermore, the producer shops and markets were seen to play an

important role as places for social interaction, joint learning and collective politically motivated action. These functions are also reflected in the implementation of the principles of *fairness*, *participation*, and *knowledge co-creation*. The producer shops were established under changed conditions and with direct consumer participation. Consumer participation was particularly pronounced in the reported support of consumers in the construction of the shops (e.g., in form of donations or volunteer work). In turn, the SOPGs' objectives and activities aimed at incentivizing solidary economy, and relationship-building between consumers and producers. This was even more pronounced with respect to the bartering practices conducted by the SOPGs, when producers took the role of consumers through exchange of products for self-consumption.

Participation

"Encourage social organization and greater participation in decision-making by food producers and consumers to support decentralized governance and local adaptive management of agricultural and food systems." Increased connectivity between the involved actor groups and the agency of the SOPGs to implement the shops and markets can be regarded as a product of new social organization. Furthermore, the groups aimed at developing new social organizational structures and processes for the shops' functioning and for its integration into local community development, based on multi-actor participation, horizontal decision making and peer learning (see also **Table 1**). Regarding decision making, the groups opted for consensus-based processes, requiring more participation in debates compared to majority vote processes. Local adaptive management was encouraged and implemented when the SOPGs readily responded to the various changing conditions (see **Figure 3**), by opening new markets and by developing new organizational arrangements.

Co-creation of Knowledge

"Enhance co-creation and horizontal sharing of knowledge including local and scientific innovation, especially through farmer-to-farmer exchange." Activities conducted by the SOPGs showed that horizontal learning was approached through informal and formal learning. Informal learning occurred as part of the daily marketing activities (e.g., exchange of knowledge on alternative production and consumption practices, learning about organizational issues). Formal learning events were organized by the SOPGs, such as trainings for participants on topics of market administration and price definition (in some of the shops, provided by group members and/or by the local public extension agency). The implementation of new marketing formats under new conditions led to an increased need for learning by involved actors. Interview partner highlighted the importance and richness of horizontal learning processes that evolved within and between the SOPGs and with consumers, and how these learning processes enriched the collective processes (see also principles *connectivity*, *participation* and *governance*).

DISCUSSION

Up to now most studies related to the COVID-19 pandemic crisis and local food system actors' adaptations to changing conditions were conducted in the early months of the pandemic, based mostly on online surveys (e.g., Tittonell et al., 2021; Zollet et al., 2021), and on expert opinions (e.g., Worstell, 2020; Nemes et al., 2021). We opted for a qualitative case study using in-person semi-structured interview methods with individuals and groups to obtain in-depth insight from first-hand local food actors' perceptions, during 2021, when conditions stabilized, and on-going processes had been in place for more than 12 months. We studied how self-organized producer groups (SOPGs) adapted their marketing objectives and activities under changing conditions caused by the pandemic crisis, considering agroecological principles to understand emerging change processes.

The analysis of changing conditions supports our previous findings in the case study region, showing disruptions in local food actors' operations mainly caused by mobility restrictions, closures of principal roads, the provincial borders, and some local markets (c.f. Frank and Amoroso, in press). In consequence, local producers' marketing and access to inputs were most affected, and they faced overall economic challenges to generate income. For consumers, access to places where to purchase food was restricted to very local options in the neighborhoods. The important impact of the closure of provincial borders, both for consumers to purchase food, and for producers to reach consumers and to purchase production inputs, is explained by the high social and commercial interconnectedness within the rural-urban continuums in the study region (Bondel, 2009). Within this context, the changed conditions triggered local food actors to focus on and to reorganize local marketing, based on collective action.

Due to the mobility restrictions and health protocols during lockdown, several farmer and handicraft markets were closed in the study area. These altered conditions supported the formation of SOPGs and the opening of producer shops, attended by one or two people, offering products from all participating producers. Within the SOPGs, the presence of producers with urban-rural migration backgrounds helped to promote links with urban environments and with consumer groups, realize activities within the markets and connect to other community development activities, beyond mere marketing transactions (Craviotti et al., 2021). Another important condition for the SOPGs to implement their responses was the increased engagement by the local government to establish the producer shops. As analyzed by Ejarque et al. (in press), in the early 2000s, when some of the pre-pandemic markets were established in the study region, local governments also provided support. However, the quality of collaboration was variable between different markets and often ephemeral (Ejarque et al., in press). This risk was also observed in some of our cases: where public institutions provided temporary support during lockdown, it turned into a conflicting situation in some of the SOPGs in the course of normalization of conditions, when the state (re-)claimed the facilities (buildings, plots) for other purposes, such as for community activities or sports. This reported conflict, on the one hand, evidenced the objectives of the emerging SOPGs to sustain and expand the established producer shops, markets, and networks beyond the emergency situation. On the other hand, it explains the desire for autonomy underlined by some of the groups. Here, our results suggest that under normalization of conditions, governments' commitment in favor of local food system development based on agroecology needs to be guaranteed to sustain and expand local transition initiatives over time.

Overall, our findings agree with those of other studies regarding the high capacity of local food actors to respond to the changing conditions caused by the pandemic. While other studies showed this capacity at the onset of the pandemic, our study adds that the capacity was maintained over time and under gradual normalization of conditions. In particular, this was shown by the SOPGs' longer-term objectives and activities conducted to keep producer shops and markets going. The reactive and immediate shock mitigation potential, also found by other studies in the early stages of the pandemic, was illustrated by the characterization of the producer shops and markets, and by the diverse objectives and activities brought to the territory by the SOPGs (c.f. **Table 1**). Most other studies in the field related this potential to concepts of resilience (Béné, 2020; Savary et al., 2020; Thilmany et al., 2020; Perrin and Martin, 2021; Tittonell et al., 2021). Regarding the short-term mitigation objectives of the SOPGs, we found this argumentation reasonable, when resilience is considered as '*the ability to cope with shocks and to keep functioning in much the same kind of way*' (Walker, 2020). However, looking at the longer-term objectives and activities of the SOPGs, it becomes clear, that the groups' aims and objectives did not strive at keeping the local food system functioning in much the same kind of way, but to radically change its structure. This shows the transformative potential of actors to operate in complex adaptive systems, as conceptualized for sustainability transitions in general (Hölscher et al., 2018), and more particular in our case, for agroecological transitions in food systems (Wezel et al., 2020). In resilience thinking, this transformative aspect explains that the SOPGs responded to disturbances by working toward new domains, reorganizing the local food system's structure, redefining values and aims, and contributing to increased resilience of the envisaged transformed local food system (Folke et al., 2010).

Regarding agroecological transitions reflected in our cases, we found that actors' responses under changing conditions were consonant with agroecological principles. By emphasizing healthy and local food production and consumption, and by promoting a common identity and reinforcing local ties, the assessed producer shops and markets and the organizational structures implemented by the SOPGs, conceptually relate to civic food networks (Renting et al., 2012), and to agroecological transitions promoted by such networks (González De Molina and Lopez-Garcia, 2021). In particular, we found that the objectives and activities of the SOPGs aimed at the revaluation of social, cultural and environmental meanings of food, and of changing relationships between producers and consumers to gain control over food production and distribution processes (c.f. Renting et al., 2012; Opitz et al., 2017).

The translation of this transformative potential into concrete actions was encouraged by the changing conditions. Changed conditions led to the occurrence of shared and complementary immediate needs of local producers and consumers, for instance, the need for social interaction and solidarity-based peer-to-peer support in times of economic crisis, as well as the need of local producers to generate alternative and diversified incomes, and the need of consumers to purchase food locally. To address these and other identified needs, social and human capital was immediately mobilized by the SOPGs to (re-)organize local food supply chains in alternative networks under suddenly changing conditions. This mobilization confirms the high ability of SOPGs to readily respond to changing conditions by making use of available capitals. Moreover, the mobilization of social and human capital facilitated joint visioning and learning for local food system development, fostered social and organizational embeddedness of marketing activities in local communities, based on solidarity and shared values (Chiffoleau, 2009). This highlighted the relevance of direct physical producer shops and markets as places for producer-producer, consumer-producer and consumer-consumer interactions. However, the interactions went beyond the issues of generating alternative incomes and to access food. They offered space for the above social purposes (Golsberg et al., 2010). Whereas in other regions, alternative marketing through digital channels was most pronounced during lockdowns (Cendón et al., 2021; Craviotti et al., 2021; Gutiérrez et al., 2021), consumers' preference of physical places linked to the social/emotional dimension of purchasing food was also revealed by Butu et al. (2020), who studied digitalization efforts for direct marketing during lockdown.

Longer-term proactive objectives and activities of the SOPGs, such as the permanent establishment of producer shops and activities to promote solidary economy and local agroecological farming and consumption practices further indicate that the groups are committed to sustain and expand their innovative practices beyond lockdown. Apparently, this finding is not surprising, as most producers were interested and/or actively engaged in alternative food practices before the pandemic. Nevertheless, it shows that changing conditions led to new needs articulated by producers and pushed them to change from the usual. The proactive character indicates that they took advantage of the changing conditions to realize their aims. This was shown by critical reflections and learning regarding sustainability of food practices within the SOPGs and with the local community. Thereby, new opportunities facilitated collective change in objectives and actions, based on learning by doing. These learning by doing processes were triggered by the changing conditions, hence new situations encouraged learning within the SOPGs. Restrictions and protocols required learning about new market organization formats (processes and structures). Further, the groups reported that learning was addressed and enacted regarding agroecological production and consumption practices, highlighting the relevance of horizontal learning processes for agroecological transitions (Anderson et al., 2019). In this sense, the crisis situation can be qualified as a trigger event for learning by local food actors to innovate. A lasting outcome of the collective processes is the improved preparedness (resilience, transformative potential) of actors to readily respond to future crisis, based on the learning from concrete (positive) experience (Kolb, 1984), and based on the newly gained knowledge, as well as newly established social networks and institutional arrangements in civic food networks. This was illustrated by the development of the new producer shop formats and by the novel strategy of reselling staple food products bought-in from other regions within the SOPGs and to local consumers, in line with the concept of food coops (c.f. Little et al., 2010).

The relevance and potential of agroecological principles for these alternative networks to develop and to operate under changing conditions was shown by the explanatory analysis of multiple interrelations of the SOPGs' objectives and activities with the principles of agroecology (Wezel et al., 2020). The changing conditions triggered change of action toward agroecology, showing that agroecology principles became a relevant means to respond and adapt to changing conditions. This was, although to varying extents, found for all principles considered in the analysis, and most pronounced regarding the principle of economic diversification and those related to social aspects (connectivity, participation, governance, knowledge co-creation). These principles were at the center of the SOPGs' objectives and activities. The adaptive management in response to a sudden shock situation was primality based on the operationalization of the principles of participation and connectivity.

Connectivity refers to the important role of consumers in agroecological transitions in food systems. In our concrete case, we showed the high relevance of connectivity and participation for the implementation and maintenance of the producer shops and markets. In line with other studies (e.g., Cendón et al., 2021; Prosser et al., 2021), increased demand for local (agroecological) food within the established civic food networks was reported by the SOPGs, based on their observation of high demand in the markets by local consumers during lockdown, and continuity of the shops' and markets' functioning and frequentation after lockdown ended. Other studies found growing consumer demand and changes in consumption behavior, either due to changing preferences for healthy food (Bisoffi et al., 2021), decrease in purchase power (Workie et al., 2020), easier access to food, or ideological-political positioning linked to consumer-producer proximity and knowledge about where and how food is produced (Craviotti et al., 2021). Our case shows that the issue of access to marketplaces and food also played an important role during lockdown, leading to (temporary) changes in buying behavior of local consumers. Further, from the assessed cases, substantial organizational and material support of the SOPGs by consumers revealed a further interest by consumers to contribute to the growth of alternative local marketing.

Our study gives only limited insight into consumers' roles because it did not cover consumers' perceptions on the SOPGs and the implemented producer shops and markets. Furthermore, changes in consumers' behavior during the expected future normalization of conditions need to be monitored. Reflections made by the interview partners from the SOPGs regarding the maintenance and growth of the producer shops and markets highlighted the important role of consumers' buying behavior, their preferences for agroecological products, and their interest in actively contributing to local agroecological transitions (c.f. Cendón et al., 2021). While we found some activities that are very likely to be sustained by the SOPGs and the participating community under normalization of conditions, such as bartering, food coop community purchases, and further consolidation of the producer shops and markets, the sustainability of changes in consumer behavior remains the big unknown variable with regard to lasting changes brought about by the pandemic (Bisoffi et al., 2021). To assess the role of consumers, and to better identify consumers' motivations and preferences for buying local food and to participate in alternative markets, we are currently conducting further consumer research related to the producer shops and markets in the study region. We consider it important to better understand why or why not consumers supported the local alternative markets in the context of the pandemic and under normalization of conditions, also taking into consideration possible socio-economic and cultural differences in the local population. This will contribute to the debate of limitations of alternative food networks to grow and to move out of niches (Sarmiento, 2017), and to contribute to scaling of agroecological transitions (González De Molina and Lopez-Garcia, 2021).

CONCLUSIONS

In light of findings from other recent research on the COVID-19 pandemic crisis and local food system actors' adaptations to changing conditions, our study responds to the call for in-depth case research to elucidate changing conditions for local actors to develop local markets and to assess the relevance of agroecological principles as a means of responding to changing conditions and to unfold longer-term transitions.

Although projections regarding the sustainability and evolution of the social processes that drove the assessed collective responses are difficult to make, our results showed that agroecological principles became important means to implement concrete local actions for transitions in a crisis situation. Moreover, we argue that through collective learning and action, encouraged by a difficult crisis situation, local food actors became better prepared for future changing conditions related to crises. They realized their capacity to act, increasing their self-determination. By showing that actors change their actions toward agroecology when new needs and opportunities arise from a crisis, it can be expected that future food crises will possibly provide additional triggers for actors to implement further local agroecological food system transition strategies.

Finally, our study showed how the consolidated agroecological principles can be used to qualitatively investigate characteristics, potentials and constraints of local actions for transitions in order to better grasp agroecological pathways enacted in real territories, and to provide decision support for policy makers to foster and potentialize such new local and community-based institutional arrangements.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article can be made available by the authors upon request, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. All interview partners gave their consent to audio record the interviews and to use the strictly anonymized recorded interview material for research purposes within the project (2019-8191.PL459.001).

AUTHOR CONTRIBUTIONS

MF conceived of the study, with conceptual support by BK, ME, ML, MN, and MA. MF, ME, and ML developed the interview guide and conducted the interviews and related field work. MF analyzed the data for the analysis categories 1, 3, 4 and 5 (see **Figure 2**). ME, ML, and MN collaboratively analyzed the data within the analysis category 2 (see **Figure 2**). The manuscript was principally written by MF, reviewed and commented by BK, ME, ML, MN, and MA. All authors contributed to the article and approved the submitted version.

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REFERENCES

Altieri, M. A., and Nicholls, C. I. (2020). Agroecology and the reconstruction of a post-COVID-19 agriculture. *J. Peasant Stud.* 47, 881–898. doi: 10.1080/03066150.2020.1782891

Anderson, C. R., Maughan, C., and Pimbert, M. P. (2019). Transformative agroecology learning in Europe: building consciousness, skills and collective capacity for food sovereignty. *Agricult. Human Val.* 36, 531–547. doi: 10.1007/s10460-018-9894-0

Beitin, B. (2002). "Interview and sampling: how many and whom," in *The SAGE Handbook of Interview Research*, eds J. Gubrium, J. Holstein, A. Marvasti, and K. McKinney (London: Sage), pp. 243–253.

Béné, C. (2020). Resilience of local food systems and links to food security—a review of some important concepts in the context of COVID-19 and other shocks. *Food Secur.* 12, 805–822. doi: 10.1007/s12571-020-01076-1

Bisoffi, S., Ahrn,é, L., Aschemann-Witzel, J., Báldi, A., Cuhls, K., DeClerck, F., et al. (2021). COVID-19 and sustainable food systems: what should we learn before the next emergency. *Front. Sustain. Food Syst.* 5, 12. doi: 10.3389/fsufs.2021.650987

Bondel, C. S. (2009). Transformaciones territoriales y análisis geográfico en ámbitos patagónicos de montaña. Doctoral tesis. Unviersidad Nacional de la plata, Argentina. Available online at: http://sedici.unlp.edu.ar/handle/10915/3094 (accessed October 16, 2021).

Butu, A., Brum,ă, I. S., Tanas,ă, L., Rodino, S., Dinu Vasiliu, C., Dobo,?, S., et al. (2020). The Impact of COVID-19 crisis upon the consumer buying behavior of fresh vegetables directly from local producers, case study: the quarantined area of Suceava County, Romania. *Int. J. Environ. Res. Public Health* 17, 5485. doi: 10.3390/ijerph17155485

Cardozo, A. G., Barbosa, L., Sisón Cáceres, L. A., Mariño, J., Garis, G., Ojeda, J. C., et al. (2022). Entramado hortícola de la Comarca Andina del Paralelo 42° Río Negro y Chubut: Diseño de estrategias de intervención. PIT interregional I072. [Info:ar-repo/semantics/informe técnico]. EEA Bariloche, INTA. Available online at: http://repositorio.inta.gob.ar:80/handle/20.500.12123/11193 (accessed February 17, 2022).

Cendón, M. L., Molpeceres, C., Zulaica, L., and Rouvier, M. (2021). Agroecología y canales cortos en el contexto del COVID-19. El caso de la horticultura marplatense. Cuyonomics. *Investigaciones en Economía Regional* 5, 90–108. doi: 10.48162/rev.42.036

Chiffoleau, Y. (2009). From politics to co-operation: the dynamics of embeddedness in alternative food supply chains. *Sociologia Ruralis* 49, 218–235. doi: 10.1111/j.1467-9523.2009.00491.x

Craviotti, C., Viteri, M. L., and Quinteros, G. (2021). Covid-19 y circuitos cortos de comercialización de alimentos en Argentina: El papel de los actores sociales. *Revista Europea de Estudios Latinoamericanos y del Caribe* 112, 29–49. doi: 10.32992/erlacs.10780

Ejarque, M., Grinberg, E., and Apablaza, G. F. (in press). Caracterización de ferias de la agricultura familiar en la Patagonia Argentina. Ediciones INTA.

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Chapin, T., and Rockström, J. (2010). Resilience thinking: integrating resilience, adaptability and transformability. *Ecol. Soc.* 15. doi: 10.5751/ES-03610-150420

Frank, M., Kaufmann, B., and Amoroso, M. M. (2020). "Explorando vías de transición hacía manejos agroecológicos: identificando actores, intereses y vías con un enfoque transdisciplinario," in *Congreso Argentino de Agroecología 1er Congreso Argentino de Agroecología: Libro de resúmenes*, eds M. F. Filippini and S. Greco (Argentina: Universidad Nacional de Cuyo), pp. 1245–1249.

Frank, M., and Amoroso, M. M. (in press). Impactos de la crisis causada por el COVID-19 y estrategias de adaptación: Estudio de caso local con productores y productoras agrícolas en la Argentina. Revista Agroecología.

Gliessman, S. (2020). Confronting Covid-19 with agroecology. *Agroecol. Sustain. Food Syst.* 44, 1115–1117. doi: 10.1080/21683565.2020.1791489

Golsberg, C., Alcoba, D., Aradas, M. E., Castiglione, G., Castro, G., Colmann, D., et al. (2010). *Agricultura familiar: Ferias de la agricultura familiar en la Argentina*. Ediciones INTA.

González De Molina, M., and Lopez-Garcia, D. (2021). Principles for designing Agroecology-based Local (territorial) Agri-food Systems: A critical revision. *Agroecol. Sustain. Food Syst.* 45, 1050–1082. doi: 10.1080/21683565.2021.1913690

Gras, C., and Hernández, V. (2021). Global agri-food chains in times of COVID-19: The state, agribusiness, and agroecology in Argentina. *J. Agrarian Change* 21, 629–637. doi: 10.1111/joac.12418

Gutiérrez, M. E., Suárez, M. V., and Villalba, A. E. (2021). Producir y comercializar en pandemia: Estrategias emergentes de los agricultores familiares en Santiago del Estero durante 2020. *Trabajo y Sociedad* XXII, 13–20.

Hale, T., Angrist, N., Goldszmidt, R., Kira, B., Petherick, A., Phillips, T., et al. (2021). A global panel database of pandemic policies (Oxford COVID-19 Government Response Tracker). *Nat. Human Behav.* 5, 529–538. doi: 10.1038/s41562-021-01079-8

HLPE (2019). High Level Panel of Expert on Food Security and Nutrition: Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition. HLPE Report 14. London: FAO.

Hölscher, K., Wittmayer, J. M., and Loorbach, D. (2018). Transition versus transformation: what's the difference? *Environ. Innov. Soc. Transit.* 27, 1–3. doi: 10.1016/j.eist.2017.10.007

IAASTD (2009). *International Assessment of Agricultural Knowledge, Science, and Technology for Development. Agriculture at a crossroads*. Washington, DC: Global Report, Island Press.

INDEC. (2010). *Instituto Nacional de Estadísticas y Censos, Argentina*. Datos del censo 2010. Available online at: https://www.indec.gob.ar/indec/web/Nivel4-Tema-2-41-135 (accessed November 10, 2021).

IPES Food (2016). From uniformity to diversity: A paradigm shift from industrial agriculture to diversified agroecological systems. IPES report. Available online at: https://cgspace.cgiar.org/handle/10568/75659 (accessed March 30, 2018).

Kamberelis, G., and Dimitriadis, G. (2011). "Focus groups: contingent articulations of pedagogy, politics and inquiry," in *The SAGE Handbook of Qualitative Research*, eds N. Denzin and Y. Lincoln (Sage), 545–561.

Kaufmann, B., and Hülsebusch, C. (2015). "Employing cybernetics in social ecological systems research," in *Exploring Cybernetics*, eds S. Jeschke, R. Schmitt, and A. Dröge (Wiesbaden: Springer Fachmedien Wiesbaden), pp. 167–184.

Kolb, D. A. (1984). *Experiential Learning: Experience as the Source of Learning and Development*. Upper Saddle River, NJ: FT press.

Kvale, S. (2012). *Doing Interviews*. London: Sage.

Lal, R. (2020). Home gardening and urban agriculture for advancing food and nutritional security in response to the COVID-19 pandemic. *Food Secur.* 12, 871–876. doi: 10.1007/s12571-020-01058-3

Little, R., Maye, D., and Ilbery, B. (2010). Collective purchase: moving local and organic foods beyond the niche market. *Environ. Plann. A: Econ. Space* 42, 1797–1813. doi: 10.1068/a4262

Madariaga, M. (2009). Sistema de soporte de decisiones para la producción agrícola de los valles cordilleranos patagónicos (SSD). *Presencia*. 53, 16–20. Available online at: https://inta.gob.ar/documentos/sistema-de-soporte-de-decisiones-para-la-produccion-agricola-de-valles-cordilleranos-patagonicos-ssd (accessed November 02, 2021).

Mayring, P., and Fenzl, T. (2014). "Qualitative inhaltsanalyse," in *Handbuch Methoden der empirischen Sozialforschung* (New York, NY: Springer), pp. 543–556.

Merton, R. (1987). The focused interview and focus groups: continuities and discontinuities. *Public Opin. Q.* 51, 550–566. doi: 10.1086/269057

Mezirow, J. (2000). *Learning as Transformation: Critical Perspectives on a Theory in Progress. The Jossey-Bass Higher and Adult Education Series*. ERIC.

Nemes, G., Chiffoleau, Y., Zollet, S., Collison, M., Benedek, Z., Colantuono, F., et al. (2021). The impact of COVID-19 on alternative and local food systems and the potential for the sustainability transition: insights from 13 countries. *Sustain. Product. Consumpt.* 28, 591–599. doi: 10.1016/j.spc.2021.06.022

Ollivier, G., Magda, D., Mazé, A., Plumecocq, G., and Lamine, C. (2018). Agroecological transitions: What can sustainability transition frameworks teach us? an ontological and empirical analysis. *Ecol. Soc.* 23, 2. doi: 10.5751/ES-09952-230205

Opitz, I., Specht, K., Piorr, A., Siebert, R., and Zasada, I. (2017). Effects of consumer-producer interactions in alternative food networks on consumers' learning about food and agriculture. *Moravian Geograph. Rep.* 25, 181–191. doi: 10.1515/mgr-2017-0016

Paganini, N., Adinata, K., Buthelezi, N., Harris, D., Lemke, S., Luis, A., et al. (2020). Growing and eating food during the COVID-19 pandemic: farmers' perspectives on local food system resilience to shocks in Southern Africa and Indonesia. *Sustainability* 12, 8556. doi: 10.3390/su12208556

Perrin, A., and Martin, G. (2021). Resilience of French organic dairy cattle farms and supply chains to the COVID-19 pandemic. *Agricult. Syst.* 190, 103082. doi: 10.1016/j.agsy.2021.103082

Prosser, L., Lane, E., and Jones, R. (2021). Collaboration for innovative routes to market: COVID-19 and the food system. *Agricult. Syst.* 188, 103038. doi: 10.1016/j.agsy.2020.103038

Renting, H., Schermer, M., and Rossi, A. (2012). Building food democracy: exploring civic food networks and newly emerging forms of food citizenship. *Int. J. Sociol. Agricult. Food* 19, 289–307. doi: 10.48416/ijsaf.v19i3.206

Rivera-Ferre, M. G., López-i-Gelats, F., Ravera, F., Oteros-Rozas, E., di Masso, M., Binimelis, R., et al. (2021). The two-way relationship between food systems and the COVID19 pandemic: causes and consequences. *Agricult. Syst.* 191, 103134. doi: 10.1016/j.agsy.2021.103134

Sarmiento, E. R. (2017). Synergies in alternative food network research: Embodiment, diverse economies, and more-than-human food geographies. *Agri. Hum. Value.* 34, 485–497. doi: 10.1007/s10460-016-9753-9

Savary, S., Akter, S., Almekinders, C., Harris, J., Korsten, L., Rötter, R., et al. (2020). Mapping disruption and resilience mechanisms in food systems. *Food Secur.* 12, 695–717. doi: 10.1007/s12571-020-01093-0

Stephens, E. C., Martin, G., van Wijk, M., Timsina, J., and Snow, V. (2020). Editorial: Impacts of COVID-19 on agricultural and food systems worldwide and on progress to the sustainable development goals. *Agricult. Syst.* 183, 102873. doi: 10.1016/j.agsy.2020.102873

Sutherland, L.-A. (2011). "Effectively organic": environmental gains on conventional farms through the market? *Land Use Policy* 28, 815–824. doi: 10.1016/j.landusepol.2011.01.009

Thilmany, D., Canales, E., Low, S. A., and Boys, K. (2020). Local food supply chain dynamics and resilience during COVID-19. *Appl. Econ. Perspect. Policy* 20, 124. doi: 10.1002/aepp.13121

Tittonell, P. (2019). Agroecological transitions: multiple scales, levels and challenges. *Revista de la Facultad de Ciencias Agrarias* 16, 13.

Tittonell, P., Fernandez, M., El Mujtar, V. E., Preiss, P. V., Sarapura, S., Laborda, L., et al. (2021). Emerging responses to the COVID-19 crisis from family farming and the agroecology movement in Latin America—a rediscovery of food, farmers and collective action. *Agricult. Syst.* 190, 103098. doi: 10.1016/j.agsy.2021.103098

UNICEF (2020). Monitoring and Mitigating the Secondary Impacts of the Coronavirus Disease (COVID-19) Pandemic on WASH Services Availability and Access. Available online at: https://www.unicef.org/documents/monitoring-and-mitigating-secondary-impacts-coronavirus-disease-covid-19-pandemic-wash (accessed March 26, 2021).

Urcola, M. A., and Nogueira, M. E. (2020). Producción, abastecimiento y consumo de alimentos en pandemia. *El rol esencial de la agricultura familiar en la territorialidad urbano-rural en Argentina*. 20, 503. doi: 10.35305/tyd.v0i0.503

van der Ploeg, J. D. (2020). From biomedical to politico-economic crisis: the food system in times of Covid-19. *J. Peasant Stud.* 47, 944–972. doi: 10.1080/03066150.2020.1794843

Vyas, S., Chanana, N., Chanana, M., and Aggarwal, P. K. (2021). From farm to fork: early impacts of COVID-19 on food supply chain. *Front. Sustain. Food Syst.* 5, 424. doi: 10.3389/fsufs.2021.658290

Walker, B. (2020). Resilience: what it is and is not. *Ecol. Soc.* 25, 2. doi: 10.5751/ES-11647-250211

Wezel, H.erren, B. G., Kerr, R. B., Barrios, E., Gonçalves, A. L. R., and Sinclair, F. (2020). Agroecological principles and elements and their implications for transitioning to sustainable food systems. a review. *Agron. Sustain. Develop.* 40, 40. doi: 10.1007/s13593-020-00646-z

Workie, E., Mackolil, J., Nyika, J., and Ramadas, S. (2020). Deciphering the impact of COVID-19 pandemic on food security, agriculture, and livelihoods: a review of the evidence from developing countries. *Curr. Res. Environ. Sustain.* 2, 100014. doi: 10.1016/j.crsust.2020.100014

Worstell, J. (2020). Ecological resilience of food systems in response to the COVID-19 Crisis. *J. Agricult. Food Syst. Commun. Develop.* 9, 23–30. doi: 10.5304/jafscd.2020.093.015

Zollet, S., Colombo, L., De Meo, P., Marino, D., McGreevy, S. R., McKeon, N., et al. (2021). Towards territorially embedded, equitable and resilient food systems? insights from grassroots responses to COVID-19 in Italy and the city Region of Rome. *Sustainability* 13, 2425. doi: 10.3390/su13052425

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"Connecting With Good People and Good Plants": Community Gardener Experiences in New York State During the COVID-19 Pandemic

Tomasz B. Falkowski[1†], Bethany Jorgensen[2†], Donald A. Rakow[3], Ashmita Das[4†], Stewart A. W. Diemont[5†], Theresa Selfa[6†] and Austin B. Arrington[7]*

[1] Department of Forestry, New Mexico Highlands University, Las Vegas, NM, United States, [2] Department of Natural Resources and the Environment, Cornell University, Ithaca, NY, United States, [3] Horticulture Section, School of Integrative Plant Science, Cornell University, Ithaca, NY, United States, [4] Department of Environmental Science, State University of New York College of Environmental Science and Forestry, Syracuse, NY, United States, [5] Department of Environmental Biology, State University of New York College of Environmental Science and Forestry, Syracuse, NY, United States, [6] Department of Environmental Studies, State University of New York College of Environmental Science and Forestry, Syracuse, NY, United States, [7] Plant Group LLC, New York, NY, United States

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Edited by:
Ivette Perfecto,
University of Michigan, United States

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Barbora DuŽí,
Institute of Geonics (ASCR), Czechia

***Correspondence:**
Tomasz B. Falkowski
tbfalkowski@nmhu.edu

†ORCID:
Tomasz B. Falkowski
orcid.org/0000-0002-9395-6161
Bethany Jorgensen
orcid.org/0000-0002-8216-1398
Ashmita Das
orcid.org/0000-0003-1692-2934
Stewart A. W. Diemont
orcid.org/0000-0001-8575-6285
Theresa Selfa
orcid.org/0000-0002-9484-8592

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Community gardens are collective projects in which participants collaborate to maintain a garden. They provide many biophysical and cultural ecosystem services, contributing to individual and community resilience and wellbeing. These benefits may be even more appreciated during a crisis such as the COVID-19 pandemic. However, since community gardens require efforts from multiple gardeners in shared spaces, the pandemic also exposed some of their vulnerabilities. This study focuses on the benefits community gardens have offered during the COVID-19 pandemic, the challenges the pandemic posed to sustaining community garden activity, and recommendations to address these issues moving forward. We conducted our study in four cities in New York representing a gradient of socioeconomic and biophysical characteristics: Binghamton, Buffalo, Ithaca, and New York City. We collected data from surveys and semi-structured interviews with community gardeners and analyzed them using mixed models and thematic coding. The primary benefits gardeners derived from their community garden experiences were: a sense of connection with other gardeners, their communities, and nature; mental and physical wellbeing; and a safe space of refuge. In addition to material shortages (e.g., seeds), the biggest challenge gardeners faced due to the pandemic was the limited degree of socializing in the gardens resulting from personal behavioral changes and rules imposed by gardens. Despite the challenges, gardeners reported enjoying the 2020 garden season. The pandemic also created opportunities for gardens to serve their communities, such as organizing programs for composting, food donation and distribution, and home gardening. Our findings suggest that community gardens can be resilient sites of reprieve during crises such as the COVID-19 pandemic, providing essential benefits for gardeners and local residents. To sustain community garden resilience, we recommend community gardens and gardeners cultivate connections and diversity, within and between the biological and human communities of their gardens.

Keywords: resilience, wellbeing, restorative commons, urban gardens, ecosystem services, social learning

INTRODUCTION

The COVID-19 pandemic poses many challenges to individual and community health and wellbeing.

Community gardens are collective projects in open spaces where gardeners collaborate to maintain a garden (Centers for Disease Control Prevention, 2020). As such, they are places where environmental challenges, social isolation, and food security issues can all be ameliorated. However, because community gardens require efforts from multiple gardeners in shared spaces, the pandemic also exposed some of their vulnerabilities and may have jeopardized their benefits to individuals and communities.

For individuals, participating in a community garden can offer a source of fresh, typically organic produce and improve dietary habits through on-site education (Wakefield et al., 2007; Centers for Disease Control Prevention, 2020; LeGreco and Douglas, 2021). One study found that adults with a household member who participated in a community garden were 3.5 times more likely to consume fruits and vegetables at least five times daily (Alaimo et al., 2008). Access to community gardens is of particular importance to the 39.5 million Americans the USDA has estimated currently reside in food deserts (Rhone et al., 2017): geographic areas where residents have few to no accessible options for securing affordable and healthy foods (Ghosh-Dastidar et al., 2017). For such individuals, gardening communally provides a lifeline to fresh fruits and vegetables that would otherwise be unavailable. Beyond nutrition and food security, community gardens contribute to individual health by providing an outlet for reducing stress, promoting a sense of wellbeing, and serving as a social gathering place, thus alleviating loneliness (Lovell et al., 2014).

The emotional and psychological benefits of human-nature connection may be particularly important as rates of mental health concerns in the general population rise during the pandemic (Ettman et al., 2022). Informed by the substantial body of literature demonstrating the benefits of gardening on multiple dimensions of wellbeing (Block et al., 2011; Soga et al., 2017; Spano et al., 2020), some studies have explored how gardening can provide therapeutic benefits, promote relaxation, and help foster a sense of connection amid the strain of the COVID-19 pandemic. For example, Marsh et al. (2021) and Egerer et al. (2022) showed gardeners felt an increased emotional connection to nature during the pandemic, providing them therapeutic benefits during stressful times. Similarly, gardening has been found to help alleviate stress and improve mental or psychological wellbeing during the pandemic (Corley et al., 2020; Giraud et al., 2021; Sia et al., 2021; Theodorou et al., 2021; Egerer et al., 2022).

At the community-level, community gardens can function as "restorative commons" when they provide publicly-accessible, non-excludable open space managed through shared governance. The "restorative" aspect of community gardens emerges when they contribute to "the health and wellbeing of individuals, communities, and the landscape" (Campbell and Wiesen, 2009, p. 11). Community gardens bolster the health and wellbeing of communities by providing spaces where civic engagement and environmental stewardship intersect (Krasny and Tidball, 2009). They can play important roles in community development and empowerment (King, 2008), mobilizing resources for advocacy, and providing places where community members can build relationships and come together to celebrate cultural traditions (Saldivar-Tanaka and Krasny, 2004). Community gardens can also be spaces that allow for social learning and knowledge-sharing among gardeners and garden visitors (Krasny and Tidball, 2009). In terms of aiding the health and wellbeing of the landscape, community gardens entail tending the land. This may involve ecologically restoring plots of land that have been neglected or degraded (Krasny and Tidball, 2009; Campbell and Wiesen, 2009). For cities, community gardens can beautify vacant lots, revitalize communities in industrial areas, revive public parks, decrease violence in some neighborhoods, and improve social wellbeing through strengthening social connections (Centers for Disease Control Prevention, 2020).

Prior to the COVID-19 pandemic, the number of community garden sites was increasing in the U.S. According to the Trust for Public Land, between 2012 and 2018 the number of community garden plots in the 100 largest U.S. cities increased by 44% (The Trust for Public Land, 2018). There was a concern that a crisis, such as a pandemic, would derail the growth in community garden participation (Birky, 2009). However, the COVID-19 pandemic substantially increased peoples' interest and participation in gardening in general, including community gardening (Schoen et al., 2021) as pandemic-related lockdowns, supply chain issues, and inconsistent regulations exacerbated the longstanding plight of food insecurity for U.S. households, exposing the fragility of the nation's food system (van der Ploeg, 2020; Weersink et al., 2021).

Much of the research on gardening during the pandemic published to date has focused on private home gardens and may not reflect the unique opportunities and vulnerabilities of community gardens. One of the studies addressing the benefits of community gardens during the pandemic found that participants in community planting programs had better mental health than those who did not, and even non-participants who lived in the communities surrounding the gardens had better mental health than those who lived in an area without a community garden (Kou et al., 2021). Likewise, Schoen et al. (2021) found that rising interest in community gardening during the pandemic was partially motivated by a desire to self-supply produce.

Our research provides insight into community gardener experiences during the 2020 growing season of the COVID-19 pandemic across four cities in New York State: Binghamton, Buffalo, Ithaca, and New York City. The aim of this study was to better understand the pandemic's impacts on community gardener experiences, including the challenges they faced; how community gardens adapted to these challenges; and how they might continue to improve moving forward.

METHODS

We investigated the following research questions:

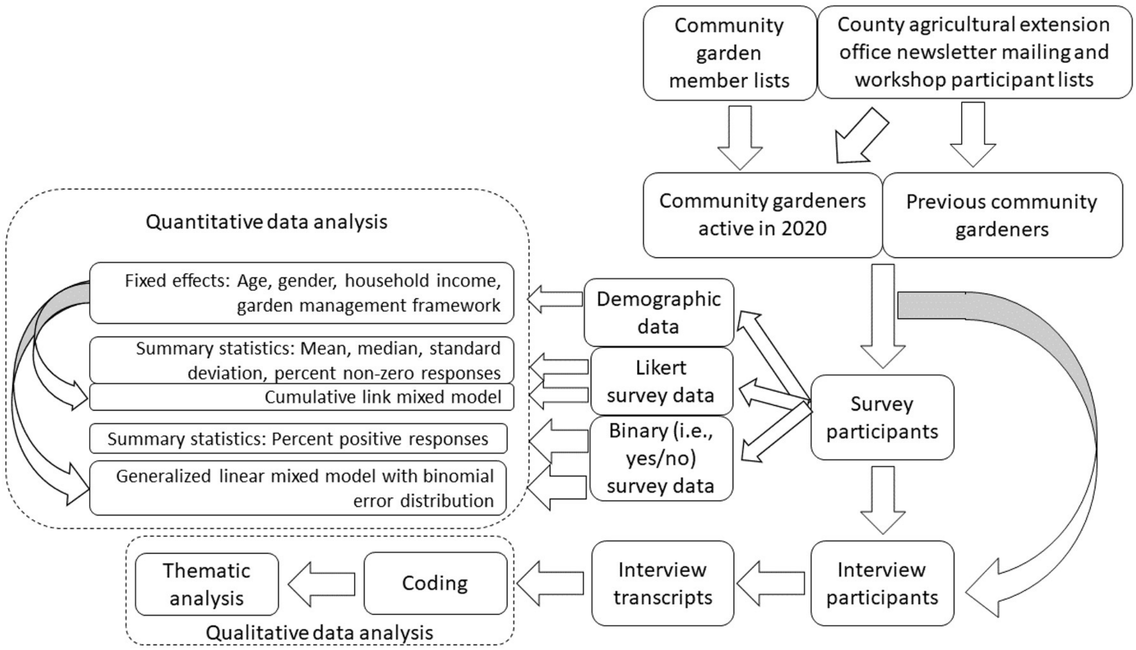

FIGURE 1 | Framework for convergent mixed methods of data collection and analysis.

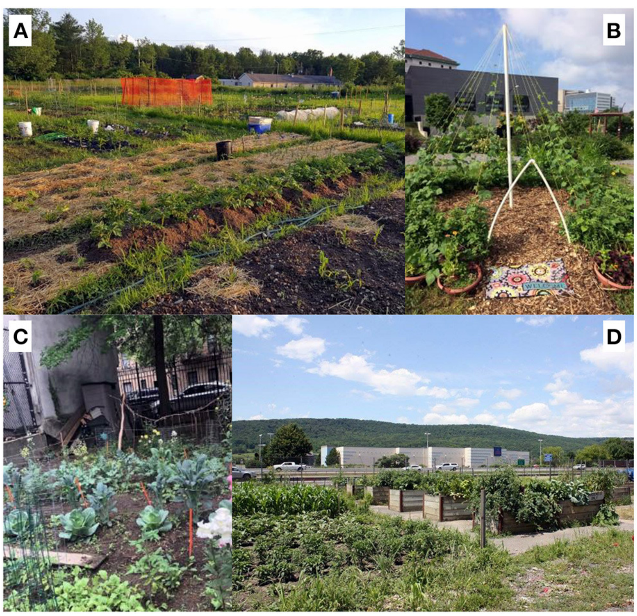

FIGURE 2 | Photographs of community gardens involved in this study: **(A)** Cornell Community Garden (Ithaca, NY), **(B)** Pelion Community Garden ©Caesandra Seawell (Buffalo, NY), **(C)** Shugah Baybees Garden (Harlem, New York City, NY), and **(D)** Otsiningo Gardens (Binghamton, NY).

1) What are gardeners' primary motivations for and benefits from participating in community gardens, and how did these change in light of the COVID-19 pandemic;
2) How did gardens change in order to adapt to the pandemic;
3) What were the challenges and barriers gardeners experienced as a result of these shifts;
4) Were there any positive opportunities that arose as a result of the pandemic; and
5) What are recommendations gardeners might offer to improve their experiences, particularly in light of the pandemic?

To address these questions, we used a convergent mixed methods approach (**Figure 1**), in which quantitative survey data and qualitative interview data were collected in parallel, analyzed separately, and subsequently integrated. We chose this design for its efficiency, particularly in collaborative projects, allowing us to deploy data collection instruments quickly (Creswell and Plano Clark, 2011). The survey and interview data instruments (**Supplementary Information**) complemented one another to fully address our research questions. The convergent mixed method also allowed us to compare and contrast the results from both survey and interview instruments to bring additional insights beyond what would be obtained by either separately.

We collaborated with community garden organizations in Binghamton, Buffalo, Ithaca, and New York City (Brooklyn and Harlem), New York (**Figure 2**). These sites represent distinct socioeconomic and biophysical characteristics, including population density, demographics, urban development, community garden size, and site history (**Table 1**). They also included two distinct community garden management approaches that are common throughout the United States: private-plot gardens, in which a common piece of land managed by a community-based garden organization is divided into plots that are allotted to and independently maintained by distinct individuals or groups; and communal-plot gardens, in which a garden is collectively maintained by a group of community members who all contribute to the work and benefit from the harvests (Lee and Matarrita-Cascante, 2019).

We hosted and administered the surveys using the Qualtrics online platform (Qualtrics., 2021). We recruited participants in several ways to broaden our sample and to include a breadth of perspectives. First, managers of collaborating gardens sent out the survey link to their listservs. We also contacted the Cornell Cooperative Extension offices in our study sites' counties, asking them to distribute the survey link *via* their newsletters and email lists of gardening workshop participants. The latter distribution channel provided an opportunity to contact active gardeners, as well as people who were interested in joining a community garden or had been members of community gardens in the past but who did not participate in one during the 2020 season.

Survey data ($n = 56$) were cleaned to remove submissions responding to fewer than half of the questions. We calculated summary statistics for different groupings of respondents depending on the response variable. Grouping variables included city, garden location urban development [i.e., either urban, suburban, or rural as defined by population density as per Pozzi and Small (2002)], garden name, garden management approach (i.e., communal- or plot-based), educational attainment, immigrant status, race, zip code, household income bracket, and gender. For binary variables, we calculated the percentage of positive responses. For Likert and numeric variables, we calculated mean, median, standard deviation, and percentage of non-zero responses. We also used modeled response values with respondent age [given that COVID-19 poses a disproportionate risk for older people (O'Driscoll et al., 2021)], gender [given changing family care-taking dynamics due to COVID-19 and gender-based differences in community garden experiences (Dolley, 2020; Philpott et al., 2020; Lopez et al., 2021)], household income [given that food insecurity disproportionately impacts poorer people (Laborde and Martin, 2020)], and their community garden management approach (given gardens' unique opportunities, vulnerabilities, and responses to the COVID-19 pandemic) as fixed effects and the city where the respondent gardened (or would have gardened) as the random effect in R (R Development Core Team, 2020). The type of mixed model depended on the type of response variable being modeled. For Likert data, we used cumulative link mixed models using the ordinal package's *clmm* function (Christensen, 2019) as described in Agresti (2018). For binary variables, we used generalized linear mixed models with a binomial error distribution using the *glmer* function in the lme4 package (Bates et al., 2015) as per Zuur et al. (2009). Significance was determined at $\alpha = 0.05$.

The interview participants ($n = 26$) (**Table 2**) were survey respondents who volunteered for follow-up interviews, or gardeners who contacted us directly upon hearing about the study from their social networks, garden managers, or extension offices. Using a semi-structured interview protocol, we conducted and recorded the interviews remotely *via* Zoom. We then transcribed the interviews verbatim and coded the interview transcripts using NVivo software (NVivo, 2020). We developed the initial code book based on our research questions (etic codes) and emergent insights from the survey and interview data (emic codes) (Hitchcock and Nastasi, 2011). We established intercoder reliability by coding a sample interview transcript and running a coding comparison query between the three coders. We checked that the percentage agreement and median Kappa coefficient for all codes were >95% and 0.5, respectively. We refined and clarified any codes that did not meet these criteria to finalize the codebook (**Supplementary Materials**). After coding all interviews, we conducted a thematic analysis based on the coded materials, which we refined iteratively to identify key themes in the interviews related to our research questions (Lester et al., 2020). Finally, we used crosstab analysis in NVivo to identify patterns in codes between participant characteristics (selected based on significant fixed effects from survey result analyses) and NVivo matrix coding queries to identify concordant and incongruent codes.

RESULTS

Motivations and Benefits

From the interviews, the major themes of connection and wellbeing emerged as the key motivations for, and benefits of, being a community garden member. To a lesser degree, gardeners noted they joined the community garden in part because they did not have adequate conditions to cultivate a garden at home (e.g., yards that were small, non-existent, inaccessible, or shaded, or had poor or polluted soil). The COVID-19 pandemic had no bearing on this motivation.

According to surveys, the highest-valued benefits gardeners derived from participating in community gardens were: providing tasty, fresh, and healthy food; exercise; connection to nature; and education (**Figure 3**). Social interaction and relationships were deemed less important according to the surveys. The median responses indicated that the importance of these benefits generally did not change from years prior to the 2020 season, and any changes that we observed were not significant. Gardeners' expectations for the 2020 garden season were largely met with a few exceptions (**Table 3**). Age was consistently a significant fixed effect influencing the importance of several benefits; older people were generally less interested in community gardens' capacity to provide tasty food ($\beta = -2.817$, $p = 0.005$), fresh food ($\beta = -3.330$, $p < 0.001$); healthy food ($\beta = -3.536$, $p < 0.001$); food stability ($\beta = -0.104$, $p < 0.004$); and sufficient food ($\beta = -2.628$, $p = 0.009$). They were also generally less satisfied with their garden experiences in 2020.

Connecting With People

The community gardens in our study, regardless of management approach, provided spaces that brought people together. The most common interview response regarding gardeners' motivations to join community gardens were friends and family who were already gardeners. Interview participants understood gardening as a source of connection to their loved ones and heritage. In certain cases, they joined the community garden anticipating socializing with friends who also were garden members. P2, a young gardener at a plot-based garden in

TABLE 1 | Descriptive statistics of the urbanized areas containing the community gardens involved in this study (Census Reporter, 2021), community garden management approach (i.e., private allotment plot or communal), and the number of survey and interview participants from each garden involved in our study.

Urban area	Urbanized area population density (people/mi^2)	Urbanized area median per capita income (USD)	Urbanized area median age (years)	Garden	Community garden management approach	Instrument	*n*
Binghamton	1,982	27,956	37	Otsiningo Gardens	Plot-based	Interview	1
						Survey	3
				Pine Street Community Garden	Plot-based	Interview	0
						Survey	2
Buffalo	2,439	33,768	40	Lincoln Community Garden	Communal	Interview	0
						Survey	1
				FeedMore WNY Garden	Communal	Interview	1
						Survey	3
				Putnam Street Community Garden	Plot-based	Interview	1
						Survey	1
				Pelion Community Garden	Communal	Interview	0
						Survey	1
				Jewish Family Services Community Garden	Communal	Interview	1
						Survey	2
Ithaca	2,213	30,276	24	Cornell Community Garden	Plot-based	Interview	10
						Survey	19
				West Village Community Garden	Communal	Interview	1
						Survey	1
				Ithaca Community Garden	Plot-based & Communal	Interview	2
						Survey	2
				Floral Avenue Community Garden	Communal	Interview	1
						Survey	1
Brooklyn	36,901	37,352	36	Prospect Heights Community Farm	Communal	Interview	2
						Survey	17
				Maple Street Garden	Communal	Interview	0
						Survey	1
				Nehmiah Ten Greenthumb Garden	Plot-based	Interview	1
						Survey	2
Harlem	9,537	38,830	35	Shugah Baybees Garden	Communal	Interview	1
						Survey	1

Note that survey and interview participants are not exclusive.

TABLE 2 | Case classifications of interview participants used for quote identification in this manuscript.

Participant #	Age (years)	Gender	Race	Household income bracket (USD)	Educational attainment	Garden community	Garden management approach	Garden urban development
P1	30	Female	Black	$12,501–25,000	Bachelor or equivalent	Harlem	Plot-based	Urban
P2	27	Female	White	>$100,000	Masters or equivalent	Ithaca	Plot-based	Suburban
P3	33	Female	Asian	>$100,000	Doctoral or equivalent	Ithaca	Plot-based	Suburban
P4	NA	Male	White	>$100,000	Doctoral or equivalent	Ithaca	Plot-based	Suburban
P5	58	Female	White	$75,001–100,000	Masters or equivalent	Ithaca	Plot-based	Suburban
P6	49	Male	Asian	$50,001–75,000	Doctoral or equivalent	Ithaca	Plot-based	Suburban
P7	34	Male	White	$75,001–100,000	Masters or equivalent	Ithaca	Plot-based	Suburban
P8	68	Female	White	>$100,000	Masters or equivalent	Brooklyn	Communal	Urban
P9	39	Female	Asian	$75,001–100,000	Doctoral or equivalent	Ithaca	Plot-based	Suburban
P10	33	Female	White	$25,001–37,000	Bachelor or equivalent	Ithaca	Plot-based	Suburban
P11	53	Male	Asian	$50,001–75,000	Doctoral or equivalent	Ithaca	Plot-based	Suburban
P12	48	Male	White	$25,001–37,000	Masters or equivalent	Brooklyn	Communal	Urban
P13	NA	NA	NA	NA	NA	Buffalo	NA	Urban
P14	71	Female	White	$50,001–75,000	Bachelor or equivalent	Buffalo	Communal	Urban
P15	NA	NA	NA	NA	NA	Buffalo	NA	Urban
P16	47	Female	Asian	$12,501–25,000	Masters or equivalent	Ithaca	Communal	Suburban
P17	36	Female	White	>$100,000	Masters or equivalent	Ithaca	Plot-based	Suburban
P18	66	Female	White	$50,001–75,000	Masters or equivalent	Buffalo	Plot-based	Urban
P19	34	Male	Two or more	$75,001–100,000	Masters or equivalent	Harlem	Communal	Urban
P20	48	Male	White	>$100,000	Bachelor or equivalent	Ithaca	Plot-based	Suburban
P21	NA	NA	NA	NA	NA	Buffalo	Communal	Urban
P22	NA	NA	NA	NA	NA	Binghamton	Plot-based	Suburban
P23	33	Non-binary/Gender fluid	Two or more	$37,001–50,000	Bachelor or equivalent	Buffalo	Communal	Urban
P24	NA	NA	NA	NA	NA	Ithaca	Plot-based	Suburban
P25	NA	NA	NA	NA	NA	Ithaca	Plot-based	Suburban
P26	70	Female	White	$25,001–37,000	Bachelor or equivalent	Harlem	Plot-based	Urban

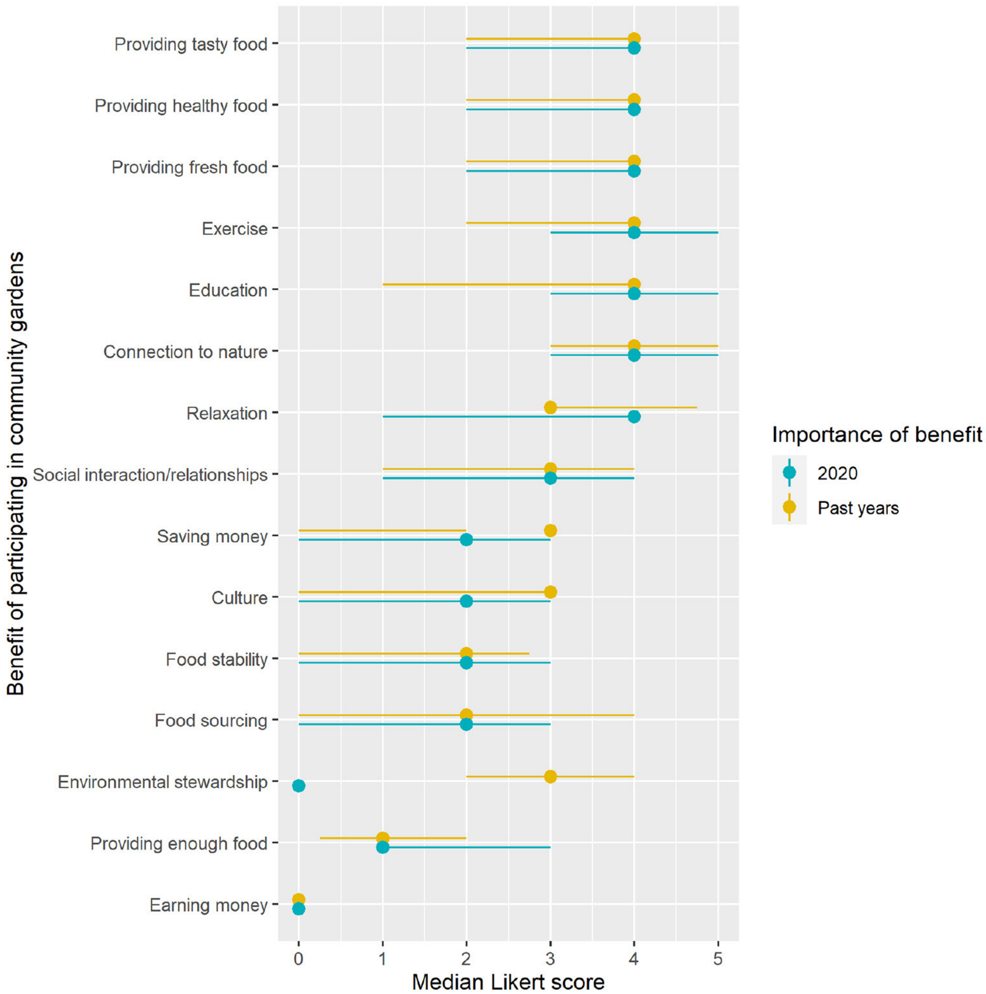

FIGURE 3 | Medians (points) and interquartile ranges (lines) for Likert scores describing the importance of various benefits of participating in community gardens (5 = essential, 4 = very important, 3 = important, 2 = somewhat important, 1 = appreciate but not important, 0 = not applicable/irrelevant).

Ithaca, articulated their intent to garden with friends, which was upended by the pandemic:

> "We have a couple friends [who] gardened at that garden last year, and I think we had planned on joining the garden prior to the pandemic hitting the US. It was initially going to be a social thing where we all go to the garden together and like you know, bring some chairs and talk about tomatoes or whatever. Obviously, that changed, and we did have a garden plot right next to our friends, but we didn't really plan on going at the same time or anything like that because of the garden rules."

Gardeners also often talked about the process of forming connections in terms of community building, which was the second most common motivation mentioned by gardeners we interviewed: to contribute to and benefit from the community that arose in and around the garden. Many gardeners mentioned the importance of their garden as a place to socialize, both for gardeners and for other members of the community. In many cases, this happened just in chatting casually with other gardeners. Socializing also occurred during moments of social learning by exchanging advice, tips, and techniques. For example, P22, a gardener in Binghamton, noted, "I am also interested in the community aspect of it where we can get to know each other and share techniques, and you're always learning things from other people." Community gardens also provided space for cross-cultural exchange, with P2 observing, "Another cool thing about the garden was there [were] a lot of people from different countries and speaking different languages." For some, the opportunities for socializing and connection that community gardens provided were particularly important during the pandemic, as P19, who gardened at a communally-managed garden in Harlem, pointed out:

> "I think the one [benefit] is social interaction. I think that's huge. I think that because there's enough space in the garden, and in this

TABLE 3 | Respondents' median Likert scores (interquartile ranges presented in brackets) for gardeners' satisfaction with the benefits provided by participating in the 2020 community garden season, the significant fixed effects correlated with these scores (NA, 1 = very unsatisfied, 2 = somewhat unsatisfied, 3 = neither unsatisfied or satisfied, 4 = somewhat satisfied, 5 = very satisfied).

Benefit of participating in community gardens	Satisfaction with 2020 garden season benefit	Significant fixed effects on satisfaction with 2020 season
Providing tasty food Providing fresh food Providing healthy food	5 [4,5]	NA
Connection to nature	5 [4, 5]	Age (β = −0.077, $p = 0.004$)
Exercise	4 [4, 5]	Male (β = 1.713, $p = 0.036$)
Education	4 [3, 5]	Age (β = −0.061, $p = 0.005$)
Relaxation	4 [4, 5]	Age (β = −0.081, $p = 0.003$)
Culture	3 [0, 4]	NA
Saving money	3 [0, 4]	NA
Social interaction/relationships	3 [2, 4]	Age (β = −0.054, $p = 0.028$)
Environmental stewardship	NA	NA
Food stability	NA	NA
Food sourcing	NA	NA
Providing enough food	4 [4, 5]	NA
Earning money	0 [0, 1.5]	NA

> time, you are able to socialize which is really huge. And especially in terms of the loneliness and depression that we're facing in these times, that was really beneficial."

Connecting With Nature

The community gardeners we surveyed and interviewed also made it clear that one of the primary benefits they enjoyed was the connection they formed with the ecological community and the place itself. Some framed this in terms of environmental stewardship by growing pollinator-friendly plants, like P3, a gardener from a plot-based garden in Ithaca, who "introduce[d] ladybugs to all our plants, and we did coordinate on some things like what pollinator plants we wanted to attract like native pollinators." Another example of this was from gardens in Harlem and Brooklyn that administered a community-wide program for collecting and composting food waste, which would then be used to nourish the garden's soil. Gardeners recognized the reciprocal relationship between themselves and the gardens. P1 said they enjoyed participating in the community garden because:

> "Just contributing to the community and finding other people who do the same as well...I'm always here for networking, connecting with good people, good people and plants... When we have harvested goods, they give not just to the people who give to the garden, but to the community who show up... I'm giving back, but it's also going to give back to me, because the compost is going to turn back into soil; then I'll plant food in it, and that will give back to me."

Connecting Despite COVID-19

One way in which connection was maintained through and in community gardens during the pandemic was food sharing. Most gardeners said they shared the same amount or more produce than in previous seasons, with some mentioning being more acutely aware of food insecurity in their community, such as P10, a gardener in Ithaca, who said:

> "I gained more of an appreciation for the value that gardening has for people individually. Especially for food security... Everyone was going through the shock waves of not being able to get the food they wanted at the supermarket and to know I could go to the garden to get some fresh tomatoes and not have to worry was pretty great."

In the interviews, urban gardeners generally spoke more about the importance of the gardens for building community and providing food security for non-gardeners during the pandemic. For example, P12, a gardener from Brooklyn, said their garden developed a new food sharing program in 2020.

> "Anyone who wanted to donate their plot for this season was being asked if they wanted to do that, we would take care of it, water it, grow it, and give it to people in the community that needed help. Maybe a third of the garden did that. We have been giving away produce every Sunday morning, and it has been word of mouth, but we put a sign out front with 'are you experiencing food insecurity because of COVID?'. It has been an honor system. We don't ask; we just give stuff away. It has been really nice."

Wellbeing

Relaxation was an important benefit for many surveyed gardeners, and the related theme of wellbeing resonated throughout the interviews. Many gardeners talked about the mental and emotional motivations for and benefits from participating in their community garden. Many expressed appreciation for their garden as a place that provided not only the opportunity for socializing and connecting with others, but also a place they could go to find solitude. During the pandemic, this was particularly important for some gardeners. P17 from Ithaca articulated this, saying:

> "I also think it definitely played a heavier part in my mental health... [Before the pandemic] sometimes I would skip going. Now, if I skip going...I need to get outside and have alone time. Family members are in the house, and it's a way to get away from all that."

Gardeners also appreciate their gardens as peaceful places of refuge from the hectic world, as mentioned by P12 in Brooklyn, who said, "It just stops the clock, the pace of our modern lives; it slows everything down and it makes you look at a whole other process that is unfolding in its own time." Gardeners also reflected on the meditative aspect of gardening, bringing them more fully to the present moment. For instance, P19 in Harlem said, "[The urban garden] was a place of relaxation and meditation, a place where I could just focus on the earth, and I would say it was definitely really therapeutic to me in that time." During such moments, gardening offers opportunities for self-reflection and a means for practicing acceptance. One participant even shared that gardening served as therapy for her as she grieved her husband's death. Many gardeners expressed that the stresses caused by the COVID-19 pandemic only underscored the importance of community gardens in fostering mental wellbeing.

Related to the reciprocal relationships gardeners establish with their gardens, gardeners mentioned the importance of how gardening gives them a sense of purpose, especially in the context of COVID-19, when work and other events and activities had been canceled. P7 from Ithaca noted, "it was one of the things that we could in fact actually do this year," and P6, also from Ithaca, said, "I probably felt a lot more comfortable setting aside time for the garden; not having that expectation of showing up somewhere certainly made it easier to feel comfortable taking...whatever time I needed to go there." Gardeners discussed how gardening created a sense of responsibility, which helped overcome inertia, malaise, anxiety, and depression due to the COVID-19 pandemic to actively engage out in the world.

Reflecting on the importance of gardening as a form of exercise expressed in the surveys, interviewed gardeners also talked about the physical benefits of gardening, again, particularly during the COVID-19 pandemic. Gardening provided gardeners a reason to leave the house at a time when many were living in lock-down conditions. It also provided a break from doing desk work while working from home, as noted by P4 from Ithaca, who said, "It was a distraction...I'm working from home, so anything to get over that." Gardeners appreciated how time in the garden meant time outside in the fresh air. Several also mentioned their garden as a good place for children to have the chance to run around. Along with the physical benefits, many gardeners also noted their appreciation for the quality of the food they grew in their gardens, which helped keep them accountable for eating healthily. For the gardeners we spoke with, their participation in a community garden was less about ensuring food security in terms of calories, and more to ensure they could get the varieties and quality of food they preferred.

Challenges, Barriers, and Opportunities

In addition to the impact of COVID-19 on the benefits gardeners derived from community gardens, we also sought to understand other challenges and barriers gardeners faced in participating in community gardens during the 2020 growing season, as well as new opportunities brought about by the pandemic. Interviews revealed that the biggest challenge most gardeners faced due to the COVID-19 pandemic was a lack of social connection due to restrictions on garden access and guests, event cancellations, gardeners being reticent to socialize, and choosing to work at times when the garden was not busy.

Disrupted Connections

Although many gardeners appreciated community gardens' capacity to cultivate social relationships and build community, the COVID-19 pandemic had mixed effects on the sense of connection they were able to derive in the 2020 season. In interviews, more gardeners expressed feeling isolation in the gardens (14) than feeling a greater sense of connection (5) due to COVID-19. Gardeners talked about noticing less socializing taking place in the garden, with P3 observing, "this is really a different world. You're really antisocial gardeners now."

Sometimes the lack of socializing was a voluntary choice on the part of gardeners who were guarded due to concerns over COVID-19 transmission, particularly in early days of the pandemic. For example, some gardeners said they chose to work in the garden during times when few other people would be there. For instance, P2, a gardener in Ithaca, said:

> "I don't think it really had that community atmosphere as much. A couple times, we'd go out and there'd be someone who was playing music while gardening, so we got a little bit of that vibe. Most of the time we tried to go when no one else was really there so we didn't have to worry about things as much. . . We were planning on having it as a social kind of thing. We ended up not doing that, and so it didn't really feel like a community garden; it was just like our garden away from home."

Similarly, some gardeners worked more efficiently to limit their time in shared spaces, like P11, another Ithaca gardener, who said, "I had a short work time, so I worked hard. I reduced my communication with my neighbor. Normally, I like talking to them, but this reduced my talking time." This guardedness and reticence to socialize was not necessarily a sign they did not care about their fellow gardeners; a few people explicitly mentioned increased concern about their neighbors and community, including P26, a gardener in Harlem, who said, "We call more now. . . Now, for example, for a whole month, if I don't see my neighbor, I call and ask if everything is okay."

In other cases, reduction in socializing was due to new COVID-19 regulations stipulated by the garden managers for health and safety reasons. Survey responses showed that these new rules were largely supported by gardeners and did not negatively impact community gardeners' experiences in 2020. For example, while many people expressed missing events that were typically held in the garden but needed to be canceled due to pandemic -related restrictions, others observed that hosting events virtually rather than in-person had the unexpected benefit of making them more accessible. Similarly, "members only" policies implemented by a few gardens made some of those gardeners uncomfortable with the newly instated exclusivity and engendered a sense of isolation from the community. As P12, a gardener in Brooklyn, mentioned, "We closed the garden [to non-members] because of COVID, but then it started to feel like just a private garden club; the people that were members had keys but then no one else could come in. . . " P24 similarly reflected about their garden in Ithaca:

> "I think the new sort of rules around visitors were a little bit limiting. . . If I was hanging out with someone and we were looking

> to do something outside, it was no longer an option to go to the garden plot together because, for obvious reasons, that wasn't allowed this year."

A few gardeners in communal gardens said they did not have access to their garden and lost the garden as a place to socialize altogether. That said, a subset of these gardens reopened later in the season. P8, from one such garden in Brooklyn, recalled, "The whole thing was [initially] closed, and everything was just haywire as far as normal contributions to the garden went, and... the requirement for doing open hours was gone, because there were no open hours."

Material Challenges

The pandemic introduced new material challenges and barriers besides the typical issues posed by pests, poor soil quality, and the weather, which affected gardener experiences and community garden viability across our study sites. In particular, gardeners mentioned COVID-19 driven supply chain disruptions limiting availability of materials like seeds, seedlings, compost, and soil. P6 from Ithaca said, "A lot of places were sold out of the varieties that I wanted. I think that was probably the biggest hurdle." By contrast, while some encountered limited seed selection, others were able to get the basics of what they wanted to grow, as indicated by P19 from Harlem, who said, "I met a really awesome guy who has a farm upstate...so we got a lot of plugs [from him], and then I was able to access plenty of seeds from the hardware store." Compared to previous purchasing habits, some gardeners also mentioned they were doing more shopping online for their gardening supplies.

Material deficiencies also impacted a limited subset of garden organizations. One garden was unable to source compost, which had previously been a shared resource for their garden community. Furthermore, some gardens' rules impacted material accessibility for gardeners, such as recommendations against gardeners sharing tools with each other or eliminating shared tools altogether. Although the overwhelming majority of gardeners largely agreed with new COVID-19-related rules, several gardeners saw the decision to eliminate shared tools as excessive in hindsight, referencing other gardens that chose to continue making shared tools available with the expectation gardeners would sanitize them after use. P20 pointed out that, among Ithaca gardeners:

> "Things have changed in terms of how we react to the idea that there's transmission. There was a lot of, I can't say overreaction, but there were lessons learned... Shared equipment, providing a wheelbarrow...I would lobby that we can safely provide that equipment."

Along with this, some gardeners talked about running into challenges due to a lack of knowledge, time, energy, physical resources, and/or human resources. The COVID-19 pandemic brought a boom of gardeners for some gardens and a bust for others. Several gardens in this study, typically larger, more established gardens with a plot-based management style, had more gardeners than ever due to high interest. On the other hand, some gardeners from smaller or communally-managed gardens talked about their gardens struggling to keep up with maintenance due to a lack of volunteers, and how the responsibility to keep the garden going fell on a pared-down number of staff or volunteers. P14 from Buffalo said, "Only having two in the [communal] garden, it was a lot more physical work, and I think we're all getting older." Similarly, in reflecting on the challenges facing the communal garden they participated in, P23, also from Buffalo, said:

> "Over the summer we had planned on bringing in a few different volunteer groups to sort of revamp the garden and get things together. Naturally we weren't able to bring on any volunteer groups because of coronavirus...two [staff] kind of collaborated together with a few...interns to get our garden really up and running again."

Safety Concerns

Perception of safety of community gardening during the COVID-19 pandemic was not a function of gardener age, race, gender, income, or other gardener characteristics. However, it was correlated to garden management type, with a greater percentage of members from communally-managed gardens seeing their garden as a safe space (43%) than those with plot-based management (33%). Additionally, 56% of plot-based gardeners reported being less sociable in the gardens in 2020 relative to previous years (compared to 28% of communal gardeners) and talked about the corresponding decline in the social benefits of participating in their community garden. As P3—who participated in a plot-based garden in Ithaca—said:

> "We just wave but definitely weren't as social with people in the plots next door to ours...I would actually work on the far side of my planting area if they were on the side of their plot that was close to mine. It was a deliberate 'give them space, give me space' kind of thing... almost antisocial behavior to plot mates."

These trends in guardedness were also reflected in varying feelings of disconnection. Plot-based gardeners discussed not socializing or talking to their neighbors as a change in behavior. In discussing his relationships with other gardeners in his plot-based garden in Ithaca, P11 stated, "Normally I like talking to [my neighbor], but this reduced my talking time." Ithaca particularly stood out as a community where gardeners became atomized in their own plots within their garden. The demographics (i.e., educational attainment), garden management style (i.e., dominated by plot-based management), and urban development (i.e., suburban) in Ithaca influenced which participants were more likely to express feelings of isolation and less likely to engage with others in their community garden. For instance, those with advanced degrees were more likely to express feeling isolated (100%) compared to those with less education (33%). Similarly, gardeners in suburban, plot-based community gardens were more likely to avoid socializing (72%) compared to those in urban and communally-managed gardens (14%).

Even so, several gardeners in suburban, plot-based gardens said they considered the garden a safe space for socializing, such as P24, who said, "things started to look up with things sort of loosening and thinking more about, you know, that the garden would probably be a pretty safe space to occupy, I... signed up," when reflecting upon the decision to join a plot-based garden in Ithaca. For a few participants in suburban gardens, concern about safety and COVID-19 transmission also gave them pause when it came to food sharing. They generally still shared their garden produce with friends and family, whereas donation seemed a bigger component of food sharing in urban gardens. Overall, most gardeners did not change their food sharing habits due to COVID-19.

Barriers

Whereas, challenges were commonplace, very few interview participants expressed any outright barriers to participation. Similarly, only 36% of survey respondents felt the COVID-19 pandemic raised substantive obstacles to their gardening experience. Not quarantines, high costs, lack of childcare, public transport, materials, time, information, or interest, nor closure of knowledge resources or gardens posed an impediment to their garden experiences ($x = 0$: Not a barrier/impediment). Even health concerns barely registered as a barrier ($x = 0.5$). By and large, in our sample, those who wanted to participate in community gardens were able to do so. That said, those with higher household incomes were less impacted by high costs and lack of public transport ($\beta = -1.562$, $p = 0.024$). Of those barriers mentioned during interviews, some were personal, including several would-be gardeners who decided not to participate in the 2020 season because either they themselves were at high-risk for COVID-19 or they were living with others who were. Another participant talked about the overwhelming pressures of other responsibilities that led to their abandonment of their garden responsibilities. Other barriers mentioned were organizational, in that some gardens did not accept new members, or had a cap on membership causing waiting lists, or, in the case of one person, their community garden was closed due to space concerns and financial constraints exacerbated by COVID-19.

Opportunities

It was just as common for gardeners to talk about the opportunities as the challenges they found in the 2020 growing season. Many gardeners talked about the pandemic providing opportunities for developing new programs, such as food donation, composting, seed starting, online courses, Victory-style Gardens [gardens planted at home residences modeled after those cultivated during wartime to supplement rations (Music et al., 2021)] (e.g., Freedom Gardens, so named to avoid wartime connotations), and volunteering to care for plots of sick members. Many of these new programs aimed to support gardeners along with the broader community, making the community garden into more of a community resource, and were an outlet for service and caring for others during difficult times. For instance, in discussing the new Freedom Gardens program offered by a community garden organization in Buffalo, P21 said:

> "Some people [said]...you just pivoted on a dime to Freedom Gardens and that's great. And I had other people say to me that's not part of your mission. You're community gardens. Why are you bothering spending your time and resources and staff time and money on residential gardens? And my answer is we make a community where they are, and if you're in a pandemic and people need food and they can't get to [a] community garden or they don't feel safe going into community gardens, we are going to do everything we can to open those gardens...it's a 'both and'."

Gardeners expressed increased awareness of food insecurity in their communities and made efforts to contribute to food donation programs. The new programs relied upon gardens being able to be flexible with shifting mission objectives and funding sources to support them. Several gardeners noted they had more time or flexibility in timing since they were working from home and not pursuing activities outside of work. At least one gardener talked about how they were able to devote more time to the garden because they had lost their job due to the pandemic.

Gardeners' Recommendations

Finally, we considered what gardeners themselves would recommend to improve their community garden experience and overcome challenges they faced, particularly in the context of the COVID-19 pandemic. Overall, during interviews, gardeners talked about being satisfied during the 2020 growing season, along with their ability to overcome challenges in ways that did not detract from their community garden experience. The majority appreciated the decisions taken by their community garden managers to keep the garden running and keep gardeners safe in light of the COVID-19 pandemic.

Notwithstanding their overall satisfaction with the 2020 community garden experience, most gardeners had suggestions for improvements, particularly in the context of the COVID-19 pandemic. From the survey data, only 16.3% of respondents claimed they had everything they needed for a successful and fulfilling garden season. Some gardeners offered suggestions for things they would like to see implemented in their garden to address the vulnerabilities the pandemic exposed, such as physically changing the garden, offering opportunities for safely developing community connections among gardeners, and extending their garden's outreach to their broader community.

Information and Knowledge-Sharing

The most common recommendation (52.7% of respondents) was for more information about gardening, particularly in an online format (47.2%). P1, a self-described less-experienced gardener who joined the garden during the pandemic proposed establishing apprenticeship-type programs that would pair new gardeners with long-time gardeners or Cooperative Extension-certified Master Gardeners. P8, a more experienced, 68-year-old gardener echoed this, suggesting the creation of a Garden Ambassadors program to introduce the garden to the community and provide gardening guidance to newcomers, saying:

> "For someone who is not familiar...with gardening or with the organization or social situation that is involved with a community

> garden, I think it could be intimidating. And I think that it would be a really good thing to have some kind of garden ambassadors or something."

Garden Accessibility

Making their garden more accessible for community members, particularly school children, was another common refrain in the interviews. P23 from Buffalo suggested, "I like the idea of being intentional about bringing in small groups of people to enjoy time there," and P8 from Brooklyn added, "It's a great thing for kids to learn about, and I think the more accessible, and, you know, friendly community gardens can be made...the better." This connects with another recommendation to increase educational opportunities for the community through the garden.

Some gardeners proposed various physical alterations to community gardens that might help restore some of the sense of community lost amid the pandemic, such as establishing a dedicated outdoor dining and event area. A few interviewees recommended changing the layout of their garden to facilitate physical distancing, including bigger plot sizes, and to make it more visible to members of the surrounding community. P15 from Buffalo articulated this, saying:

> "It was configured as a small plot here, a small plot there, a small plot somewhere else. I think that was a problem...I think if in a perfect world, there would be an acre, an acre and a half plot somewhere...in kind of a central location that's central to the community that needs to be served…"

Garden Networks and Mutual Aid

Additionally, gardeners proposed creating community garden networks where gardeners from different gardens can share ideas, experiences, and resources. Gardeners also discussed recommendations for improving connections between their garden and the broader community. For example, some gardeners we interviewed said they would like to see more collaboration with mutual-aid groups in their communities to make their garden into more of a community resource. This was also borne out in the example of several gardeners whose motivations for participating in the community garden included its function as a community resource in light of the pandemic. As P12 from Brooklyn pointed out, the pandemic "kind of re-centered the garden as a place that could give back to the community and versus just like a hobby kind of thing you are just going to plant some seed, but it was like actually a tangible thing that we could do." This could entail organizing food and seed exchanges or establishing more of a social media presence to facilitate connections between garden members and with the broader community. In particular, gardeners from Buffalo and Brooklyn talked about their hopes to continue the Freedom/Victory Garden programs their gardens started during the pandemic to allow those who did not feel safe in the community garden to grow food at home. As P8, also from Brooklyn, stated:

> "The garden is, right now, intending to continue the Victory Garden in the next season. I don't know if it's been you know, officially established or whatever, but I think that, you know, until we get world peace and everybody has enough to eat, which is not happening immediately, I think it would be a really good thing to continue, and I believe that only happened because of COVID."

Others articulated more organizational alternatives, such as holding collective work days to lighten the burden of care for the garden and give gardeners opportunities to build relationships with each other by working together. P6, a member of a plot-based garden in Ithaca, said, "I have a cooperative mind, so it seems like with just a little bit of effort we can make everyone's life a lot easier by [collectively] piling our rocks over there [outside the garden] at the beginning of the season."

DISCUSSION

Community Garden Connections During COVID-19

Our findings suggest that community gardens could be resilient sites of reprieve and relative normalcy for their gardeners during the COVID-19 pandemic and other crises. Generally, gardeners' primary motivations for and benefits from participating in their community garden were not substantially impacted by the pandemic. Each community garden implemented new rules to reduce risk of COVID-19 transmission, and for the most part these rules were supported and upheld by gardeners. While the community gardeners in our study experienced a mix of opportunities and challenges during the 2020 growing season, very few encountered outright barriers preventing them from participating at all in their garden.

Community gardens are typically places for socializing and relationship-building. The majority of community gardens in our study were able to offer gardeners safe spaces to socialize and participate in a collective endeavor linking them to their broader socioecological community (Svendsen, 2009). Interviewed gardeners consistently praised community gardens as places for cultivating positive connections with others, which Birky (2009) also identifies as a key component of the community garden experience. This aligns with studies that have found community gardens to be hubs for community building (Saldivar-Tanaka and Krasny, 2004; King, 2008). To our surprise, however, social relationships were not rated as particularly important in the survey. It may be that gardeners did not recognize the importance of this benefit prior to the disruption of the pandemic, and the dissatisfaction with the social interaction in their community garden in 2020 may have undermined how respondents rated its importance for that season. It may also have been that gardeners who were more outgoing were more likely to participate in the interviews.

The COVID-19 pandemic negatively impacted community building for many participants, who indicated they were not satisfied with social relationships in their community garden during the 2020 season due to COVID-19-related rules and behavior changes. Similar to Mejia et al. (2020), we found that community gardens offered a space gardeners felt was safe on the whole, but even so, many indicated their gardens felt less social during the 2020 growing season than in previous years.

This feeling of isolation was particularly acute among gardeners maintaining private plots. Even so, the separation afforded by this management approach did not necessarily translate into a greater feeling of safety, compared to gardeners working in communal gardens.

Our findings show that community gardens can also be refuges where gardeners and community members can find peace, solace, relaxation, and solitude. These characteristics are all the more critical given the mental health crisis exacerbated by COVID-19. Our results corroborate the growing number of studies demonstrating the therapeutic benefits of spending time in nature, and particularly gardens (Mahbub Hossain et al., 2020; Pfefferbaum and North, 2020; Rajkumar, 2020; Kumar and Nayar, 2021).

The community gardeners in our study reported creating meaningful connections with nature through their gardens at a time when COVID-19 restrictions confined many to spending most of their time indoors. Spending time in nature is important for physical and mental wellbeing (Frumkin et al., 2017), and during the pandemic people have exhibited increased interest and involvement in community gardens (Lin et al., 2021; Mullins et al., 2021; Schoen et al., 2021; Theodorou et al., 2021), perhaps more uniformly than other forms of greenspaces (Rice and Pan, 2021). Our study supports research showing that community gardening is a unique way to connect with nature and foster socioecological resilience. Gardens provide places for peace and solace as well as belonging, with the added dimension of gardeners' physical connections to the place through tending the plants and the soil (Krasny and Tidball, 2009). For many gardeners, being part of their community garden offered them a way to connect socially and ecologically with something greater than themselves. This finding supports the argument that active stewardship through community gardening links the individual to the collective in ways that are restorative in and for public space (Svendsen, 2009).

Unlike outdoor recreation, the active stewardship of community gardens provides gardeners with additional purpose while spending time in nature, and promotes a more intimate, positive relationship between people and their broader ecological community. This has been particularly important during the COVID-19 pandemic. Participants noted they were thankful for the sense of responsibility they derived from their community garden because it helped them get out the door and gave them something tangible to do during a time when many other events and options for recreation or entertainment were not available. Similar to findings from Giraud et al. (2021), some participants indicated their gardens fostered eudemonic wellbeing as caring for plants provided a sense of purpose. This highlights the reciprocal relationship several of our interviewees expressed having with their gardens. Similar to Marsh et al. (2021) findings, participants in our study reiterated that gardens were therapeutic, in part due to their creating a space for experiencing and connecting to nature in a reciprocal manner. The practice of cultivating a garden alongside others directed gardeners' attention to caring for living things in the present, which could be of particular importance during a pandemic that highlighted the uncertainty and fragility of life and good health. All of these benefits corroborate the findings of other studies regarding community gardens' role in maintaining participants' wellbeing and resilience in the face of the additional stresses and challenges imposed by the pandemic (e.g., Theodorou et al., 2021; Egerer et al., 2022).

Lessons for Community Garden Resilience

Our findings suggest that the community gardens in this study demonstrated successful adaptability and resilience in the face of the crisis caused by the COVID-19 pandemic. Some of this resulted from community gardens' capacities to support the resilience of individual gardeners, but there were also collective features of the gardens themselves underlying their emergent resilience. Perhaps the most important of these is diversity (Krasny and Tidball, 2009). For example, our results suggest gardens whose membership is dominated by inexperienced gardeners may be more threatened by a crisis because they lack the knowledge, experience, or confidence needed to manage a community garden. Community gardens with primarily older gardeners may find maintenance challenging if members do not feel comfortable working in the garden due to the greater risk posed to them by a virus such as COVID-19 or lack the physical ability to overcome labor shortages, as was the case for one of the gardens in our study. A mentorship program, as proposed by our study participants, could help address such knowledge and labor gaps. Similarly, community gardens should build relationships with other local organizations to build diverse networks (Saldivar-Tanaka and Krasny, 2004; Krasny and Tidball, 2009; Svendsen, 2009). For example, gardens with primarily younger, less-experienced members could pair with local elder care facilities and Master Gardener organizations, and those serving older communities could collaborate with local schools.

Another factor that can contribute to community gardens' resilience is diversity of management styles. Several communally-managed gardens in our study struggled to stay running due to COVID-19-related labor shortages and group work restrictions. On the other hand, some plot-based community gardens struggled to provide gardeners with the full social experience they had hoped for. A combination of management styles within individual gardens, such that some areas are communally-managed and others are plot-based, could provide a sense of community and safety for members, depending on their personal preferences. It could also help gardeners with individual plots to deal with large-scale challenges such as rocky soil, which need to be addressed through collaborative efforts between gardeners.

Such an arrangement might also help address gardeners' concerns about the governance structures of their gardens. For example, some gardeners in larger, communally-managed gardens said they would like to have more flexibility and less top-down management, while a few gardeners from plot-based gardens suggested more of a centralized organizational structure. Our study suggests a cross-scale approach may be beneficial to quickly adapt to changing conditions. Some decisions could be left for individual gardeners to make as they prefer, others may need to be decided on by all members, and some decisions could be delegated to committees of gardeners, depending on their urgency and scope, as described in Fox-Kämper et al. (2018). Ultimately, there is no uniform approach to determine which user groups should make which decisions in a garden, as this depends on each garden's context.

Several community gardens in our study struggled to adapt to new COVID-19 regulations and recommendations early in the pandemic when there was more uncertainty about COVID-19 transmission. Here, both the smaller and the larger community gardens had advantages in our sample. Small gardens could fly under the radar of regulations, and their small number of members allowed them to fall under limits on group gatherings. Larger gardens were deemed essential community-serving organizations, and the resources they had at their disposal allowed them to provide support to their gardeners amid the challenges of the pandemic.

Community gardens' unique characteristics also presented vulnerabilities to the pandemic which may manifest similarly in other times of crisis. Typically, community gardens provide venues for social learning, and sharing knowledge is one way gardeners build strong interpersonal relationships (Krasny and Tidball, 2009). During the 2020 growing season, decreased sociability in the garden may have reduced opportunities for social learning to take place. In particular, some newer community gardeners in our study expressed being challenged by their lack of knowledge, similar to Sia et al. (2021) finding regarding challenges faced by new home gardeners during the pandemic. The pandemic also impacted material resource sharing between gardeners (e.g., tool-sharing prohibited, limited resources, etc.). These inconveniences were not barriers, however, and we saw examples of some gardens overcoming them by providing sanitizing and handwashing stations or implementing community composting programs. Similarly, some gardens helped facilitate socializing by holding outdoor events with limited attendance, hosting virtual events, and providing social media platforms for interactions between members. These approaches may be useful for addressing the isolation felt particularly acutely by gardeners in plot-based community gardens during the 2020 season.

Cultivating networks within community gardens as well as between gardens and the broader community in which they are situated can help overcome challenges to sustain and improve the adaptability of community gardens. Nested (i.e., smaller networks integrated within larger networks), and small-world (i.e., most network components are not directly connected, but most components are related by a small number of intermediate connections) networks are resilient because they efficiently balance the precarity of isolation and the stability of fully-connected lattice networks (Csermely, 2006). The community gardens in our study that operated in isolation encountered resource scarcity and threats to access that may have been circumvented by partnering with larger organizations, city government, and local businesses. Similarly, forming networks with other community gardens can allow exchange of ideas and information to improve gardeners' experiences (Svendsen, 2009). In turn, community gardens can also contribute to the networks of which they are a part by serving as restorative commons: providing food, greenspace, and opportunities for public gathering and social learning.

Community gardens in our study demonstrated their commitment to supporting their broader socioecological communities in a variety of ways. For example, some gardens implemented new programs such as food waste collection to bolster compost production or provided Freedom/Victory garden kits to community members who did not feel comfortable coming to the garden to enjoy the benefits of gardening at home. Community gardeners also continued sharing their produce with others in their community, whether with friends and family, by donating to food pantries, or by offering pick-up times when anyone could come by for some produce. This supports recent studies demonstrating that the positive effects of gardens on wellbeing extend to the broader community (Corley et al., 2020; Kou et al., 2021). Because they are community-oriented, community gardens can extend benefits beyond individual participants and in so doing serve as restorative commons (Campbell and Wiesen, 2009) even during a global crisis such as the COVID-19 pandemic.

Limitations

While the community gardens included in this study represented a distinct socioeconomic and biophysical cross-section of gardens and gardeners in New York, the overall sample size of survey participants ($n = 56$) was relatively small. Despite its interaction with other socioeconomic factors in affecting experiences, motivations, and inequalities, we ultimately did not include race as a factor in our quantitative analyses to prevent model overfitting given our small sample size. In addition, the 26 interview participants were predominantly White and Asian individuals with higher educational degrees, with under-representation of Black/African Americans, no representation of Hispanic individuals, or individuals with limited educational attainment. There is a concern that those who agreed to complete the survey and/or be interviewed were not representative of the gardener populations at these sites.

We attempted to address the disproportionate representation of Ithaca gardeners in our sample by including "city" as a random effect in our models. Even so, this may have biased our results comparing the effects of individual gardeners' characteristics on their responses. For instance, differences we saw in feelings of isolation between those urban and suburban community gardeners could also have been a confounding effect, as many suburban gardens had plot-based management (including most Ithaca gardens), while more of the urban gardens were communally-managed, making it impossible to disentangle the effect of garden management approach and urban location.

Future studies should attempt to consider a wider range of community gardeners to reflect a more complete range of experiences of this diverse group. It would also be interesting to directly compare the experiences of community and home gardeners. Finally, there is uncertainty about how lasting the phenomena observed during the pandemic will be, which must be established before determining substantive shifts community gardens should take to support gardeners.

CONCLUSION

The COVID-19 pandemic substantially increased peoples' interest and participation in gardening in general, including community gardening. If community gardens are to continue flourishing in their capacity to help gardeners manage stress, connect with nature, and increase food security throughout and beyond the COVID-19 pandemic, they must continue to evolve, particularly to retain members and/or grow. In addition to the gardener recommendations shared in the Results section, this research reveals some of the unique vulnerabilities and opportunities the COVID-19 pandemic has presented in community gardens. Our findings can inform how community gardeners and garden managers cultivate their gardens as restorative commons for the public good. The challenges facing community gardens depend on their unique context, and our findings regarding differences between private-plot and communally-managed gardens demonstrate there are no one-size-fits-all recommendations for all gardens. We hope community garden organizations draw inspiration from this study to inform how they engage with their communities to adapt in times of crisis.

This study underscores the importance of keeping community gardens open and accessible. They provide sundry benefits to gardeners and the broader communities in which they are situated. Many of these benefits, such as exercise, relaxation, social connection, and food sovereignty, are all the more important to ensure physical and emotional wellbeing during times of crisis, such as the ongoing pandemic. Community garden organizations need to do more to facilitate social interaction, as this valued benefit was substantially curtailed in 2020. Community gardens also can serve as nature- or eco-therapy to help address the increased rates of mental illness during the pandemic. Finally, we concur with recommendations that policy makers play an important role in the broader community to take planning and public health measures to ensure all citizens have access to gardening, given its multiple benefits for health and wellbeing. Given the low risk of COVID-19 fomite transmission (Chen, 2021; Lewis, 2021; Mondelli et al., 2021) and transmission in open-air areas (PHE Transmission Group, 2020; Razani et al., 2021) if proper precautions are taken, communities should promote community gardens as safe spaces to work together and enjoy.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because IRB exemption restrictions precluded sharing the collected human subjects data with anyone outside of the research team. Requests to access the datasets should be directed to TF, tbfalkowski@nmhu.edu.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Cornell University Institutional Review Board for Human Participant Research. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

TF proposed this project, developed survey and interview instruments, distributed surveys, conducted interviews, coded interview transcripts, conducted thematic analysis, analyzed survey data, and wrote the manuscript. BJ proposed this project, developed survey and interview instruments, conducted interviews, conducted thematic analysis, and wrote the manuscript. DR proposed this project, developed survey and interview instruments, and wrote the manuscript. AD proposed this project, developed survey and interview instruments, coded interview transcripts, and revised the manuscript. SD and TS proposed this project, developed survey and interview instruments, and revised the manuscript. AA proposed this project and developed survey and interview instruments. All authors contributed to the article and approved the submitted version.

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REFERENCES

Agresti, A. (2018). *An Introduction to Categorical Data Analysis*. Hoboken, NJ: John Wiley & Sons, Inc.

Alaimo, K., Packnett, E., Miles, R. A., and Kruger, D. J. (2008). Fruit and vegetable intake among urban community gardeners. *J. Nutr. Educ. Behav.* 40, 94–101. doi: 10.1016/j.jneb.2006.12.003

Bates, D., Maechler, M., Bolker, B., and Walker, S. (2015). Fitting linear mixed-effects models using lme4. *J. Stat. Softw.* 67, 1–48. doi: 10.18637/jss.v067.i01

Birky, J. (2009). *The Modern Community Garden Movement in the United States: Its Roots, its Current Condition and its Prospects for the Future* (Graduate theses and dissertations). Available online at: https://digitalcommons.usf.edu/etd/1860 (accessed January 6, 2022)

Block, L. G., Grier, S. A., Childers, T. L., Davis, B., Ebert, J. E. J., Kumanyika, S., et al. (2011). From nutrients to nurturance: a conceptual introduction to food well-being. *J. Public Policy Market.* 30, 5–13. doi: 10.1509/jppm.30.1.5

Campbell, L. K., and Wiesen, A. (2009). *Restorative Commons: Creating Health and Well-being Through Urban Landscapes*. University of Minnesota: United States Forest Service.

Census Reporter. (2021). Census Reporter. Available online at: https://censusreporter.org

Centers for Disease Control and Prevention (2020). *Community Gardens*. Washington, D.C.

Chen, T. (2021). *Fomites and the COVID-19 Pandemic: An Evidence Review on Its Role in Viral Transmission*. Vancouver, BC: National Collaborating Centre for Environmental Health.

Christensen, R. H. B. (2019). *Ordinal—Regression Models for Ordinal Data*. Kongens Lyngby, Denmark: Technical University of Denmark.

Corley, J., Okely, J. A., Taylor, A. M., Page, D., Welstead, A. B., Skarabela, B., et al. (2020). Home garden use during COVID-19: associations with physical and mental wellbeing in older adults. *J. Environ. Psychol.* 73, 101545. doi: 10.1016/j.jenvp.2020.101545

Creswell, J. W., and Plano Clark, V. L. (2011). *Designing and Conducting Mixed Methods Research*. Los Angeles, CA: SAGE Publications.

Csermely, P. (2006). *Weak Links: Stabilizers of Complex Systems From Proteins to Social Networks*. Berlin, NY: Springer.

Dolley, J. (2020). Community gardens as third places. *Geogr. Res.* 58, 141–153. doi: 10.1111/1745-5871.12395

Egerer, M., Lin, B., Kingsley, J., Marsh, P., Diekmann, L., and Ossola, A. (2022). Gardening can relieve human stress and boost nature connection during the COVID-19 pandemic. *Urban Forest. Urban Greening* 68, 127483. doi: 10.1016/j.ufug.2022.127483

Ettman, C. K., Cohen, G. H., Abdalla, S. M., Sampson, L., Trinquart, L., Castrucci, B. C., et al. (2022). Persistent depressive symptoms during COVID-19: a national, population-representative, longitudinal study of US adults. *Lancet Reg. Health Am.* 5:100091. doi: 10.1016/j.lana.2021.100091

Fox-Kämper, R., Wesener, A., Münderlein, D., Sondermann, M., McWilliam, W., and Kirk, N. (2018). Urban community gardens: An evaluation of governance approaches and related enablers and barriers at different development stages. *Landsc. Urban Plan.* 170, 59–68. doi: 10.1016/j.landurbplan.2017.06.023

Frumkin, H., Bratman, G. N., Breslow, S. J., Cochran, B., Kahn Jr, P. H., Lawler, J. J., et al. (2017). Nature contact and human health: A research agenda. *Environ. Health Perspect.* 125:075001. doi: 10.1289/EHP1663

Ghosh-Dastidar, M., Hunter, G., Collins, R. L., Zenk, S. N., Cummins, S., Beckman, R., et al. (2017). Does opening a supermarket in a food desert change the food environment? *Health Place* 46, 249–256. doi: 10.1016/j.healthplace.2017.06.002

Giraud, E. G., El-Sayed, S., and Opejin, A. (2021). Gardening for food well-being in the COVID-19 era. *Sustainability* 13, 9687. doi: 10.3390/su13179687

Hitchcock, J., and Nastasi, B. (2011). "Mixed methods for construct validation," in *The SAGE Handbook of Innovation in Social Research Methods*, eds M. Williams, and W. P. Vogt WP (Thousand Oaks, CA: SAGE Publications).

King, C. A. (2008). Community resilience and contemporary agri-ecological systems: reconnecting people and food, and people with people. *Syst. Res.* 25, 111–124. doi: 10.1002/sres.854

Kou, H., Zhang, S., Wenjia, L., and Yuelai, L. (2021). Participatory action research on the impact of community gardening in the context of the COVID-19 pandemic: investigating the seeding plan in Shanghai, China *IJERPH* 18, 6243. doi: 10.3390/ijerph18126243

Krasny, M. E., and Tidball, K. G. (2009). Applying a resilience systems framework to urban environmental education. *Environ. Educ. Res.* 15, 465–482. doi: 10.1080/13504620903003290

Kumar, A., and Nayar, K. R. (2021). COVID 19 and its mental health consequences. *J. Mental Health* 30, 1–2. doi: 10.1080/09638237.2020.1757052

Laborde, D., and Martin, W. (2020). *Poverty and Food Insecurity Could Grow Dramatically as COVID-19 Spreads*. Washington, DC: International Food Policy Research Institute.

Lee, J. H., and Matarrita-Cascante, D. (2019). Gardeners' past gardening experience and its moderating effect on community garden participation. *Sustainability* 11, 3308. doi: 10.3390/su11123308

LeGreco, M., and Douglas, N. C. (2021). *Everybody Eats: Communication and the Paths to Food Justice*. Oakland, CA: University of California Press.

Lester, J. N., Cho, Y., and Lochmiller, C. R. (2020). Learning to do qualitative data analysis: a starting point. *Hum. Resour. Dev. Rev.* 19, 94–106. doi: 10.1177/1534484320903890

Lewis, D. (2021). COVID-19 rarely spreads through surfaces. So why are we still deep cleaning? *Nature* 590, 26–28. doi: 10.1038/d41586-021-00251-4

Lin, B. B., Egerer, M. H., Kingsley, J., Marsh, P., Diekmann, L., and Ossola, A. (2021). COVID-19 gardening could herald a greener, healthier future. *Front. Ecol. Environ.* 19, 491–493. doi: 10.1002/fee.2416

Lopez, B., Kennedy, C., Field, C., and McPhearson, T. (2021). Who benefits from urban green spaces during times of crisis? Perception and use of urban green spaces in New York City during the COVID-19 pandemic. *Urban Forest. Urban Green.* 65, 127354. doi: 10.1016/j.ufug.2021.127354

Lovell, R., Husk, K., Bethel, A., and Garside, R. (2014). What are the health and well-being impacts of community gardening for adults and children: a mixed method systematic review protocol. *Environ. Evid.* 3, 20. doi: 10.1186/2047-2382-3-20

Mahbub Hossain, M. D., Tasnim, S., Sultana, A., Faizah, F., Mazumder, H., Zou, L., et al. (2020). Epidemiology of mental health problems in COVID-19: a review. *F1000Res* 9, 636. doi: 10.12688/f1000research.24457.1

Marsh, P., Diekmann, L. O., Egerer, M., Lin, B., Ossola, A., and Kingsley, J. (2021). Where birds felt louder: The garden as a refuge during COVID-19. *Wellbeing Space Society* 2, 100055. doi: 10.1016/j.wss.2021.100055

Mejia, A., Bhattacharya, M., Nigon-Crowley, A., Kirkpatrick, K., and Katoch, C. (2020). Community gardening during times of crisis. *J. Agric. Food Syst. Comm. Dev.* 10, 1. doi: 10.5304/jafscd.2020.101.006

Mondelli, M. U., Colaneri, M., Seminari, E. M., Baldanti, F., and Bruno, R. (2021). Low risk of SARS-CoV-2 transmission by fomites in real-life conditions. *Lancet Infect. Dis.* 21, e112. doi: 10.1016/S1473-3099(20)30678-2

Mullins, L., Charlebois, S., Finch, E., and Music, J. (2021). Home food gardening in canada in response to the COVID-19 pandemic. *Sustainability* 13, 3056. doi: 10.3390/su13063056

Music, J., Finch, E., Gone, P., Toze, S., Charlebois, S., and Mullins, L. (2021). Pandemic victory gardens: potential for local land use policies. *Land Use Policy* 109:105600. doi: 10.1016/j.landusepol.2021.105600

NVivo (2020). *QSR International Pty Ltd*. Hawthorn East, Vic, Australia.

O'Driscoll, M., Ribeiro Dos Santos, G., Wang, L., Cummings, D. A. T., Azman, A. S., Paireau, J., et al. (2021). Age-specific mortality and immunity patterns of SARS-CoV-2. *Nature* 590, 140–145. doi: 10.1038/s41586-020-2918-0

Pfefferbaum, B., and North, C. S. (2020). Mental health and the Covid-19 pandemic. *N. Engl. J. Med.* 383, 510–512. doi: 10.1056/NEJMp2008017

PHE Transmission Group (2020). *Factors Contributing to Risk of SARS-CoV2 Transmission Associated With Various Settings*. London, UK: Public Health England.

Philpott, S. M., Egerer, M. H., Bichier, P., Cohen, H., Cohen, R., Liere, H., et al. (2020). Gardener demographics, experience, and motivations drive differences in plant species richness and composition in urban gardens. *E&S* 25, art8. doi: 10.5751/ES-11666-250408

Pozzi, F., and Small, C. (2002). "Vegetation and population density in urban and suburban areas in the USA," in *Third International Symposium of Remote Sensing of Urban Areas*. 1–6.

Qualtrics. (2021). *Qualtrics*. Provo, UT: Qualtrics.

R Development Core Team (2020). *R: A Language and Environment for Statistical Computing*. Vienna: R Foundation for Statistical Computing.

Rajkumar, R. P. (2020). COVID-19 and mental health: a review of the existing literature. *Asian J. Psychiatr.* 52, 102066. doi: 10.1016/j.ajp.2020.102066

Razani, N., Malekinejad, M., and Rutherford, G. W. (2021). Clarification regarding "outdoor transmission of SARS-CoV-2 and other respiratory viruses: a systematic review. *J. Infect. Dis.* 224, 925–926. doi: 10.1093/infdis/jiab298

Rhone, A., Ver Ploeg, M., Dicken, C., Williams, R., and Breneman, V. (2017). *Low-Income and Low-Supermarket-Access Census Tracts, 2010-2015*. United States Department of Agriculture. Economic Information Bulletin No. (EIB-165). Washington, D.C.

Rice, W. L., and Pan, B. (2021). Understanding changes in park visitation during the COVID-19 pandemic: a spatial application of big data. *Wellbeing Space Soc.* 2, 100037. doi: 10.1016/j.wss.2021.100037

Saldivar-Tanaka, L., and Krasny, M. E. (2004). Culturing community development, neighborhood open space, and civic agriculture: the case of Latino community gardens in New York City. *Agric. Human Values* 21, 399–412. doi: 10.1023/B:AHUM.0000047207.57128.a5

Schoen, V., Blythe, C., Caputo, S., Fox-Kämper, R., Specht, K., Fargue-Lelièvre, A., et al. (2021). "We have been part of the response": The effects of COVID-19 on community and allotment gardens in the global north. *Front. Sustain. Food Syst.* 5:732641. doi: 10.3389/fsufs.2021.732641

Sia, A., Yok Tan, P., Chee, J., Wong, M., Araib, S., Foong Ang, W., et al. (2021). The impact of gardening on mental resilience in times of stress: a case study during the COVID-19 pandemic in Singapore. *Urban Forest. Urban Green.* 68, 127448. doi: 10.1016/j.ufug.2021.127448

Soga, M., Gaston, K. J., and Yamaura, Y. (2017). Gardening is beneficial for health: a meta-analysis. *Prev. Med. Rep.* 5, 92–99. doi: 10.1016/j.pmedr.2016.11.007

Spano, G., D'Este, M., Giannico, V., Carrus, G., Elia, M., Lafortezza, R., et al. (2020). Are community gardening and horticultural interventions beneficial for psychosocial well-being? A meta-analysis. *IJERPH* 17, 3584. doi: 10.3390/ijerph17103584

Svendsen, E. (2009). "Cultivating resilience: urban stewardship as a means to improving health and well-being," in *Restorative Commons: Creating Health and Well-being Through Urban Landscapes*, edsL. L. K. Campbell, and A. Wiesen A (Newtown Square, PA: University of Minnesota: United States Forest Service).

The Trust for Public Land (2018). *Here's the Dirt on Park Trends: Community Gardens are Growing*. San Francisco, CA: The Trust for Public Land.

Theodorou, A., Panno, A., Carrus, G., Alessio Carbone, G., Massullo, C., and Imperatori, C. (2021). Stay home, stay safe, stay green: The role of gardening activities on mental health during the Covid-19 home confinement. *Urban Forest. Urban Green.* 61, 127091. doi: 10.1016/j.ufug.2021.127091

van der Ploeg, J. D. (2020). From biomedical to politico-economic crisis: the food system in times of Covid-19. *J. Peasant Stud.* 47, 944–972. doi: 10.1080/03066150.2020.1794843

Wakefield, S., Yeudall, F., Taron, C., Reynolds, J., and Skinner, A. (2007). Growing urban health: community gardening in South-East Toronto. *Health Promot. Int.* 22, 92–101. doi: 10.1093/heapro/dam001

Weersink, A., Massow, M., von, Bannon, N., Ifft, J., Maples, J., McEwan, K., et al. (2021). COVID-19 and the agri-food system in the United States and Canada. *Agric. Syst.* 188, 103039. doi: 10.1016/j.agsy.2020.103039

Zuur, A. F., Ieno, E. N., Walker, N. J., Saveliev, A. A., and Smith, G. M. (2009). *Mixed Effects Models and Extensions in Ecology with R (Vol. 574)*. New York, NY: Springer.

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Perceived Effects of COVID-19 Pandemic on Food Security in Southeast Nigeria

Jane Munonye[1], Emeka Osuji[1], Michael Olaolu[1], Anthony Okoisu[2], Joy Obi[1], Gladys Eze[1], Sikiru Ibrahim-Olesin[1], Loveday Njoku[1], Mark Amadi[1], Chibuzo Izuogu[1] and Gillian Azuamairo[2]*

[1] Department of Agriculture, Alex Ekwueme Federal University Ndufu-Alike, Abakaliki, Nigeria, [2] Department of Agribusiness and Management, Alex Ekwueme Federal University Ndufu-Alike, Abakaliki, Nigeria

The present study evaluated the perceived effects of the COVID-19 Pandemic on food security in Southeast Nigeria. A multi-stage random technique was used to select 209 households. Data for the study were collected with the aid of a structured questionnaire and were analyzed using descriptive statistics, *z*-test, food security model, and Tobit regression model. Results showed that the mean household size was 9.6 persons, which indicates a large household size. The percentage rate of food consumption of the households before the Pandemic was higher relative to the COVID-19 event. Again, exorbitant prices of food materials were noticed during the COVID-19 as compared to the period before the Pandemic. About 10.5% of the households met the minimum food requirements as proposed by World Health Organization (WHO), and Food and Agriculture Organization (FAO) as against the majority of 76.1%. The three dimensions of food security which include availability, accessibility, and utilization were interposed by a number of factors, such as artificial scarcity, and an increase in food prices. Furthermore, social distancing and lockdown imposition were COVID-19 determinants of the food security status of households in the Southeast Nigeria. About 24% of the households were food-secured compared to 76% that were insecured during the Pandemic. Robust and effective food and agricultural policy formulations and implementations were recommended in Southeast Nigeria.

Keywords: COVID-19, effects, food security, pandemic, Southeast, Tobit model

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Shankar Chandra Mandal,
University of Dhaka, Bangladesh
Sefater Gbashi,
University of Johannesburg,
South Africa

****Correspondence:***
Emeka Osuji
osujiemeka2@yahoo.com

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INTRODUCTION

Background and Rationale

The corona virus disease 2019 (COVID-19) is a global health Pandemic that shut down the whole countries of the world (FAO, 2021). Earlier, human coronavirus (HCoVs) had long been in existence causing "common cold" in healthy people and it was considered an inconsequential pathogen due to its minor effects (FAO, 2020a). The advent of the twenty first century brought in two highly pathogenic HCoVs, namely severe acute respiratory syndrome coronavirus (SARS–CoV), and Middle East respiratory syndrome coronavirus (MERS–CoV), which emerged from animal reservoirs causing a global epidemic with alarming morbidity and mortality (Paules et al., 2020; Sallent, 2020). The recent COVID-19 which broke out in Wuhan, China in December 2019 is classified as another zoonotic pathogen human coronavirus (United Nations, 2020a; WHO, 2020a). On February 11, 2020, the International Committee on Taxonomy of Viruses (ICTV) announced the new COVID-19 as "severe acute respiratory syndrome coronavirus 2 (SARS–CoV2)" (United Nations, 2020b; WHO, 2020a). As of May 15, 2020, globally, 4,307,287 cases were confirmed and 295,101 deaths had been recorded in more than 216 countries and territories (UNCTAD, 2020b; WHO, 2020b). Nigeria recorded her first case of COVID-19 in February 2020 (NCDC, 2020a,b) and by March 23, 2020, federal schools in Nigeria were mandated to close as a result of the escalating spread of COVID-19 and by March 30, 2020, the commercial state hub in Nigeria such as Lagos, Abuja; the capital city and Ogun state in Nigeria were placed under lockdown to contain the spread (NCDC, 2020b). Subsequently, the majority of the states joined the lockdown as soon as the directive was given by the Federal Government of Nigeria. As of May 14, 2020, Nigeria had recorded 5,162 confirmed cases and 167 deaths (De-Wit et al., 2016; Johns, 2020; UNCTAD, 2020a; World Bank, 2020b). According to International Monetary Fund (IMF, 2020), the COVID-19 crisis is reported to have a crippling effect on the global economy. It is tagged a global phenomenal threat, ranging from ill-health, food insecurity, economic shocks and setbacks, economic stagnation, human depression, poor social interaction, stagnant agricultural production, limited housing, limited education service delivery, and border closures (Devereux et al., 2020; Laborde et al., 2020; Vanapalli et al., 2020; Waltenburg et al., 2020). Consequently, Southeast Nigeria had its share of the adverse impacts of the COVID-19 Pandemic (Ogunji et al., 2021; Uche et al., 2021). This is because the region was neither prepared nor armed to absorb the initial shock orchestrated by the Pandemic (Mbachu et al., 2020; Uche et al., 2021). Southeast Nigeria was thrown into learning by doing *ad-hoc* measures to contain the virus spread, and as a result of the Nigerian government's enforcement of several COVID-19 measures such as lockdown, stay at home, social distancing, quarantine, banning large–private and public gathering, and crowded transportations (Ekoh et al., 2021; Ogunji et al., 2021; Uche et al., 2021). Despite these measures, the COVID-19 Pandemic kept raging as confirmed cases in Southeast Nigeria continue to rise arbitrarily. As of March 18, 2022, the number of confirmed cases had risen to 12,569 and death cases to 172 (NCDC, 2022). The lockdown measures adopted in Southeast Nigeria focused largely on flattening the COVID-19 epidemic curve; however, food supply and agricultural production which are the hub of the Southeast Nigeria suffered the most as food crop farmers were sent off their farms as a result of the sudden lock down imposed by the government and this singular act worsened economic activities; more especially, food production in the region (Egwue et al., 2020; Adebowale et al., 2021). As the lockdown continued, food and other livestock goods were equally restricted from entering the Southeast Nigeria from other neighboring states due to border closure (Agbugba, 2020a; Uche et al., 2021). This development further heightened food insecurity in the region causing severe pains and created a huge food supply-demand gap (Ohiaa et al., 2020; Obayelu et al., 2021; Uche et al., 2021). The issue of lockdown without an alternative source of food supply and provisions constituted major economic problems and food security challenges in the Southeast region (Arouna et al., 2020; Egwue et al., 2020; United Nations World Food Programme, 2020; Ekoh et al., 2021). Although the lockdown was meant to contain the spread of the coronavirus disease in the short-run, its long-run effects exacerbated food security situation in Southeast Nigeria making the region vulnerable to chronic starvation, malnutrition, food inadequacy, food shortage, low food supply, and persistent poverty (Adebowale et al., 2021; Uchechukwu et al., 2022). Until now, the region is yet to come out from the negative impacts and shocks of COVID-19 Pandemic. However, food security is the ability to meet target consumption levels on a year-to-year basis. It is said to exist when every households have sufficient access to food to meet their dietary needs for a productive and healthy life (Headey and Martin, 2016; FAO, 2018; Oleribe et al., 2020; United Nations, 2020a; Worstell, 2020) but such was not the case in Southeast Nigeria as the COVID-19 Pandemic introduced intense food scarcity, excruciating hunger, pain, and food deficit. With rising population growth in Southeast Nigeria, food crop production is yet to keep pace with meeting domestic food demands (FAO, 2020a; United Nations, 2020b; Ogunji et al., 2021). This had equally aggravated food security and ushered in food insecurity in the Southeast region.

Earlier, several empirical studies had looked at the food security situations in Nigeria, (Babatunde et al., 2007; Agada and Igbokwe, 2015; Ahmed et al., 2015) examined the factors influencing food security and its coping strategies. Akukwe (2019) evaluated household food security and its determinants, while Egwue et al. (2020) and Agbawodikeizu et al. (2021) investigated food insecurity of rural households during COVID-19 and the impact of COVID-19 Pandemic on economic activities and well-being of older adults in Southeast Nigeria. Amongst these studies, none had assessed the perceived effect of COVID-19 Pandemic on individual household food security with reference to COVID19 determinants, recommended food consumption, calorie in-takes, and food sources of individual households before and after the Pandemic. More so, no study had examined the true state of COVID-19 determinants on individual food secured households and food insecured households in Southeast Nigeria, hence the true essence of this study. This study filled the gap in knowledge by providing an objective assessment of the true picture of COVID-19 Pandemic on food security in the Southeast Nigeria.

Objectives of the Study

The broad objective of the study is to access the perceived effect of the COVID-19 Pandemic on food security in Southeast Nigeria. Hence, the specific objectives include:

i. To describe the standardized food groups/classifications
ii. To identify the demographic characteristics of the sampled households
iii. To ascertain the food groups consumed before and during the Pandemic
iv. To determine the food prices before and during the Pandemic
v. To determine the minimum food requirements, source of food delivery, and availability of food during COVID-19 Pandemic
vi. To isolate the factors affecting food availability, accessibility, and use during the Pandemic
vii. To estimate the perceived effect of COVID-19 determinants on food security status of households in Southeast Nigeria

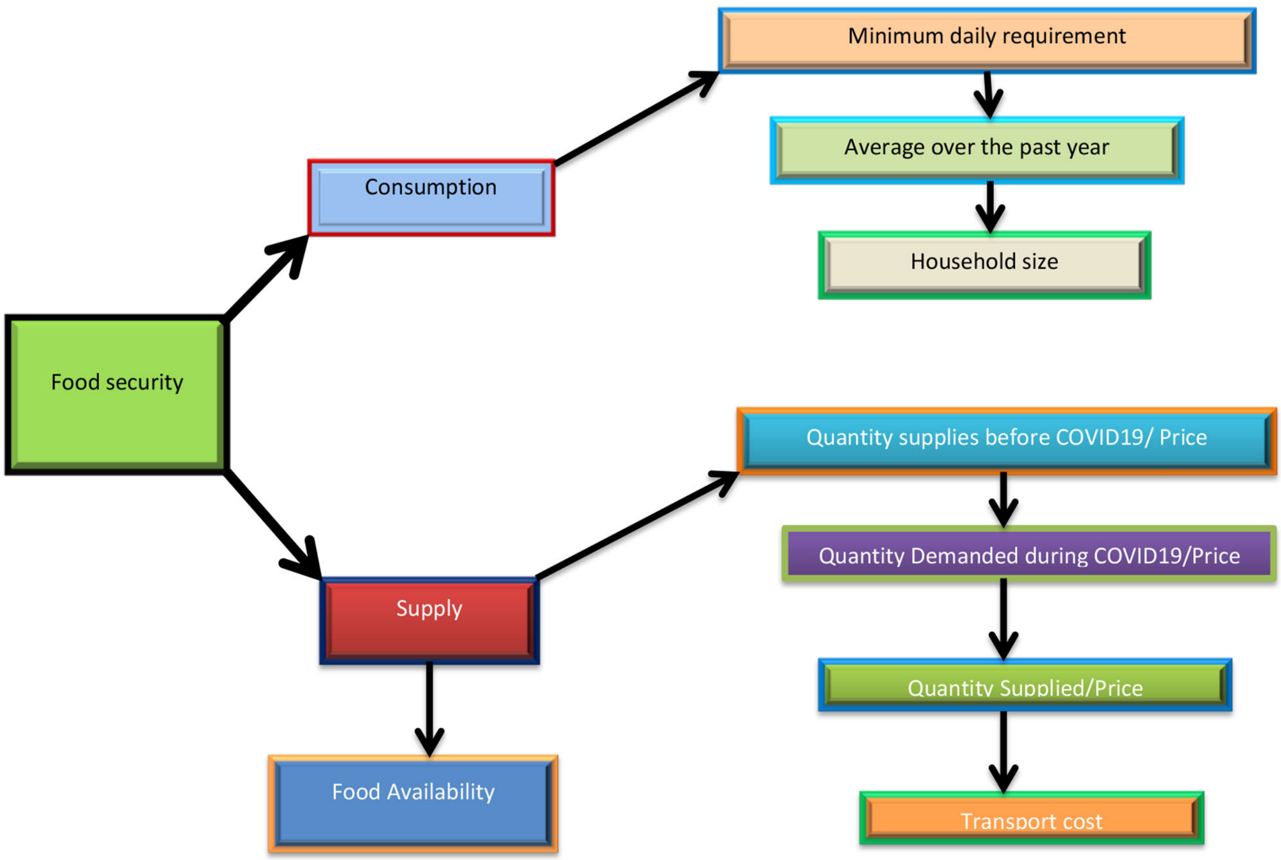

FIGURE 1 | Structural framework, food security, and COVID-19 pandemic. Source: Munonye, 2022.

viii. To estimate the food security indices of households during COVID-19.

MATERIALS AND METHODS

Study Design

The study was designed to elicit detailed information from the sampled respondents who were selected using a multi-stage sampling technique. Information on the specific objectives of the study was collected using the data instrument (questionnaire) which was administered in person. The data collected were analyzed using both descriptive and inferential statistics (percentage, mean, z-test, Tobit model, and food security model). The study was structured into five stages: Introduction, Materials and methods, Results, Discussion, and Conclusion.

Setting

Description of the Study Area

The study area is the Southeast geopolitical zone of Nigeria. Nigeria is divided into six geo-political zones—North-central, North-east, North-west, South-east, South-south, and South-west.

Southeast zone is made up of five states: Abia, Anambra, Ebonyi, Enugu, and Imo. This zone is also known as Igboland because it is largely dominated by the Igbo-speaking tribe of Nigeria. The zone is bounded on the north by Kogi and Benue States, on the east by Cross River State, on the south by Akwa Ibom and Rivers States, and on the west by Delta and Edo States. According to the National Bureau of Statistics, the 2016 population estimate of the area was 21,955,414 persons (NBS, 2017). The vegetation of the area is predominantly rainforest, which supports the cultivation of food crops, such as rice, maize, yam, cassava, oil palm, cowpea, sweet potato, cocoyam, plantain, banana, melon, bambara nut, breadfruit, groundnut, and various vegetables and fruit trees. The people of the region largely engage in farming and trading activities, as well as in other occupations, such as civil service, corporate businesses, etc. The region has divergent beliefs, perceptions, and attitudes about food and nutritional practices, especially during COVID-19. Data was collected for a period of 6 months starting from January to June 2021. Structural framework of food security and Covid 19 and geographical map of Nigeria showing the Southeast regions were shown in **Figures 1**, **2** respectively.

Data Collection

The questionnaire was developed by the researchers and used as a survey instrument for data collection. It was prepared following the recommendations of FANTA (2020), FAO (2020a), WHO

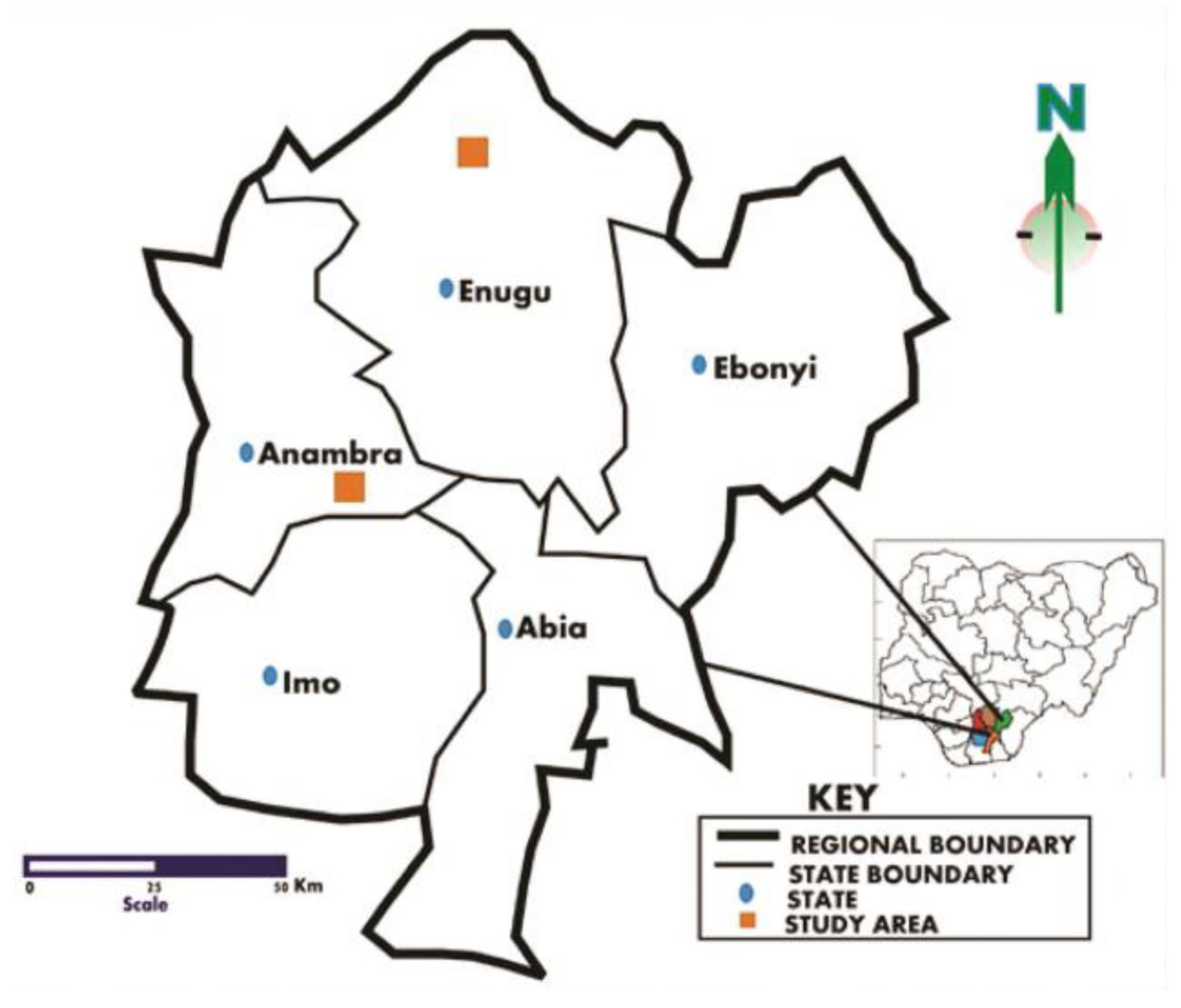

FIGURE 2 | Map showing the Southeast geographical zone of Nigeria. Source: Munonye, 2022.

(2020a) and on dietary and nutrient food contents required for each household. The questionnaire was administered in person to the 240 selected households in Anambra, Ebonyi, and Enugu States, respectively. The researchers guided the filling of the questionnaire to ensure total compliance from the households (respondents). However, out of the 240 distributed questionnaires, only 209 were found useful for data analysis. This was based on sufficient information regarding the core objectives of the study. Others were voided due to errors and insufficient data. Data collected were carefully sorted out, standardized, coded, and entered in an excel spreadsheet for data analysis using descriptive and inferential statistics. Moreover, before the actual data collection, the first pilot survey was conducted using 20 households to determine the effectiveness of the questionnaire in terms of reliability. This action was repeated again, after 1 month. The test-retest reliability of the questionnaire yielded a correlation coefficient of 0.80 and was significant at 1 and 5% levels. This shows the overall reliability and suitability of the questionnaire for actual data collection. Items included in the final instrument were as follows:

- Demographic characteristics of the households estimated using mean and percentage.
- Different food categories consumed before and during the Pandemic, scored using frequency; that is the number of occurrences of respondents per food category.
- Food prices of commodities before and during the Pandemic. Respondents were asked to input the actual food prices or food cost per commodity listed and the mean value determined.
- Sources of food delivery, scored using the frequency
- Availability of food, scored using the frequency

- Factors affecting food availability, accessibility, and use, scored using the frequency
- Determinants of food security status of households, scored using binary numbers.

Sampling Technique (Participants)

The study was a cross-sectional study, and its eligibility criteria were based on the true experience and encounter of the households with COVID-19 Pandemic. The study adopted purposive and multi-stage sampling techniques. In the first stage, three states out of the five states in Southeast Nigeria were purposively picked due to worsening food security situations in the states orchestrated by COVID-19 as depicted by the National Food Council of Nigeria. The states were Anambra, Enugu, and Ebonyi. In the second stage, two local government areas mostly affected by the COVID-19 Pandemic according to regional reports of the National Food Council of Nigeria were purposively selected from each of the states, giving a total of six local government areas. In the third stage, two communities were randomly selected from the local government areas resulting in a total of 12 autonomous communities across the states. In the fourth stage, with the help of the community leaders, 20 households (respondents) were randomly picked across the selected communities, giving a sample size of 240 households.

Variables Used in the Study

The variables used in the study were identified and defined in the following section.

Demographic Factors Such as

Age of households (Years)
Number of males (Number)
Number of females (Number)
Male-headed household (Percentage)
Female-headed household (Percentage)

Food Groups Consumed and Food Prices

Cereals/grains
Fish and seafood
Root/tubers and plantain
Vitamin a rich fruits and vegetables
Other fruits and vegetables
Milk and milk products
Oil/fats
Meat (organ and fresh meat)
Edible insects
Seeds and pulses/nuts
Sugar/honey
Eggs
Miscellaneous (spices, condiments, etc.)

Note: Respondents were asked to indicate the food groups consumed and food prices before and during the Pandemic.

Food Requirements

Minimum food requirements
Source of food delivery
Availability of food during COVID-19 Pandemic.

Note: Respondents were asked to indicate their minimum food requirements, source of food delivery, and availability during the Pandemic.

Factors Affecting Food Availability, Accessibility, and Use During the Pandemic

Artificial scarcity
Increase in food price
Lockdown policy
Panic purchase
Lack of storage facilities
Lack of electricity supply
Low income
Lack of employment
Family size
Climate change
Poor government policy
Labor reduction.

Note: Respondents were asked to indicate the variable factors applicable to them.

Variable Determinants of COVID 19

X_1 = Social distancing (Observed = 1, 0 = otherwise)
X_2 = Lockdown imposition (Observed = 1, 0 = otherwise)
X_3 = On-line orders (Yes = 1, 0 = otherwise)
X_4 = Increase in disease spread (High = 1, 0 = otherwise)
X_5 = Government policy on food market closure (Observed = 1, 0 = otherwise)
X_6 = Loss of jobs (Yes = 1, 0 = otherwise)
X_7 = Low income (Yes = 1, 0 = otherwise)
X_8 = Household size (No. of persons)
X_9 = Panic purchase (Yes = 1, 0 = otherwise)
X_{10} = Increase in food prices (Yes = 1, 0 = otherwise)

Food Index Variables

Percentage of households
Number of households
Mean of household size
Mean food security index/standard deviation
Mean household's daily calorie intake (kcal)
Mean households per capita daily calorie intake (kcal)
Food insecurity gap index
Food surplus gap index
Food surplus/insecurity gap index
Headcount ratio

Note: Measured in percentages, numbers, mean, and food security indices.

Data Source and Measurement

Demographic factors or characteristics of the households were sourced from field survey report 2021 and were measured using descriptive statistics. Food groups consumed and food prices were sourced from field survey report 2021 and were measured using descriptive and Z-test statistics. Food requirements were sourced from field survey report 2021 and were measured using descriptive statistics. Factors affecting food availability, accessibility, and use during the Pandemic were sourced from field survey report 2021 and were measured using descriptive statistics. COVID-19 variable determinants were sourced from field survey report 2021 and were measured using Tobit regression model. Food index variables were sourced from field survey report 2021 were measured using both descriptive statistics and food security model.

Bias

In accessing the effect of COVID-19 Pandemic on food security in Southeast Nigeria, the researchers carefully followed up on the household respondents in filling the data instrument (questionnaire) to ensure the correctness and ascertain the appropriateness of the data information provided in order to eliminate potential errors and/ or human induced bias.

Study Size

Initially, the researchers randomly selected 240 household respondents using multi-stage sampling technique. However, after careful examination of the data instrument, only the respondents from 209 households were finally used for the study based on the correctness and appropriateness of the data provided, which were carefully certified by the researchers for data analysis. The selected households were picked from the three states in Southeast Nigeria namely Enugu, Anambra, and Ebonyi.

Quantitative Variables

The variables used in this study were quantified and handled using food security index model and Tobit regression model.

The food security index model was proposed by Marion (2010) and adopted by Otu et al. (2014) and Saleh and Mustafa (2018). The model seeks to ascertain the household daily per capita calorie intake vs. the recommended daily per capita calorie requirements of households. The food security index model is specified as follows;

$$\mathrm{FS_I} = \frac{H_{DPCCI}}{R_{DPCCR}} -------- \quad (1)$$

Where

$\mathrm{FS_I}$ = Food security index

$\mathrm{H_{DPCCI}}$ = Household's daily per capita calorie intake

$\mathrm{R_{DPCCR}}$ = Recommended daily per capita calorie requirement.

Furthermore, the food insecurity gap index (FIGi), food surplus gap index (FSGi), and the headcount ratio (HCR) of the food security were calculated for the sample households based on the food security index. The food insecurity gap measures the extent to which food in-secured households on average fall below the food security line and the food surplus gap measures the extent to which food secured households exceeded the food security line. The headcount index measures the percentage of the sampled households that are food insecured or secured. The HCR, food insecurity gap, and food surplus gap were also projected by Marion (2010) and are defined as follows:

$$\mathrm{Hf_i} = \frac{X}{Z} ---- \quad (2)$$

$$\mathrm{Hf_s} = \frac{y}{Z} ---- \quad (3)$$

$$\mathrm{FIG_i} = \frac{1}{X}\sum_{i}^{X} = 1 \textit{ where } D_\mathrm{i} = \frac{C_{i-R}}{R} ---- \quad (4)$$

$$\mathrm{FSG_i} = \frac{1}{Y}\sum_{i}^{Y} = 1 \textit{ where } D_\mathrm{i} = \frac{C_{i-R}}{R} ---- \quad (5)$$

Where;

Hfs = Headcount index for food secured households

Hfi = Headcount index for food insecured households

$\mathrm{FIG_i}$ = Food insecurity gap index

$\mathrm{FSG_i}$ = Food surplus gap index

X = Number of food insecured households

Z = Total number of households in the sample

Y = Number of food secured households

Di = Daily per capita calorie deficiency or surplus for ith households

Ci = Daily per capita calorie consumption of food item for ith households

R = recommended daily per capita calorie requirement.

The recommended minimum daily calorie requirement per adult equivalent of 2,100 kcal by WHO (2020c) and the United States Committee on International Nutrition (USCIN, 2020), 1,800 kcal by FAO (2020b), and National Average Calorie Requirement of 2,700 Kcal (Babatunde et al., 2007) were used as baselines in defining the food security line for the study. Hence, households that are below the food security line are classified as food insecured households, while those households that are above are classified as food-secured households. Again, households' daily per capita calorie consumption was estimated using the food nutrient composition table as shown in **Table 1**. This involves a comprehensive list of standardized food groups and/or classifications consumed in Nigeria. The calories were calculated from the energy values of various food components which were converted into kilograms. The estimated daily calorie (energy) supply of the households was divided by the household size adjusted for adult equivalents using the consumption factor for age–sex categories. The food security model was used to determine the distribution of food security indices of households during COVID-19 Pandemic in Southeast Nigeria.

Tobit regression model was proposed by James (1958) and had been used by many (Mazibuko and Antwi, 2019; Yang et al., 2019; Amore and Murtinu, 2021) in estimating censored or truncated continuous variables. Tobit regression model is explicitly expressed as follows:

$$\mathrm{Y = X_iB + U_i} ---- \quad (6)$$

Where

Y = a latent unobservable variable

B = Vector of unknown coefficients

$\mathrm{U_i}$ = Error term assumed to be independently distributed with mean zero and constant variance

TABLE 1 | Standardized food groups/classifications.

Food group	Examples
Cereals/grains	Corn/maize, rice, sorghum, millet or any other grains or foods made from these (e.g., bread, corn flakes, golden morn, noodles, spaghetti, pap, agidi, or other grain products)
Roots, tubers, and plantain	Potatoes, yam, cassava, cocoyam, plantain, or other foods made from these roots and tuber (e.g., garri, tapioca, fufu, plantain chips, potato chips)
Vitamin a rich vegetables and fruits	Banana, papaya, mango, carrot, palm fruit, red/yellow sweet pepper
Other fruits and vegetables	Garden egg, fresh and canned tomatoes, African pear, avocado pear, pineapple, apple, watermelon, African star apple, ube mgba, guava, soursop, orange, cucumber, grape, cabbage, lettuce, green, spinach, pepper fruit, waterleaf, onion, garlic, ginger, scent leaf, bitter leaf, okazi, oha, coconut, pumpkin leaf, okra, garden egg leaf, date, wild fruits, and fruit juice.
Meats, organs, and edible insects	Beef, pork, mutton, chevon, goat, game, turkey, guinea fowl, chicken, duck, other birds, insects (termites, locust, crickets), snail, liver, kidney, intestine, heart, or other organ meats or blood-based foods
Eggs	Eggs from chicken, duck, guinea fowl or any other egg
Fish and seafood	Fresh, frozen or dried fish, crayfish, crab, shellfish, and other sea foods
Pulses, nuts, and seeds	Beans, groundnut, melon, walnut, cowpea, tiger nut, soybean, cashew nut, bambara nut, oil bean, breadfruit, jackfruit, akidi, palm kernel nut, pigeon pea, or foods made from these (e.g., moi-moi, akara, peanut butter)
Milk and milk products	Milk, yogurt
Oil and fat	Margarine, butter, vegetable oil, bleached palm oil, groundnut oil, olive oil, etc.
Sugar/honey	Sugar, sugar cane, honey, ice cream, chocolates, candies, sweet, chewing gum, cookies, and cakes
Miscellaneous	Black pepper, salt, condiments (Onga, Maggi cube, Royco cube, Knor, Ajinomoto, Vedan) hot sauce, Uda, Uziza seed and other local spices, beverages, alcohol, etc.

Source: FANTA (2020), FAO (2020a), and WHO (2020b).

X_i = Vector of independent variables.

If data for the dependent variable is above the limiting factor, zero, in this case, Y is observed as a continuous variable. If Y is at the limiting factor, it is held at zero. This relationship is presented mathematically in the following two equations:

$$Y_i = X_i\beta + u_i \ \text{if} \ X_i\beta + u_i > 0 \quad (7)$$

$$Y_i = 0 \ \text{if} \ X_i\beta + u_i \leq 0 \quad (8)$$

i =1, 2, ———–—N

Where

N = the number of observations

Y_i = the dependent variable

X_i = the vector of independent variables

β = the vector of unknown coefficients

u_i = the error term.

Equations 8 and 9 represent a censored/truncated distribution. The model assumes that there is an underlying stochastic index equal to ($X_i\beta + u_i$) which is observed only when it is positive and hence qualifies as an unobserved, latent variable. The Tobit model is used to estimate the expected value of Y_i as a function of a set of explanatory variables (X_i) weighted by the probability that $Y_i > 0$ (James, 1958). It estimates the probability of an outcome in which the dependent variable follows a continuous normal distribution of the event occurring; in this case, the dependent variable (FS_I) is the probability of an event outcome that is different from having either 0 or 1 (just as it occurs in the use of Probit or Logit regression estimates). Thus, the dependent variable (FS_I) was a continuous occurring variable with 0 and 1 occurring at extreme limits. Hence, the data set involves observations that are continuous but excludes any value that is outside the extreme values, 0 or 1. However, the use of continuous dependent variables with extreme limits of this nature gave rise to some censored or truncated values, which are more compatible with Tobit estimations. Hence, this informed the use of Tobit model in estimating the perceived effect of COVID-19 determinants on food security status of households in Southeast, Nigeria. Moreover, substituting Y in equation (7) above with (FS_I), the Tobit model is specified as follows:

$$FS_I = X_iB + U_i - - - - - \quad (9)$$

Where

FS_I = Estimated food security index of ith households

B = Vector of unknown coefficients

U_i = Error term, assumed to be independently distributed with mean zero and constant variance

X_i = Vector of independent variables, which includes the following:

X_1 = Social distancing (Observed = 1, 0 = otherwise)

X_2 = Lockdown imposition (Observed = 1, 0 = otherwise)

X_3 = On-line orders (Yes = 1, 0 = otherwise)

X_4 = Increase in disease spread (High = 1, 0 = otherwise)

X_5 = Government policy on food market closure (Observed = 1, 0 = otherwise)

X_6 = Loss of jobs (Yes = 1, 0 = otherwise)

X_7 = Low income (Yes = 1, 0 = otherwise)

X_8 = Household size (No. of persons)

X_9 = Panic purchase (Yes = 1, 0 = otherwise)

X_{10} = Increase in food prices (Yes = 1, 0 = otherwise).

Statistical Methods

The statistical methods employed in this study were descriptive statistics and Z-test statistics. The descriptive statistics includes the frequency counts, percentage, standard deviations, and mean estimates.

The Z-test, statistic was propounded by Carl (1777–1855) and was adopted by Ryeji et al. (2018). The Z-test was used to test the statistical significance differences in mean households for ith food consumed/prices before and during the Pandemic. The Z-test is expressed as:

$$Z = \frac{X_1 - X_2}{\sqrt{\frac{SD_1}{n_1} + \frac{SD_2}{n_2}}} ------ \quad (10)$$

Where;

Z = Z-test statistic

X_1 = Mean household distribution of ith food consumed/prices before the Pandemic

X_2 = Mean household distribution of ith food consumed/prices during the Pandemic

SD_1 = Standard deviation distribution of ith food consumed/prices before the Pandemic

SD_2 = Standard deviation distribution of ith food consumed/prices during the Pandemic

n_1 = Total number of households for ith food consumed/prices before the Pandemic

n_2 = Total number of households for ith food consumed/prices during the Pandemic.

RESULTS

Participants

The researchers made use of 209 household respondents who were carefully selected and were confirmed eligible for inclusion in the study.

DISCUSSION

Key Results

The food groups were structurally categorized into 12 groups and/or classifications consequent upon Objective I, which describes the standardized food groups/classifications.

The demographic characteristics showed that the households had a mean age of 49 years, household size of 9.6 persons, mean numbers of males and females households were 5.1 and 4.5 persons, and percentage of the male- and female-headed households were 82 and 18, respectively. This is consequent upon Objective II, which identifies the demographic characteristics of the sampled households.

The food groups consumed before and during the Pandemic showed that majority of the households attested to the fact that foods were consumed more before the Pandemic than during the Pandemic due to the ugly impact of COVID-19 and this is consequent upon Objective III, which ascertains the food groups consumed before and during the Pandemic.

The food prices before and during the Pandemic showed that the majority of the households indicated that foods prices were higher during the Pandemic relative to before the Pandemic due to the negative impact of COVID 19 and this is consequent upon Objective IV, which determines the food prices before and during the Pandemic.

The minimum food requirements, source of food delivery, and availability of food during COVID-19 Pandemic showed that the majority of the households did not meet the minimum food requirements as recommended by FAO, WHO, and FANTA. The majority sourced foods *via* online orders and home deliveries, while food materials were not readily available due to lockdown and border closures. This is consequent upon Objective V, which determines the minimum food requirements, source of food delivery, and availability of food during the COVID-19 Pandemic.

The factors affecting food availability, accessibility, and use during the Pandemic showed that a good number of factors, such as artificial scarcity, increase in food prices, lockdown, panic purchase, lack of storage facilities, etc. influenced the food security of the households during the COVID-19 Pandemic. This is consequent upon Objective VI, which isolates the factors affecting food availability, accessibility, and use during the Pandemic.

The estimated COVID-19 determinant of food security status of the households showed that lockdown imposition, increase in disease spread, Government policy, loss of jobs, low income, and household size were important significant COVID-19 determinants of food security status of the households in Southeast Nigeria. This is consequent upon Objective VII, which estimates the perceived effect of COVID-19 determinants of the food security status of households in Southeast Nigeria.

The food security indices of households during COVID-19 showed that 24.4% of the households were food secured while 75.6% were food insecured. The food secured households had an estimated food security index of 4.59 while food insecured households had a 1.21 index. The FSGi indicated a high index value of 2.10 for food secured households and a marginal index of 0.99 for insecured households. This is consequent upon Objective VIII, which estimates the food security indices of households during COVID-19.

Limitations

The study experienced constraints on the part of following up respondents of the 240 households regarding the filling of the data instruments. In some cases, the respondents of the households were absent on visits of the researchers thus making it a tedious exercise for the researchers who painstakingly revisited the respondents of the households on several occasions to monitor and ensure the genuineness of the data instruments.

Interpretations

The standardized food group/classification is presented in **Table 1.** This is sequel to the recommendations of WHO (2020a), FAO (2020a), and FANTA (2020) on dietary and nutrient food contents for each household. They were of the opinion that each household should integrate these groups of food into their meal consumption on daily/weekly bases to ensure adequate calorie intake, good healthy living, and

TABLE 2 | Demographic characteristics of the households.

Variable	Mean/%	Standard deviation
Age	48.8	12.30
Household size	9.6	2.96
Number of males	5.1	1.56
Number of females	4.5	1.64
Male headed household	81.8%	0.67
Female headed household	18.2%	0.37
Sample size	209	

Source: Field survey data, 2021.

be immune against infectious germs and diseases that attack the human body (Ahmed et al., 2015). Furthermore, these groups of foods reflect the dietary quality and balanced rations needed by every household for health sustenance, tissue growth, and general body development. Each household is expected to meet these food requirements as stipulated. From **Table 1**, the various classes of foods include "cereals/grains, fish and seafood, root/tubers and plantain, seeds/pulses/nuts, vitamin A-rich fruits and vegetables, other fruits and vegetables, milk and milk products, oil/fats, meat (organ and flesh meat) and edible insects, sugar/honey, eggs, and miscellaneous food (spices, condiments, and beverages)."

The demographic characteristic of the household is presented in **Table 2**. The mean age of the households was 49 years, with a high standard deviation of 12.30; this implies that the respondents sampled during the period of COVID-19 Pandemic were more of the young and energetic group. Having been incarcerated indoors as a result of the COVID-19 Pandemic, the young and energetic people put pressure on the available and limited household foods. As they were young, they consumed more food relative to the aging members of the family (Kiramat et al., 2022). The mean household size was 9.6 persons; this means that the household size of the respondents was relatively large, and this could have serious food security implications as large families found it difficult to cope with the available food during the Pandemic that caught the world unawares (Osuji et al., 2017; Egwue et al., 2020). The mean numbers of males and females were 5.1 and 4.5 persons per household; this implies the number of males and females per household who were impacted by the COVID-19 Pandemic. More so, this further means that there are more males relative to the females in a household and this posed a big challenge to household food security during the COVID-19 Pandemic, as male folks were considered to consume more food than the female folks (Agada and Igbokwe, 2015). The percentage of the male and female-headed households were 82 and 18, respectively; this implies that the male-headed household outnumbered the female-headed household with over 456%. This further shows that the household responsibilities were shouldered by men in providing for their families even during the COVID-19 Pandemic (Agbugba, 2020a). The COVID- 19 Pandemic interfered with this responsibility as the majority of the male-headed households were basically indoors and could not source food and other domestic family needs and thus affecting their food intake (Ekoh et al., 2020b).

The food groups consumed before and during the Pandemic is presented in **Table 3**. The Table reveals that various foods were consumed before and during the Pandemic. About 82% of the households consumed cereals/grains before the Pandemic relative to the low consumption rate of 60.3% during the Pandemic. This implies that COVID-19 Pandemic negatively lowered food consumption in the Southeast zone of Nigeria due to incessant lock downs and indoor incarcerations (Egwue et al., 2020). Cereals/grains refer to staple food crops, such as rice, wheat, maize, guinea corn, etc., mostly eaten by over 80% of households in Nigeria (Mulubrhan et al., 2020). This indicated the high consumption rate recorded across the respondents both before and during the Pandemic. More of fish and seafood were consumed before the Pandemic with over 187% of the households. Fish and seafood are protein-rich food materials which are needed by each household in bodybuilding, tissue growth, and development (Akukwe, 2019). The impact of the COVID-19 situation which occurred suddenly deprived majority of the households from accessing the food material partly because of the forceful incarceration of the fishermen who were barred from fishing and also due to the unavailability of the food materials due to lockdown which prevented the smooth supply and delivery of such food materials by fish merchandise (Ohiaa et al., 2020). About 57% of the households consumed root/tubers and plantain, during the Pandemic which was far less than 74.2% of the households who consumed more of root/tubers and plantain before the Pandemic. This group of food refers to cassava, yam, coco-yam, plantain, etc. The COVID-19 Pandemic dealt with these food crops in the sense that farmers were constrained from visiting their farms to carry out their agricultural activities which brought about increased hunger, starvation, malnutrition, food shortage, low food supply, and poor food accessibility during the COVID-19 Pandemic (FAO, 2020a). In addition, most farmlands were rendered idle and unproductive due to the inability of the farmers to carry out their occupational operations (Arouna et al., 2020). Vitamin A-rich fruits and vegetables had an increasing consumption rate of over 167% before the Pandemic; this implies that more than 47.8% households consumed these food materials before the Pandemic relative to the 28.7% that consumed the food materials during the Pandemic. Other fruits and vegetables were equally consumed more before the Pandemic than during the Pandemic. These fruits and vegetables are very rich in minerals and vitamins required for body growth, bone formations, and tissue developments. About 49.3% of the households consumed milk and milk products before the Pandemic as compared to a minority of 24.9% during the Pandemic; these are products derived from farm animals both in raw or processed forms, such as extracted milks, processed milks, yogurts, etc. (Barrett, 2020; Yaffe-Bellany and Corkery, 2020). These set of food products are proteinous in nature and needed for body and organ development. The COVID-19 Pandemic impeded animal husbandry where such food products are got from and rendering breeders of livestock comatose (Barrett, 2020). Oil/fats were also consumed more before the Pandemic by 56% of the households

TABLE 3 | Reported food groups consumed before and during the Pandemic.

Food groups	Frequency/(Percentage)			
	Before the Pandemic	During the Pandemic	*Z*-test	*P*-values
Cereals/grains	171 (81.8)	126 (60.3)	4.8532	<0.00001***
Fish and seafood	146 (69.9)	78 (37.3)	6.66692	<0.00001***
Root/tubers and Plantain	155 (74.2)	119 (56.9)	3.7054	0.0002***
Vitamin a rich fruits and vegetables	100 (47.8)	60 (28.7)	4.0251	<0.0001***
Other fruits and vegetables	120 (57.4)	89 (42.6)	3.0325	<0.00244***
Milk and milk products	103 (49.3)	52 (24.9)	5.1643	<0.0001***
Oil/fats	117 (56.0)	90 (43.0)	2.6413	<0.0083**
Meat (organ and fresh meat)	135 (64.6)	79 (37.8)	5.4797	<0.0001***
Edible insects	48 (23.0)	32 (15.3)	1.9893	<0.0466*
Seeds and pulses/nuts	111 (53.1)	70 (33.5)	4.0472	<0.0001***
Sugar/honey	105 (50.2)	43 (20.6)	6.3411	<0.0001***
Eggs	105 (50.2)	62 (29.7)	4.294	<0.0001***
Miscellaneous (spices, condiments, etc)	107 (51.2)	77 (36.8)	2.9559	<0.00308**

Source: Field survey data, 2021. Significance at 1, 5**, and 10%***.*

as against the 43% consumption during the Pandemic. These food materials include margarine, butter, vegetable oil, bleached palm oil, groundnut oil, etc. They are known for muscle development, body formation, and tissue enhancement. **Table 3** further shows an increasing 171% in meat consumption before the Pandemic; this implies that greater percentage of the households consumed more meat products before the Pandemic than during the Pandemic. This is also as a result of the COVID-19 situation that grounded animal husbandry in the Southeast Nigeria (Uche et al., 2021). Edible insects, such as termites, locust, and crickets were consumed more before the Pandemic than during the Pandemic; this refers to victual insects usually substituted in most times for their nutritional content capacities needed by the body for maximum growth and development. About 53.1% of the households consumed seeds and pulses/nuts before the Pandemic as against 34% during the Pandemic. These seeds and nuts include beans, groundnut, melon, walnut, cowpea, tiger nut, etc. Sugar/honey and eggs had an increasing consumption rate of 50% before the Pandemic with less than 22 and 31% of the households during the Pandemic; this implies a high consumption rate over these food groups before the Pandemic. Other miscellaneous foods (spices, condiments, etc.) were consumed by less than 37% of the households during the Pandemic which represents 72% less of consumption rate during the COVID-19 Pandemic. The COVID-19 Pandemic negatively influenced the food consumption rates during the Pandemic as lesser food categories were evidently consumed as shown in **Table 3**. This was obviously due to the frequent and total lockdowns imposed by both the federal and state governments in the Southeast zone of Nigeria which grounded all economic and agricultural activities leading to epileptic food supply, food shortages, low food quality, and higher food prices (Young and Crush, 2019; Oleribe et al., 2020). The lockdown experienced in the Southeast region coupled with other Covid-19 logistics adversely impacted on the provision of the needed food categories by different households. According to Ogunji et al. (2021), lockdowns arising from COVID-19 triggered a massive food recession and major disruptions in food value chains across the Southeast region in Nigeria. Furthermore, the Z-test statistics carried out indicated higher significance levels showing that the food consumption of the household before the COVID-19 Pandemic significantly differs from that consumed during the Pandemic; that is, the households were much better off with respect to food consumption before the Pandemic than during the Pandemic. This assertion validated the fact that COVID-19 Pandemic negatively grounded food security in the Southeast region of Nigeria.

The food prices before and during the Pandemic is presented in **Table 4**. The table reveals that the prices of food materials before the Pandemic was obviously lower relative to the high and exorbitant prices obtained during the Pandemic; for instance, the price of cereals/grains soared higher during the Pandemic as compared with the price before the Pandemic. The exorbitant price could be because of the demands on cereals/grains since they are majorly staple food consumed regularly by over 80% of the populace in Southeast Nigeria (Mbachu et al., 2020; Ogunji et al., 2021). These food materials are energy giving foods required by every household. Fish and seafood had over 62.2% increases in price during the Pandemic; this is due to the lockdown effects that crippled the fishing business and made fishermen to compulsory retire (Adebowale et al., 2021). Root/tubers and plantain were less than N33, 000 before the Pandemic as against over N76, 000 estimated during the Pandemic; this could also be because of higher demands placed on this food category especially cassava, yam, plantain, etc. They are mostly eaten in their raw form or processed into flour which could be on high demands during the Pandemic (UNSCN, 2020). Vitamin A-rich fruits and vegetables and other fruits and vegetables had the same triple effects on prices during the Pandemic than before the Pandemic; there is over 33.5 percentage

TABLE 4 | Food prices before and during the Pandemic.

Food groups	Food prices Mean (N)			
	Before the Pandemic	During the Pandemic	*Z*-test	*P*-values
Cereals/grains	5492.86	9610.71	4.144	0.000***
Fish and seafood	4672.30	7506.08	2.225	0.029**
Root/tubers and plantain	3206.80	7756.31	2.918	0.004**
Vitamin a rich fruits and vegetables	2618.80	6493.00	2.271	0.210**
Other fruits and vegetables	2131.82	7688.64	3.211	0.002***
Milk and milk products	4080.54	8381.61	4.150	0.000***
Oil/fats	3210.71	5054.29	5.641	0.400***
Meat (organ and fresh meat)	3858.11	6389.86	4.091	0.002***
Edible insects	3111.22	5642.33	2.149	0.064**
Seeds and pulses/nuts	3158.82	6284.31	3.998	0.300***
Sugar/honey	2690.98	6801.37	3.438	0.001***
Eggs	3302.71	7068.64	1.921	0.192*
Miscellaneous (spices, condiments, etc.)	3172.00	5956.67	1.557	0.125*

Source: Field survey data, 2021.Significance at 1, 5**, and 10%***.*

increase in these food prices during the Pandemic; the high prices could be due to the medical advice for people to consume more of fruits and vegetables rich in Vitamin A (WFP, 2020). The essence was to build up body immune systems as to guard the body against contacting the dreaded coronavirus and other infectious diseases (UNSCN, 2020). This probably attracted the higher increases in prices during the Pandemic. Milk and milk products had a double increase in price during the Pandemic; this could be due to their protein contents heavily required for body build and nourishment during the Pandemic. Oil/fats equally doubled its price during the Pandemic; this could be a result of higher demands on domestic cooking which cannot be varied (UNDP, 2020). Meat (organ and fresh meat) had over 60% increase in price during the COVID-19 Pandemic; this increase in price could be as a result of limited meat shop sellers who took good advantage of the closed meat markets and other market where meats are sold to inflate their meat prices. This was sequel to the lockdown imposed by the governments which affected markets and other wholesale and retail shops (UNDP, 2020). Edible insects were equally sold at a higher price during the Pandemic relative to before the Pandemic. The price of seeds and pulses/nuts and sugar/honey were higher during the Pandemic than before the Pandemic; thus, these food categories doubled in their prices due to higher demands on them. Eggs and other miscellaneous food materials were also doubled in their prices, especially eggs which had a percentage price increase of about 47% during the Pandemic. The respondents reported buying eggs at prices higher than the usual price before the Pandemic. This arose as a result of the lockdown imposition across the Southeast zone which ultimately grounded poultry production and as a result of this, egg sellers, who were able to smuggle in eggs, sold eggs at exorbitant prices relative to their former price (Uche et al., 2021). Eggs are important food materials rich in protein required by every household during the Pandemic for healthy living and maximum growth, especially in children (UNDP, 2020). The overall implication of the result showed that food prices were relatively low before the Pandemic but during the Pandemic, prices of food items soared rapidly. The high prices of food materials during the Pandemic evidently benefited the marketers or sellers on the short-run chain; they made reasonable sales and profits arising from the lockdown escapade that brought the entire Southeast Nigeria to a sudden halt. No doubt, the COVID-19 Pandemic worsened food security in the Southeast Nigeria *via* uncertainty in food access and inadequate food supply chain thus creating a huge deficit–supply gap (Ogunji et al., 2021). Demands for available food increased tremendously and could not meet up with the supply; this resulted in the shortage of food supply in the long-run and induced higher food prices experienced in Southeast Nigeria (Oleribe et al., 2020). Furthermore, the Z-test statistics gave an overall significance value, indicating that a significant difference exists in food prices before the Pandemic and during the Pandemic. That is, the food prices before the Pandemic differs greatly from the food prices during the Pandemic.

Minimum food requirements, source of food delivery and availability of food during COVID-19 Pandemic is presented in **Table 5**. From the table, it is understood that about 10.5% of the respondents met the minimum food requirements according to the reports from WHO (2020a), FAO (2020b), and FANTA (2020). This assertion was observed during the period of data collection from the households in view of the groups of food consumed during the Pandemic. It was further observed that these minorities of households were able to access the available dietary and nutritional food materials to meet the minimum food requirements. This resulted in panic purchasing of available food materials, which made households stockpile foodstuff (Worstell, 2020; Adebowale et al., 2021). This was done to avert possible hunger, starvation, malnutrition, etc. during the COVID-19 Pandemic. Again, 76.1% of the households had a no response to the minimum food requirements implying that they were not able

TABLE 5 | Minimum food requirements, source of food delivery, and availability of food during COVID-19 Pandemic.

Variables	Frequency	Percentage
Meeting minimum food requirements during COVID-19		
Yes	22	10.5
No	159	76.1
No response	28	13.4
Total	209	100
Sources of food delivery during the Pandemic		
Visit available markets, stores, shops, etc.	96	45.9
Online orders/Home delivery services	113	54.1
Total	209	100
Availability of food during the Pandemic		
Readily available	69	33
Not available	115	55
No response	25	12
Total	209	100

Source: Field survey data, 2021.

TABLE 6 | Factors affecting food availability, accessibility, and use during the Pandemic.

Factors	Frequency	Percentage
Artificial scarcity	125	59.8
Increase in food price	179	85.6
Lockdown policy	134	64.1
Panic purchase	63	30.1
Lack of storage facilities	119	56.9
Lack of electricity supply	65	31.1
Low income	134	64.1
Lack of employment	101	48.3
Family size	64	30.6
Climate change	56	26.8
Poor government policy	115	55.0
Labor reduction	92	44.0

Source: Field survey data, 2021.

to meet the minimum food requirements as specified basically due to the sudden emergence of the COVID-19 Pandemic which swept the whole world off their feet (WHO, 2020c).These groups of households reported making use of any available food at their disposals in satisfying their domestic food needs during the Pandemic and thus, did not bother meeting the minimum food requirements as specified. That is, they were of less concern to minimum food requirements owing to the negative effects of COVID-19 in term of food shortage and unavailability in Southeast Nigeria (Akukwe, 2019; Ekoh et al., 2021). However, 13.4% of the households gave a zero response to the minimum food requirements, implying that they were neither here nor there, regarding the minimum food requirements. They were speechless and dumbfounded due to the biting impact of COVID-19 Pandemic which impaired the food security of their households. About 45.9% of the households sourced their foods *via* available markets, opened stores, shops, etc. This was because the Covid-19 Pandemic led to the closing and shutting down of major markets, stores, shops, etc. across the southeast region whose aim was to avert the possible spread of the COVID diseases which was presumed to spread *via* close contacts with infected persons (WFP, 2020b). This singular act limited the number of available markets, stores, etc. Online orders/home delivery services was used by 54.1% of the households; this became an alternative to the physical buying and selling in the opened markets, shops, and stores as majority of the households resulted to online ordering of domestic foods, since they were not allowed to visit the open markets due to the COVID-19 lock down that greeted the entire Southeast region of the country (Mbachu et al., 2020). The online ordering request commands available foods to be delivered at doorstep under strict compliance with COVID-19 protocols put by the government (WFP, 2020a). Indeed, the online ordering was a source of relief to most homes that were suffering from food shortage and scarcity. Again, less than 55% of the households opined that food was not readily available during the Pandemic due to evidential reasons, such as the lockdown syndrome, the spread of COVID disease, ban on movements, grounding of agriculture, etc. (Torero, 2020). Due to the lockdown, vehicle movements were restricted in the Southeast zone, and this further restricted the movement of food materials across the Southeast zones (Uchechukwu et al., 2022). Furthermore, agriculture which happens to be the main stay of food production was grounded to pieces as the farmers failed to visit their farmlands due to the lockdown and the government's ban on movement due to the spread of COVID-19 disease (Terazono and Munshi, 2020). On the contrary, about 33% of the households gave a positive response toward food availability, implying that foods were readily available precisely on demands or online ordering and/or available markets (Barrett, 2020). They reported that they were able to access available food, though in limited quantity, due to available funds or capital. About 12.0% of respondents declined answers on food availability. Again, they were dumbstruck on the prevalence of the COVID-19 Pandemic ravaging the Southeast zones and other parts of the country.

Factors affecting food availability, accessibility, and use during the Pandemic is presented in **Table 6**. The table reveals that 60% of the households opined that artificial scarcity affected food availability, accessibility, and use during the Pandemic; this means that the COVID-19 Pandemic created some form of artificial scarcity in the sense that some of the marketers or goods sellers took good advantage of the period and hoarded their wares, making it look scarce with an ulterior motive of making excess profits at sales (Agbawodikeizu et al., 2021).This attitude of the sellers or marketers really affected food availability, accessibility, and use during the Pandemic. About 86% of the households attested that increase in food prices hugely influenced negatively the three dimensions of food security (food availability, accessibility, and use) during the Pandemic; this implies that the COVID-19 Pandemic initiated increase in prices of food materials due to the total lockdowns imposed by the government that clapped down markets and other sources of food vendors thereby initiating artificial scarcity leading to increase in food prices of food materials (Oginni et al., 2020). About 64.1% of the households indicated that the lockdown policy embarked on by the government as an alternative measure to flatten the COVID-19 epidemic curve and curtail the spread of the coronavirus affected food availability, accessibility, and use during the Pandemic. This means that the lockdown policy led to the closure of open markets, shops, stores, and impeded vehicular movement of goods and products into the Southeast regions thereby threatening food security in the zone (Ohiaa et al., 2020). Panic purchase was testified by 30.1% of the households; this factor affected the availability, accessibility, and use of food during the Pandemic (Ekoh et al., 2021). In a bid to defeat hunger, starvation, and malnutrition during the Pandemic, out of panic, people purchased expired food products without checking or confirming their expiration regarding the dates, which they eventually did not consume or made use of during the Pandemic. Lack of storage facilities was reported by 57% of the households; this implies that storage facilities that were inadequate due to the lockdown imposition affected the availability, accessibility, and use of food during the Pandemic (Ekoh et al., 2021). Lack of electricity supply was also attested by 31.1% of the households; this factor worsened the storage and preservation of perishable items. thus affecting the availability, accessibility, and use of food during the Pandemic (Uchechukwu et al., 2022). About 64.1% of the households indicated low income; it was generally obvious and true that the COVID-19 Pandemic induced low capital since people's jobs and source of earnings were hugely interrupted resulting from the lockdown (Agbawodikeizu et al., 2021). As a result, incomes were affected, and this negatively influenced food security in the Southeast region. Lack of employment was reported by 48.3% of the respondents; similarly, the COVID-19 Pandemic heavily led to massive loss of jobs across the Southeast Nigeria. Majority of the private companies and business enterprises begun the act of laying off their staff due to the biting impacts of the Pandemic as the companies were not able to sustain their salaries and other allowances; this back drop bankrupts the affected staff and impeded their food accessibility and use during the Pandemic (UNDP, 2020). Family size was reported by less than 32% of the respondents, in truth, families with large households felt the seriousness of the Pandemic, as they were not able to cope during the Pandemic (Aven and Bouder, 2020). Climate change was also attested to and evidently affected food availability, accessibility, and use during the Pandemic. Alterations in weather and seasonal changes affected farm production (Uche et al., 2021), which transited to food shortage and supply during the Pandemic. Poor government policy and labor reduction were reported by over 90% of the households; this means that lockdown policy of the government without adequate and proper food provisions largely affected food availability, accessibility, and use during the Pandemic (Agbugba, 2020a). The government perceived the lockdown as an alternative measure without seeing the negative side effects on food security in the Southeast region of Nigeria.

The estimated COVID-19 determinant of food security status of households in Southeast Nigeria is presented in **Table 7**. The log-likelihood value of 176.990 was highly significant at 1% level, implying that the COVID-19 variables significantly declined food security in the Southeast zone of Nigeria. The high value estimated on Pseudo (R^2) indicated the fitness of the model. The coefficient of social distancing, online orders, and panic purchasing were not significant even at a 10% probability level. The coefficient of lockdown imposition was significant and negative; this implies that an increase in lockdown imposition by the government declined the food security in the zone. This is true due to the effects of the lockdown imposition shut-down open markets and other marketing outlets where food materials could be sourced leading to food deficit and shortage (Ekoh et al., 2020a). The increase in disease spread coefficient was significant at a 1% level and negative; this implies that food security (availability, accessibility, and utilization) worsened as the coronavirus disease spreads rapidly. This was evidently true because the Southeast zone experienced increase in the virus spread, and this hugely affected food availability, accessibility, and use during the Pandemic (Uche et al., 2021). The coefficient of government policy was significant at 1% level and negative; this implies that increase in poor policies of government decreased the food security in the Southeast zone of Nigeria. This was on the bases of immature and sudden measures (policy) to curtail the spread of the coronavirus. These policies (lock-down, closing of food markets, shops, stores, closing of abattoirs, ban on vehicular movement, etc.) were sudden policies that crippled food security in the Southeast Nigeria Agbugba (2020b).Coefficient of loss of jobs was significant at 1% level and negative; this implies that food security aggravated in the Southeast zone due to increased loss of jobs. The COVID-19 period led to a massive loss of jobs in the Southeast zone, especially by private multinational and other private companies (Altieri and Nicholls, 2020; Mbachu et al., 2020; Torero, 2020), and this basically affected the income of workers and thus, translated to food deficit in the zone. The coefficient of low income was significant at 10% level and negative; this implies that the increase in the low income of the respondents exacerbated food security in the zone, the Pandemic period led to massive job losses and shut-down of businesses which affected the income of the populace, and this made it difficult to access or purchase food materials during the Pandemic (UNDP, 2020). The coefficient of household size was significant at a 5% level and negative; this implies that food security in Southeast Nigeria was exacerbated with an increase in the household size. Families with large household sizes found it extremely difficult to cope during the Pandemic, as the available food materials were limited and insufficient to satisfy their domestic food needs (Adebowale et al., 2021). The coefficient of increase in food prices was significant at 1% level and negative; this implies that food security in Southeast Nigeria got worsened with increased food prices. The sudden and imminent lockdown and closure of markets, shops, mini stores, had tremendous effects on food prices, as it doubled the usual market price (Devereux et al., 2020). This stems partly from the creation of artificial scarcity by marketers and partly from government inabilities to provide alternative measures to cushion the negative effects of their actions and policies. An increase in food prices was the major factor as averred by the respondents because it affected the three pillars of food security dimensions (availability,

TABLE 7 | Estimated COVID-19 determinants of food security status of households in Southeast Nigeria.

Variables	Parameters	Coefficients	*t*-values	Std. Error
Constant	b_o	−0.8499	−2.8194**	0.3014
Social distancing	b_1	−4.9160	−1.4466ns	3.3983
Lockdown imposition	b_2	−0.8414	−4.0494***	0.2077
On-line orders	b_3	0.6635	1.4584ns	0.4549
Increase in disease spread	b_4	−0.7769	−4.8474***	0.1602
Government policy	b_5	−4.8314	−4.8470***	0.9967
Loss of jobs	b_6	−3.6436	−3.9138***	0.9309
Low income	b_7	−0.8847	−1.6577*	0.5337
Household size	b_8	−4.9674	−2.4994**	1.9874
Panic purchase	b_9	0.8978	1.0953ns	0.8197
Increase in food prices	b_{10}	−0.0394	−4.4986***	0.0088
Log likelihood		−176.990**		
Pseudo (R^2)		0.8999		
N		209		

Source: Field survey data, 2021. Significance at 1, 5**, and 10%*** levels.*

accessibility, and usability). Food availability was affected due to prohibitions on movement and closure of informal food markets to observe social distancing and to curtail the spread of the virus. Food access was threatened by high food prices and affected households with relatively low income (World Bank, 2020a). These high prices made retailers to have profiteered from panic purchases.

The food security index of households during COVID-19 is presented in **Table 8**. The result shows that 24.4% of the households were food secured during COVID-19 Pandemic as against 75.6% that were not secured. This implies that a lesser number of the households were food secured while the majority of the households were not secured. The former could be due to the food accessibility, availability, and utilization as against the latter (Ogunji et al., 2021). Similarly, the total number of food-secured households was 51 relative to 158 insecured households; this means households in Southeast Nigeria had an increasing percentage of about 309.8% in food insecurity during the Pandemic; this may be due to the lockdown imposed in the states that shut down the economy of the Southeast Nigeria (Uchechukwu et al., 2022). The mean household size of food secured, and insecured households were 4.4 and 6.6, respectively; this implies a serious implication for food security in the zone (Agbawodikeizu et al., 2021). Food insecured households had approximately 6 persons per household and were worse-off during the COVID-19 Pandemic; this was due to their inability to access adequate and sufficient food materials needed to meet their domestic demands (UNDP, 2020). The food secured households had an estimated mean food security index of 4.59 relative to 1.21 obtained from the food insecured households. This means that food secured households had a higher mean food security index in comparison with the food insecured households with a lower food security index. The low food security index could result from the inability of the households to cope with the biting effects of the COVID-19 Pandemic and the limited food materials during the Pandemic due to the lockdown imposition and closure of markets experienced in the Southeast Nigeria (Ekoh et al., 2020a,b). This further implies an upward percentage increase of 379.3% in food insecurity in the Southeast Nigeria. The mean household daily calorie intake (kcal) of food secured and insecured households were 15,512.07 and 1,422.06, respectively, in addition to the mean household per capita daily calorie intake (kcal) estimated at 19,104.41 and 1,270.94 for food secured and insecured households. Here, the average daily calorie intake cum per capita daily calorie intake for food secured households were 15,512.07 and 19,104.41 kcal, which were higher than the recommended minimum daily calorie requirement of 2,100 kcal by (WHO) and (USCIN), 1,800 kcal by (FAO) and the national average calorie requirement of 2,700 kcal, signifying the maximal food security. While the average daily calorie intake cum per capita daily calorie intake for food insecured households were 1,422.06 and 1,270.94 kcal, respectively, which were lower than the recommended minimum daily calorie requirement of 2,100 kcal by WHO and USCIN) 1,800 kcal by (FAO), and the national average calorie requirement of 2,700 kcal, signifying a shortfall in the food security in Southeast Nigeria. These results further imply that the food secured households met the recommended calorie intake of 2,100 kcal by WHO and (USCIN, 1,800 kcal by FAO and the national average calorie requirement of 2,700 kcal, per capita per day as against the food insecured households that were unable to meet the recommended daily per capita calorie requirements of 2,100 kcal by WHO and USCIN, 1,800 kcal by FAO and national average calorie requirement of 2,700 kcal, during the COVID−19 Pandemic experienced in the Southeast Nigeria. This further indicated that a greater percentage of the households, 76%, were food insecured during the COVID-19 Pandemic. The reason for this variance still revolves around the sudden lockdown policy of the government that grounded every economic activity, for instance, food production and distribution in the Southeast Nigeria (Oginni et al., 2020). The FIGi gave estimated values of 0.89 and 3.98 for food secured and insecured households, respectively; this implies that food secured

TABLE 8 | Food security indices of households during COVID-19.

Food security indices	Food secured households	Food in-secured households	Pooled
Percentage of households	24.4	75.6	100
Number of households	51	158	209
Mean of household size	4.4	6.6	11.0
Mean food security index/ Std. Dev.	4.59/(3.47)	1.21/(0.98)	5.8/(4.45)
Mean households daily calorie intake (kcal)	15512.07	1422.06	16934.13
Mean households per capita daily calorie intake (kcal)	19104.41	1270.94	20375.35
Food insecurity gap index	0.89	3.98	4.87
Food surplus gap index	2.10	0.99	3.09
Food surplus/insecurity gap index	2.36	0.24	2.6
Head count ratio	0.28	0.97	1.27

Source: Field survey data, 2021.

households had a marginal insecurity gap index as against food insecured households with a high prevalence index of 398%. Again, the FSGi indicated a high index value of 2.10 for food secured households and a marginal index of 0.99 for insecured households, meaning that the food secured households were able to access and utilized food materials during the COVID-19 Pandemic relative to the latter. The FSGi/FIGi which measure the extent of deviation from the food security line shows that food secure households exceeded the calorie requirement by 236%, while the food insecured households fell short of the calorie requirement by 24%. This shows a wide margin between the food secured and food insecured households in the Southeast Nigeria. The wide margin connotes the preponderance of the COVID-19 Pandemic in the zone (Uchechukwu et al., 2022). The result further revealed a HCR of 0.28 for food secured households and 0.97 for food insecured households; this implies that about 28% of the households were food secured and 97% were food insecured.

Generalizability

The study proved that the ongoing COVID 19 Pandemic worsened food security status of households in the Southeast region with an emphasis on the estimated food security indices of households in Southeast Nigeria.

CONCLUSION

The findings of the study revealed that the food security situation in the Southeast, Nigeria during the COVID-19 Pandemic deteriorated and led to hunger, malnutrition, excruciating poverty, starvation, and food insecurity. The study showed that the mean household size was 9.6 persons; this means that the household size of the respondents was relatively large and this had serious food security implications as large families found it very difficult to cope with the available food during the Pandemic that caught the world unawares. About 82% of the households consumed cereals/grains before the Pandemic relative to the low consumption rate of 60.3% during the Pandemic. This suggests that COVID-19 Pandemic negatively lowered food consumption in the Southeast zone of Nigeria due to incessant lockdowns and indoor incarcerations. Cereals/grains refer to staple food crops, such as rice, wheat, maize, guinea corn, etc., mostly eaten by over 80% of households in Nigeria. This no doubt indicated the high consumption rate estimated across the households both before and during the Pandemic. The lockdown experienced in the Southeast region coupled with other COVID-19 logistics adversely impacted the provision of the needed food categories by different households. It triggered a massive food recession and major disruptions in food value chains across the Southeast region of Nigeria. Again, the prices of food materials before the Pandemic were obviously lower relative to the high and exorbitant prices obtained during the Pandemic; for instance, the prices of most staple foods soared higher during the Pandemic as compared with the price before the Pandemic. The exorbitant price could be as a result of its demands since they are majorly consumed regularly by over 80% of the populace in Southeast Nigeria. Again, the majority of the households, i.e., 76.1%, had a no response to the minimum food requirements implying that they were not able to meet the minimum food requirements as specified by WHO, FAO, and FANTA basically due to the sudden emergence of the COVID-19 Pandemic which swept the whole world off their feet. A good number of factors, such as artificial scarcity, increase in food prices, lockdown policy, panic purchase, lack of storage facilities, lack of electricity supply, low income, etc., affected the three dimensions of food security which include availability, accessibility, and utilization. Furthermore, social distancing, lockdown imposition, online orders, increase in disease spread, government policy, loss of jobs, low income, household size, etc., were recognized as COVID-19 determinants of food security status of households in Southeast Nigeria. About 24% of the households were food secured compared to 76% that were insecured during the Pandemic. The FSGi/FIGiwhich measure the extent of deviation from food security line shows that food secured households exceeded the calorie requirement by 236%, while the food insecured households fell short of the calorie requirement by 24%. This shows a wide margin between the food secured and food insecured households in the Southeast Nigeria.

RECOMMENDATIONS

The study recommended the following based on its findings.

1. Robust and effective policy formulations and implementations regarding food production in the Southeast Nigeria.
2. Revitalization and rejuvenation of the agricultural sector which is the primary source of food production in Nigeria by deployment of modern agrotechnologies to replace crude implements which induce fatigues.
3. Supply of agricultural incentives, such as land provision, improved seedlings, agrochemicals, soft agricultural -loans, etc. These incentives would no doubt motivate the poor household farmers to full scale-up-agricultural production.
4. Massive job creation and provision to cushion the effects of job losses during the COVID-19 Pandemic will enhance the financial capacity of the populace to access and meet domestic food requirements.
5. Childbirth in Nigeria should be regulated to allow for household heads to provide adequately for their families; this is because large families were the major hit by the COVID-19 Pandemic.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethics review and approval/written informed consent was not required as per local legislation and institutional requirements.

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All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

REFERENCES

Adebowale, O. O., Adenubi, O. T., Adesokan, H. K., Oloye, A. A., Bankole, N. O., and Fadipe, O. E. (2021). SARS-CoV-2 (COVID-19 Pandemic) in Nigeria: multi-institutional survey of knowledge, practices and perception amongst undergraduate veterinary medical students. *PLoS ONE* 16, e0248189. doi: 10.1371/journal.pone.0248189

Agada, M. O., and Igbokwe, E. M. (2015). Food security and coping strategies among ethnic groups in North Central Nigeria. *Dev. Country Stud.* 4, 31–45. doi: 10.9734/EJNFS/2015/14875

Agbawodikeizu, P. U., Ezulike, C. D., Ekoh, P. C., George, E. O., Okoye, U. O., and Nnebe, I. (2021). Exploring the impact of COVID-19 Pandemic on economic activities and well-being of older adults in South-Eastern Nigeria: lessons for gerontological social workers. *J. Gerontol. Soc. Work* 64, 613–628. doi: 10.1080/01634372.2021.1907497

Agbugba, I. K. (2020a). *How Federal Government Can Make Agriculture Sustainable in Post-Covid-19 Pandemic season, Exclusive Interview: AGRONIGERIA*. Available online at: https://www.granthaalayahpublication.org/journals/index.php/granthaalayah/article/view/IJRG20_B12_3982

Agbugba, I. K. (2020b). *IFAMA Goes Digital: COVID-19 Pandemic Has Reaffirmed the Need to Develop Nigeria's Agriculture Sector, Food for the Future, International Food and Agribusiness Management Association, Rotterdam, The Netherlands*. Available online at: https://agrifoodnetworks.org/article/dr.-ikechi-agbugba-corona-has-reaffirmed-the-need-to-develop-nigerias-agric

Ahmed, F. F., Eugene, C. E., and Abah, P. O. (2015). Analysis of food security among farming households in Borno State, Nigeria. *J. Agric. Econ. Environ. Soc. Sci.* 1, 130–141. doi: 10.4314/ajtcam.v12i1.14

Akukwe, T. I. (2019). Household food security and its determinants in agrarian communities of Southeastern Nigeria. *J. Trop. Agric. Food Environ. Extens.* 19, 54–60 doi: 10.4314/as.v19i1.9

Altieri, M. A., and Nicholls, C. I. (2020). Agroecology and the reconstruction of a post-COVID-19 agriculture. *J. Peasant Stud.* 47, 881–898. doi: 10.1080/03066150.2020.1782891

Amore, M. D., and Murtinu, S. (2021). Tobit models in strategy research: Critical issues and applications. *Glob. Strategy J.* 11, 331–355. doi: 10.1002/gsj.1363

Arouna, A., Soullier, G., del-Villar, P. M., and Demont, M. (2020). Policy options for mitigating impacts of covid-19 on domestic rice value chains and food security in West Africa. *Glob. Food Security* 26, 100405. doi: 10.1016/j.gfs.2020.100405

Aven, T., and Bouder, F. (2020). The COVID-19 Pandemic: how can risk science help?. *J. Risk Res.* 23, 849–854. doi: 10.1080/13669877.2020.1756383

Babatunde, R. O., Omotosho, O. A., and Sholotan, O. S. (2007).Factors influencing food security status of rural farming households in North Central Nigeria. *Agric. J.* 2, 351–357. Available online at: https://medwelljournals.com/abstract/?doi=aj.2007.351.357

Barrett, C. (2020). Actions now can curb food systems fallout from COVID-19. *Nat. Food* 1, 319–320. doi: 10.1038/s43016-020-0085-y

Carl, F. G. (1777–1855). *Z-Test* | Encyclopedia.com.

Devereux, S., Bén,é, C., and Hoddinott, J. (2020). Conceptualising COVID-19's impacts on household food security. *Food Security*. 12: 769–772, doi: 10.1007/s12571-020-01085-0

De-Wit, E., van Doremalen, N., Falzarano, D., and Munster, V. J. (2016). SARS and MERS: recent insights into emerging coronaviruses. *Nat. Rev. Microbiol.* 14, 523. doi: 10.1038/nrmicro.2016.81

Egwue, O. L., Agbugba, I. K., and Mukaila, R. (2020). Assessment of rural households' food insecurity during covid-19 Pandemic in South-East Nigeria. *Int. J. Res. Granthaalayah* 8, 182–194. doi: 10.29121/granthaalayah.v8.i12.2020.2713

Ekoh, C. P., George, E. O., Ezulike, C. J., and Okoye, U. O. (2020a). The facemask: a tool for protection or an instrument for the transmission of COVID-19 in Nigeria? *J. Soc. Work Dev. Soc.* 2, 7–15. doi: 10.1177/2333721420986301

Ekoh, P. C., Agbawodikeizu, P. U., Ejimkaraonye, C., George, E. O., Ezulike, C. D., and Nnebe, I. (2020b). COVID-19 in rural Nigeria: diminishing social support for older people in Nigeria. *Gerontol. Geriatr. Med.* 6, 1–7.

Ekoh, P. C., Ejimkaraonye, C., George, E. O., and Agbawodikeizu, P. U. (2021). 'Better to die of disease than die of hunger': the experience of Igwes (traditional rulers) in the fight against the COVID-19 Pandemic in rural South-east Nigeria. *Rural Remote Health*. 21, 6691. doi: 10.22605/RRH6691

FANTA (2020). *Food nutrition, Food and Nutrition Technical Assistance*, Abuja: FANTA.

FAO (2018). *Food shortage and implications in Nigeria*. Rome: Food and Agricultural Organization of United Nations.

FAO (2020a). *Impacts of COVID-19 on Food Security and Nutrition: Developing Effective Policy Responses to Address the Hunger and Malnutrition Pandemic*. Rome: Food and Agricultural Organization of United Nations.

FAO (2020b). *FAO Statistical Reports*. Rome: Food and Agricultural Organization of United Nations.

FAO (2021). *FAO Statistical Reports*. Rome: Food and Agricultural Organization of United Nations.

Headey, D. D., and Martin, W. (2016). The impact of food prices on poverty and food security. *Ann. Rev. Resource Econ.* 8, 329–351. doi: 10.1146/annurev-resource-100815-095303

IMF (2020). *Regional Economic Outlook. Sub-Saharan Africa: COVID-19: an Unprecedented Threat to Development*. Washington, D C: International Monetary Fund (IMF).

James, T. (1958). *Econometric Book. Revised Edition. Tobit Model*. London: London Publishers

Johns, H. (2020). *Novel Coronavirus (COVID-19) Cases Data*. Available online at: https://data.humdata.org/dataset/novel-coronavirus-2019-ncov-cases

Kiramat, U., Shahtaj, B., and Amna, R. (2022). Modeling the determinants of household's food security in Pakistan using classical and machine learning methods. *EPRA Int. J. Multidisciplinary Res.* 8, 219–225. doi: 10.36713/epra9335

Laborde, D., Martin, W., Swinnen, J., and Vos, R. (2020). COVID-19 risks global food security. *Science* 369, 500–502. doi: 10.1126/science.abc4765

Marion, N. (2010). Towards a food insecurity multidimensional index (fimi). *Master Hum. Dev. Food Security* 2010/2011, 6–10. Available online at: https://www.semanticscholar.org/paper/Towards-a-Food-Insecurity-Multidimensional-Index--Napoli-Muro/e37dad6f2c3e6d3f159ab68e6c7867b3ea3034ad

Mazibuko, N. V. E., and Antwi, M. A. (2019). Socio-economic factors influencing smallholder farmers agricultural infrastructure availability, accessibility and satisfaction: a case on North West Province in South Africa (May 31, 2019). *OIDA Int. J. Sustain. Dev.* 12, 11–26. doi: 10.22004/ag.econ.284790

Mbachu, C. N. P., Azubuike, C. M., Mbachu, I. I., Ndukwu, C. I., Ezeuko, A. Y., Udigwe, I. B., et al. (2020). COVID-19 infection: Knowledge, attitude, practices, and impact among healthcare workers in a South-Eastern Nigerian state. *J. Infect. Dev. Ctries.* 14, 943-952. doi: 10.3855/jidc.13248

Mulubrhan, A., Amare, K.A., Abay, L.T., and Jordan, C., (2020). *Impacts of COVID-19 on food security panel data evidence from Nigeria, The International Food Policy Research Institute (IFPRI)*. Development Strategy and Governance Division. IFPRI Discussion Paper 01956.

Munonye, J. O. (2022). *Structural Framework, Food Security, and COVID-19 Pandemic*.

NBS (2017). *Census Reports, Nigeria Bureau of statistics*. Abuja: NBS.

NCDC (2020a). *An Update of COVID-19 Outbreak in Nigeria*. Available online at: https://ncdc.gov.ng/diseases/sitreps/?cat=14andname=An

NCDC (2022). Covid 19 updates in Nigeria, Nigeria Center for Disease Control, Abuja, Nigeria

NCDC (2020b). *COVID-19 Regulations, 2020*. Available online at: https://covid19.ncdc.gov.ng/resource/COVID-19_REGULATIONS_2020_20200330214102.pdf.

Obayelu, A. E., Obayelu, O. A., and Bolarinwa, K. K. (2021). Assessment of the immediate and potential long-term effects of COVID-19 outbreak on socioeconomics, agriculture, security of food and dietary intake in Nigeria. *Food Ethics 6* 5. (2021). doi: 10.1007/s41055-021-00085-w

Oginni, O. A., Amiola, A., Adelola, A., and Uchendu, U. A. (2020). Commentary on the Nigerian response to the COVID-19 Pandemic. *Psychol. Trauma* 12, 553–556. doi: 10.1037/tra0000743

Ogunji, J., Iheanacho, S., Ogunji, C. V., Olaolu, M., Oleforuh-Okoleh, V., Amaechi, N., et al. (2021). Counting the cost: the effect of covid-19 lockdown on households in South East Nigeria. *Sustainability* 13, 12417. doi: 10.3390/su132212417

Ohiaa, C., Bakareyb, A. S., and Ahmad, T. (2020). COVID-19 and Nigeria: putting the realities in context. *Int. J. Infect. Dis.* 95, 279–281. doi: 10.1016/j.ijid.2020.04.062

Oleribe, O., Ezechi, O., and Osita-Oleribe, P. (2020). Public perception of COVID-19 management and response in Nigeria: a crosssectional survey. *BMJ Open* 10, e041936. doi: 10.1136/bmjopen-2020-041936

Osuji, E. E., Ehirim, N. C., Balogun, O. L., and Onyebinama, I. C. (2017). Analysis of food security among farming households in Imo State, Nigeria. *Int. J. Agric. Dev*. 20, 3021–3027. Available online at: https://publication.babcock.edu.ng/asset/docs/publications/AGRI/9360/4575.pdf

Otu, W., Ibok, L., Idiong, C., Idiong, T., Nsikan, E., Bassey, O., et al. (2014). Food security and productivity of urban food crop farming households in Southern Nigeria. *J. Agric. Sci.* 2, 01–1 doi: 10.12735/as.v2i3p01

Paules, C. I., Marston, H. D., and Fauci, A. S. (2020). Coronavirus infections, more than just the common cold. *JAMA* 323, 707–708. doi: 10.1001/jama.2020.0757

Ryeji, J., Seung, B. S., Hee, J. L., and Haewon, K. (2018). "On the robustification of the Z-test statistic," in *Conference: KIIE Conference Paper* (Gyeongju).

Saleh, M. K., and Mustafa, A. S. (2018). Food security and productivity among urban farmers in Kaduna State, Nigeria. *J. Agric. Extens.* 22, 171–180 doi: 10.4314/jae.v22i1.15

Sallent, M. (2020). *External Debt Complicates Africa's COVID-19 Recovery, Debt Relief Needed. Africa Renewal, July 2020*. UN Economic Commission for Africa. Available online at: https://www.un.org/africarenewal/magazine/july-2020/external-debt-complicates-~africaspost-covid-19-recovery-mitigating-efforts.

Terazono, E., and Munshi, N. (2020). Choc Waves: How Coronavirus Shook the Cocoa Market. *Financial Times*. Available online at: https://www.ft.com/content/37aa0ac8-e879-4dc2-b751-3eb862b12276 (accessed July 30, 2020).

Torero, M. (2020). Without food, there can be no exit from the Pandemic. *Nature* 580, 588–589. doi: 10.1038/d41586-020-01181-3

Uche, U. O., Uwaezuoke, O., Victor, O. U., Joy, N. U., Ejikeme, G. O., and Ambrose, O. S. (2021). COVID-19 and the food deficit economy in Southeastern Nigeria. *Cogent Arts Human*. 8, 1–9. doi: 10.1080/23311983.2021.1909893

Uchechukwu, M. C., Chiagoziem, O. E., Greg, N. I., Ugonma, W. D., Princewill, U. N., Chidinma, O. A., et al. (2022). Stakeholders' hopes and concerns about the COVID-19 vaccines in Southeastern Nigeria: a qualitative study. *BMC Public Health* 22, 330 doi: 10.1186/s12889-022-12754-4

UNCTAD (2020a). *The COVID-19 Shock to Developing Countries: Towards a 'Whatever it takes' Programme for Two-Thirds of the World's Population Being Left Behind. March 2020*. Available online at: https://unctad.org/en/PublicationsLibrary/gds_tdr2019_covid2_en.pdf

UNCTAD (2020b). *World Investment Report 2020: International Production Beyond the Pandemic*. Geneva: UN. Available online at: https://unctad.org/en/PublicationsLibrary/wir2020_en.pdf).

UNDP (2020). *The Covid-19 Pandemic in Nigeria*. Citizen perceptions and the secondary impacts of Covid-19, Brief 4, May 17 2020 by UNDP Nigeria on behalf of the UN System in Nigeria

United Nations (2020a). *The Impact of COVID-19 on Latin America and the Caribbean*. Available online at: https://unsdg.un.org/resources/policy-brief-impact-covid-19-~latin-america-and-caribbean

United Nations (2020b). *The Impact of COVID-19 on Food Security and Nutrition*. Available online at: https://reliefweb.int/sites/reliefweb.int/files/resources/sg_policy_brief_on_covid_impacto~n_food_security.pdf

United Nations World Food Programme (2020). *World Food Programme Gears up to Support Children Left Without Meals due to COVID-19 School Closures*. Available online at: https://www.wfp.org/news/world-food-programme-gears-support-children-left-without-meals-due-covid-19-school-closures

UNSCN. (2020). *United Nations System Standing Committee on Nutrition*. New York City, NY, United States. Available online at: https://sustainabledevelopment.un.org/index.php?page=view&type=30022&nr=120&menu=3170

USCIN (2020). *Food Nutrition Values and Requirement and Recommendations*. New York, NY: United States Committee on International Nutrition. 17.

Vanapalli, K. R., Sharma, H. B., Ranjan, V. P., Samal, B., Bhattacharya, J., Dubey, B. K., et al. (2020). Challenges and strategies for effective plastic waste management during and post COVID-19 Pandemic. *Sci. Total Environ.* 750, 141514doi: 10.1016/j.scitotenv.2020.141514

Waltenburg, M. A., Victoroff, T., Rose, C. E., Butterfield, M., Jervis, R. H., Fedak, K. M., et al. (2020). Update: COVID-19 among workers in meat and poultry processing facilities — United States, April–May 2020. *Morbid. Mortal. Wkly. Rep.* 69, 887–892. doi: 10.15585/mmwr.mm6927e2

WFP (2020). Food assistance: cash and in-kind, *World Food Programme*. Available online at: https://www.wfp.org

WFP. (2020a). *World Food Programme: Overview - November 2020*. Available online at: https://reliefweb.int/report/world/world-food-programme-overview-november-2020

WFP. (2020b). *World Food Programme: United Nations, Peace, Dignity, and Equality on a Healthy Planet*. Available online at: https://www.un.org/en/about-us/nobel-peace-prize/wfp-2020

WHO (2020a). *Coronavirus Disease (COVID-2019) Situation Reports*. Available online at: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/situation-reports/

WHO (2020b). *WHO Director-General's Opening Remarks at the Media Briefing on COVID-19 - 11 March 2020*. Available online at: https://www.who.int/

director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19---11-march-2020

WHO (2020c). *World Health Organization, 1 in 3 people globally do not have access to safe drinking water – UNICEF, WHO*. New York, NY; Geneva: WHO. Available online at: https://www.who.int/news/item/18-06-2019-1-in-3-people-globally-do-not-have-access-to-safe-drinking-water-unicef-who

World Bank (2020a). *Brief: Food Security and Covid-19*. Washington, DC: Worldbank.

World Bank (2020b). *Global Economic Prospects, June 2020*. Washington, DC, World Bank. Available online at: https://www.worldbank.org/en/publication/global-economicprospects#overview

Worstell, J. (2020). Ecological resilience of food systems in response to the COVID-19 crisis. *J. Agric. Food Syst. Commun. Dev.* 9, 23–30. doi: 10.5304/jafscd.2020.093.015

Yaffe-Bellany, D., and Corkery, M. (2020, April 11). Dumped milk, smashed eggs, plowed vegetables: the food waste of the Pandemic. *New York Times*,. Available online at: https://www.nytimes.com/2020/04/11/Business/coronavirus-destroyingfood.html?searchResultPosition=1.

Yang, X., Zhaofang, Z., Wei, L., Zhen, T., Xin, G., Zhongchi, W., et al. (2019). The Impact of government role on high-quality innovation development in Mainland China. *Sustainability* 11, 5780. doi: 10.3390/su11205780

Young, G., and Crush, J. (2019). *Governing the informal food sector in cities of the global south*. Hungry cities, Discussion Paper 30. Available online at: https://hungrycities.net/wp-content/uploads/2019/04/DP30.pdf

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Ivette Perfecto,
University of Michigan, United States

REVIEWED BY
Shalander Kumar,
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India
Ian Jenson,
Meat & Livestock Australia, Australia

*CORRESPONDENCE
Ernesto Hernández-Martínez
ernesto.hernandez@unj.edu.pe

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The vulnerability of a centralized food system: An opportunity to improve food security in times of COVID-19-Peru perspective

Vicente Amirpasha Tirado-Kulieva[1], William Rolando Miranda-Zamora[1], Ernesto Hernández-Martínez[2]*, Tania Jakeline Choque-Rivera[3] and Olivia Magaly Luque-Vilca[3]

[1]Facultad de Ingeniería de Industrias Alimentarias y Biotecnología, Universidad Nacional de Frontera, Sullana, Peru, [2]Facultad de Ingeniería, Universidad Nacional de Jaén, Jaén, Peru, [3]Facultad de Ingeniería de Procesos Industriales, Universidad Nacional de Juliaca, Juliaca, Peru

COVID-19 has had a strong impact on the food supply chain (FSC) in many countries. The objective of this study was to determine the vulnerability of the FSC in a developing country, namely Peru. The main weakness of the FSC is its centralization, and COVID-19 aggravated this deficit in Peru. This prevents its stability on a large scale, especially in rural areas, which suffer from food and nutritional insecurity. In spite of this, the food system was stabilized due to agricultural, livestock and fishing potential of Peru. In addition, the efforts of local producers and informal vendors helped to maintain the availability of food throughout the country. Several examples of short (and decentralized) FSC were described, highlighting their importance for supplying the population in different areas of the country. In addition, they allow for rapid resolution of interruptions such as the current health crisis. Also mentioned are some suggestions for strengthening Peru's FSC such as the use of new technologies, self-production of food and the exploitation of non-conventional food sources. Emphasis is placed on the importance of environmental sustainability of the FSC and of implementing strategies to prevent illness among workers. This study aims to reflect on the importance of having a resilient and flexible FSC. Taking Peru as a model, the information provided is useful to understand how to improve the food system through the intervention of all the agents involved, such as government, academia, industry and the population.

KEYWORDS

coronavirus, SARS-CoV-2, Peru, food supply chain, food system, food and nutrition security, sustainability

Introduction

As of 29 July 2022, there have been 572,239,451 confirmed cases of infection and 6,390,401 deaths due to coronavirus disease 2019 (COVID-19) (WHO, 2022). This is caused by Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2). COVID-19 has caused great impact in social and economic terms, affecting all industries (Singh et al., 2021). Specifically, COVID-19 has significantly affected the food sector. The food and beverage sector is one of the most relevant and fastest growing industries in the world (Mukhamedjanova, 2020; Memon et al., 2021). It had global revenues of $8 trillion in 2020 and is forecast to increase to $9.1 trillion by 2025 (STATISTA, 2021). On average, food manufacturing represents 12% of the Gross Domestic Product (GDP) of all countries (Bakalis et al., 2020).

The international blockade and the measures imposed by national governments to deal with the pandemic have disrupted the food supply chain (FSC) (Rizou et al., 2020). More than 450 meatpacking plants, more than 250 food processing plants and more than 90 farms were reportedly affected by COVID-19 in the United States. In addition, more than 54,000 workers in the FSC were infected by COVID-19 and more than 200 workers lost their lives. Similar cases were shown in Brazil, Ghana, Germany and France (Aday and Aday, 2020). Farmers in Bangladesh had significant losses of pointed gourd, yardlong beans, bottle gourd, cucumber and brinjal, valued at $692, $633, $223, $223, $131 and $59 per acre, respectively (Alam, 2021). In India, a 10% reduction in the availability of fruits, vegetables and edible oils was witnessed (Mahajan, 2021). In this context, the pandemic has demonstrated the vulnerability of the FSC at critical times and globally.

The impact on imports and exports was severe due to the disruption of international physical supply chains, resulting in high costs. Government restrictions on economic and personal activity (e.g., labor shortages due to not being able to go to work) threw the FSC into chaos, creating an economic crisis (Kerr, 2020) and disrupting the production of farmers, ranchers and fishermen. In the slaughterhouses of France, there was a 30% reduction in the labor force, and in India, the shortage was so high that it reduced cereal production by more than 20% (Rahimi et al., 2021). In addition, there was evidence of low demand and consequent significant loss of food due to the closure of restaurants and related businesses. In Arequipa, Peru, a large number of restaurants were closed, seriously affecting producers/sellers of chicken and potatoes (Malone et al., 2021). All this generated unprecedented food insecurity, a global problem that is being fought every day.

Arguably, all countries have the same battle against COVID-19, but developing countries have a greater challenge, primarily because many of them have a centralized food supply chain (CFSC), with participation and decision making by one or a few responsible agents. For example, the products are sold in a few markets, which are far from a large part of the population. In the case of exports, there are no seaports (there is only one in most cases) close to the production areas. According to Kumar et al. (2021), this makes production, processing, marketing and provisioning difficult. The pandemic has arrived late in Latin America, which has allowed Latin American countries to be better prepared. However, their health and technological deficits and socioeconomic inequalities have had a serious impact from which they have not yet fully recovered (Benítez et al., 2020). There are few studies in this field related to Latin American countries. Specifically, in Peru, although it is a world power in terms of agriculture and fisheries, its food security was strongly affected by COVID-19, leaving its vulnerability exposed. The objective of this study is to determine the vulnerability of the food system in Peru and the impact caused by COVID-19. In addition, some challenges of the topic will be defined and multiple alternative solutions will be offered to improve the country's food system. This is the first study of its kind focused on Peru and the information provided will also be useful for implementing strategies to improve food systems in other countries.

Peru's measures to combat the pandemic

Unlike in other continents, COVID-19 spread relatively late to Latin American countries. Peru was able to establish a contingency plan. It reported its first case of infection on 6 March 2020. On 11 March 2020, through Supreme Decree No. 008-2020-SA, a health emergency was declared at the national level, for a period of ninety (90) calendar days (Parlamento Andino, 2022).

On March 15, the government provided intensive and rapid responses to prevent the spread of the virus such as Ministerial Resolution N° 039-2020-MINSA and Emergency Decree N° 025-2020 focused on improving surveillance, containment and response systems to reduce the impact of COVID-19 (Parlamento Andino, 2022). Quarantine measures (for 3 months) and curfew (until January 2022) were established. The use of masks was enforced, it was suggested to keep a minimum distance of one meter, to wash hands frequently with soap and water and to avoid crowded spaces without natural ventilation (Velásquez-Quispe et al., 2021). A large number of health professionals were hired, and intensive care beds and equipment were acquired for cases of severe symptomatology (Benítez et al., 2020; Romero, 2020). In addition, social programs were implemented, early retirement pensions were allowed, and economic bonuses (such as the Urban, Rural, Independent and Universal Family bonus) were granted to maintain short-term stability for poor families (Siche, 2020), who were affected by the massive loss of jobs. Similarly, the government provided economic assistance to micro and small micro and small businesses (MYPES) to reduce the impact of the pandemic. The financings were quickly implemented through Emergency Decree N° 029-2020. Credits were also provided through the Business Support Fund for MYPES and the Reactiva Peru Program (Parlamento Andino, 2022).

According to Marco (2020), the Peruvian government first spent more than US$25 billion, which represents 12% of GDP. This proportion was the largest in all of Latin America. Argentina, for example, spent only 1% of its GDP. Despite this, Peru has multiple deficiencies due to its health system, labor informality, and the large number of migrants from Venezuela, among other factors (Vázquez-Rowe and Gandolfi, 2020). These factors make it vulnerable, also considering that, as an emerging economy, it faces greater barriers to its sustainability (Bunclark, 2021). Shrestha et al. (2020) determined that Peru is one of the countries with the highest pandemic vulnerability index in the world, considering factors such as economy, health capacity, globalization through travel, event cancellation, work index, FSC and academic level. Therefore, in relation to COVID-19, Peru is one of the countries with a very high mortality rate. As of 01 August 2022, 3,909,870 positive cases and 214,303 deaths have been confirmed (Worldometer, 2022).

It should be noted that Peru remains in a state of health emergency until August 2022 according to Supreme Decree N° 003-2022-SA (Parlamento Andino, 2022).

Food and nutrition insecurity

Background

During this health crisis, life-saving activities are essential, but the scarcity and inaccessibility of food makes this battle difficult (Singh et al., 2021). Therefore, it is also vital to maintain and improve food and nutritional security, through its four fundamental pillars (Figure 1) (Sharma, 2020; Burlea-Schiopoiu et al., 2021; Kumar et al., 2021). One of the factors causing the food security deficit is food waste (sale and consumption) and loss (production, transformation, etc.) at the stages of the FSC, especially if the food is perishable. This leads to a reduction in the availability of nutritious foods and a substantial increase in costs. For example, due to low demand, if a farmer, rancher or fisherman does not sell their food, they must store it. This means an increase in costs and also a reduction in product quality.

Peru is one of the countries with the highest rate of food loss and waste in Latin America, with annual values of approximately 12.8 million tons, representing more than 47% of total production (Banco de Alimentos Perú, 2021). According to the study by Bedoya-Perales and Dal' Magro (2021), based on data from Peru from 2007 to 2017, the average loss/waste per capita was 426.56 kg/year across all FSC stages, and 67.34 kg/year at the final consumer stage. In the study by Requena-Sanchez et al. (2022), from 2019 to 2020 there was no evidence of an increase in food waste in Comas, Lima, Peru. However, an increase in the waste of single-use plastic containers and bags was reported, which is related to the increase in food delivery services.

Impact on Peru

Restrictions on business, people and transportation affected local commerce. In the food sector, the stability in the capacity and efficiency of farmers, food manufacturers, wholesale distributors and retailers has been lost (FAO, 2020a). Border closures, trade measures in Peru, crisis in foreign markets and with strategic partners [Ministry of Agriculture and Irrigation of Peru (MINAGRI, 2020)] affected the FSC (Mukhamedjanova, 2020). The impact was more severe than expected due to Peru's dependence on imports and its leading position in agri-food exports (van der Ploeg, 2020). In addition, the isolation affected the dynamics of economic activity in general (Varona, 2021). For example, transit restrictions limited the fishing and subsequent distribution of different marine products in Lima (Peru's capital) and other areas of the country (Bassett et al., 2021).

Several studies have confirmed the vulnerability of the Peruvian food system. Erokhin (2020) analyzed the impact of COVID-19 in 45 countries, concluding that Peru was severely affected in trade, foreign exchange and food supply. From March to August 2020 there was a reduction in fishing and purchase of fish (e.g., 83% less hake). As a result, 620 jobs were affected with an overall loss of approximately US$913 thousand (Grillo-Núñez et al., 2021). In addition, in one of the first studies conducted at the beginning of the pandemic, it was determined that there was a significant reduction in income of 37% of the participants (Sanchez et al., 2020). This generated greater limitations in the acquisition of food, mainly for Peruvians who subsist on their daily income (Cañari-Casaño et al., 2021). This deficit increased health problems and the prevalence index of food insecurity (PIFI) (Bakalis et al., 2020; O'Hara, 2021).

Regarding socioeconomic status, a study conducted from March to December 2020 found that Peruvian families with low incomes were 42% more likely to experience food insecurity (Curi-Quinto et al., 2021). From May to June 2020, Cañari-Casaño et al. (2021) found that Peruvians with incomes below $255/month were highly likely to experience moderate or severe food insecurity. This is ironic considering that currently (25 February 2022) the minimum salary in the country is PEN 920 (US$ 242.17). According to the study by Cuenca Jaque et al. (2020), from March to April 2020, 57.3% of Peruvians were already experiencing economic problems and difficulties in acquiring basic necessities. In addition, 69.8% of Peruvians indicated that they only had enough food for 1 week and 56.8% indicated that with the money they had they could only buy enough food for 2 weeks. A study conducted in May 2020 found that 56.9% of Peruvians spent more on food than before the

FIGURE 1
Basic dimensions of food and nutrition security.

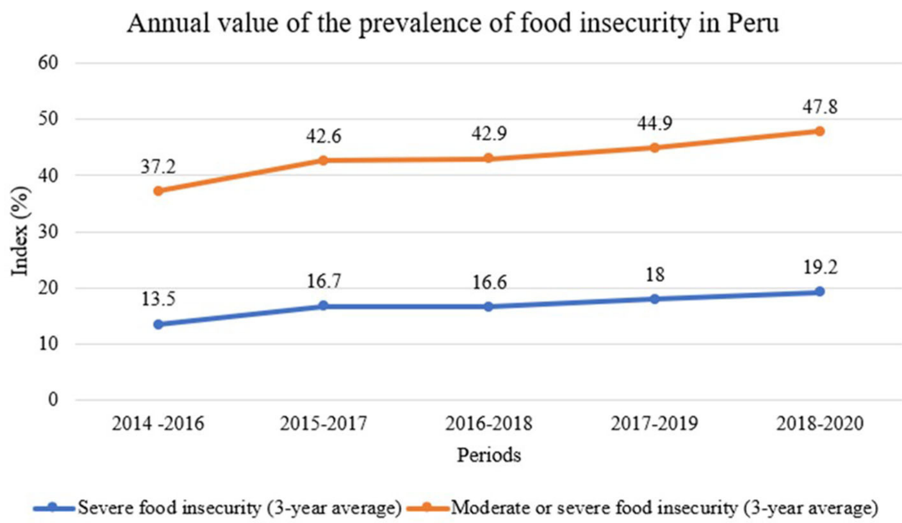

FIGURE 2
Prevalence of food insecurity in Peru. Based on data from (FAOSTAT, 2021).

pandemic (Cequea et al., 2021). These results are worrisome and the crisis increased as the isolation prolonged. It should be considered that the PIFI before the pandemic was already negative. From the period 2014–2016 to 2018–2020 in Peru, severe food insecurity increased by 10.6% and moderate or severe insecurity by 5.7%, as shown in Figure 2.

Centralization in the food supply chain

A food system must be multidisciplinary and interconnected (Han et al., 2021). It should cover the greatest number of people (producers, government, industry, consumers) and avoid inequalities regardless of their geographic location within the country (Cable et al., 2021). The main factor contributing to internal food shortages is centralized distribution, which, due to lack of adequate logistics, concentrates all raw materials and/or products in one place or in very limited areas. This affects the availability of food for the population living in *discriminated* cities (Cullen, 2020). It also increases the costs of products when they are sold in areas far from production and/or transformation. This is chaotic when crises such as the current pandemic occur because it is more difficult to solve problems (Abdullah et al., 2021). Does not allow for quick responses to disruptions at any stage, demand surges or product shortages. Figure 3 shows the United Kingdom's FSC with the number of participants at each stage. Compared to the other stages, there

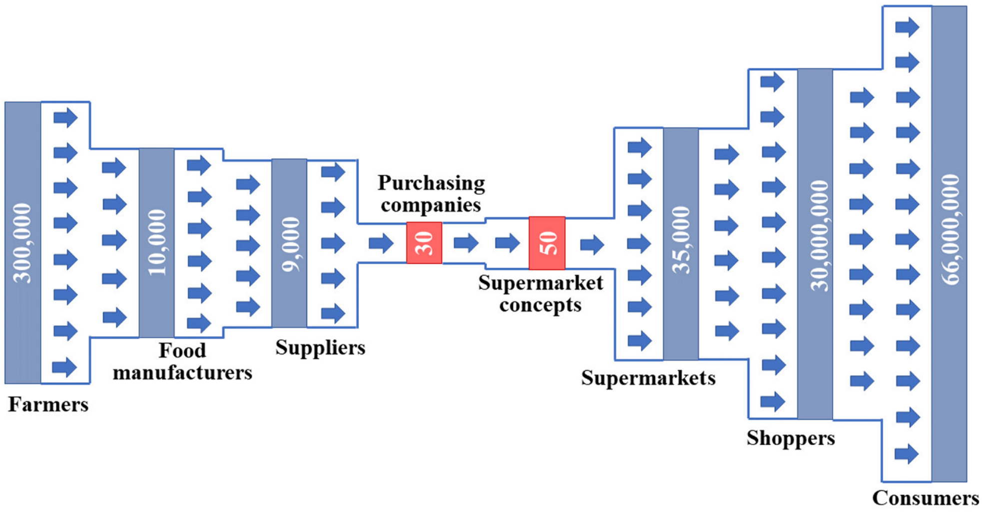

FIGURE 3
Graphical representation of the agents (numbers in white) involved in each stage of the United Kingdom's FSC. Adapted from Bakalis et al. (2020).

is a bottleneck in the Suppliers and Supermarkets stage. The number of agents involved in the Purchasing companies and in Supermarket concepts (red boxes) stage is very low. This means that only a selected group of organizations acquire and control a large part of the food consumed. In the event of a crisis in this small group of organizations, the FSC would suffer an untimely and difficult-to-solve disruption. This example clearly shows how most FSCs are vulnerable because they are dominated by a few large, but centralized, organizations (Hobbs, 2020).

To solve this problem, FAO (2020b) mentions that it is essential to create regionalized food supply chains (RFSCs) at strategic points throughout the country. This will provide greater linkages between urban and rural areas, allowing for local production and availability, short-distance transportation and few intermediaries between producers and consumers (Marusak et al., 2021). The short distance also makes it possible to obtain fresher and cheaper foods (Barman et al., 2021). In case of risk, the self-sufficiency of each RFSC allows mitigating the adverse effects, reducing the overall damage (Thilmany et al., 2021). This confirms the resilience of RFSCs, which means that they are flexible and adaptable. This type of short chain has been successful in rural and urban areas in all European Union countries (Bakalis et al., 2020). Marusak et al. (2021) evaluated the effect of RFSCs on the resilience of food systems based on seven case studies from Texas and Iowa. It was concluded that the RFSCs are faster in terms of adaptation, managing to be efficient in maintaining sustainability in this COVID-19 context. Chenarides et al. (2021) used a FSC model for fresh onions in the United States based on real options theory. Increased flexibility was found to increase the resilience of the FSC. The results also showed that these types of adaptable FSC have a higher value in the market.

Resistance of the Peruvian food system to centralization

Despite the efforts made, Peru has greater centralism than other Latin American countries such as Brazil, Chile, and Colombia (Binder, 2018). This is due to the few initiatives taken by the authorities, the lack of infrastructure, the scarce and deficient interconnection routes between regions. The food industry in Peru is conditioned to serious structural and logistical limitations that force it to be dependent on privileged zones (Lazo, 1984). A clear example is Lima, which receives the highest proportion of state support. Although moderate poverty and chronic malnutrition have been significantly reduced throughout the country in the last two decades, progress has been uneven in rural and Amazonian areas (Vargas et al., 2021). Useche (2016) highlight that between urban and rural areas in Peru there is a wide gap in terms of food security. According to Castro-Bedriñana et al. (2021), the average chronic malnutrition rate in Lima is 5% and in rural areas it is over 33%. In rural areas of Peru, 4 out of every 5 children between 6 months and 2 years old suffer from malnutrition (UNICEF, 2019). Similarly, Abizaid et al. (2020) evaluated the effect of the pandemic in marginalized areas of Ucayali, a region of the Peruvian Amazon. It was corroborated that the population of Ucayali received fewer economic bonuses and there is no guarantee that the people who needed them received them.

TABLE 1 Examples of some CFSCs in Peru.

Product	Place of production	Main port of export	Approximate distance (km)	References
Cocoa	Cusco	Callao (97% of total production)	1,000	(Briceño-Garmendia et al., 2016a)
	Piura		900	
	San Martín		800	
	Amazonas		700	
	Ayacucho		500	
	Junín		200	
Quinoa	Puno	Callao (88.4% of total production)	1,200	(Briceño-Garmendia et al., 2016c)
	Arequipa		1,000	
	Cusco		1,000	
	Ayacucho		500	
	Apurimac		400	
	Junín		200	
Coffee	Huánuco	Paita (54.8% of total production)	1,100	(Briceño-Garmendia et al., 2016b)
	Ucayali		1,000	
	Junín		1,000	
	Pasco		800	
	Cajamarca		500	
	Piura		Same region	

There was also a scarce and unequal distribution of food by the state.

Coffee, cocoa and quinoa exports are some examples of non-integrated logistics chains (or RFSCs). Briceño-Garmendia et al. (2016d) mention that these products are transported in small and medium-sized informal vehicles that travel long distances. As shown in Table 1, the production areas are very distant from the seaport destined for export. New ports should be implemented in different strategic areas of the country to reduce the distance with the production areas. In the case of cocoa cultivation in Piura, the port of Paita can be used, which is located in the same region. Quinoa is mainly produced in the south of the country; however, this area lacks seaports. In the case of coffee, the port of Paita can be used to receive coffee from Piura, and for the production of other zones, the port of Callao can be used. Similarly, potatoes are produced in cities such as Junín and Ayacucho, but are processed in Lima, with a significant number of intermediaries between each stage (Delgado et al., 2021).

Regarding onion, 52% of its production occurs in the south of the country, but only 2% is shipped through the port of Matarani, which is located in the same region (Arequipa). The rest of the production is transported to the ports of Callao and Paita, which means an increase in distance of up to 1,000 km (Briceño-Garmendia et al., 2016d). In addition, it should be considered that onion is a susceptible product that loses its quality during long transportation. This can be solved with the decentralization of the ports, considering that the ports of Callao and Paita should not cease to be used. On the contrary, it is important to take advantage of the fact that onions can be produced in all areas of Peru.

Other evidence of the importance of decentralization in Peru comes from Mercado (2017), who evaluated the quinoa FSC in Puno and Junín. They concluded that the chain containing linkages between collectors, processors and exporters ensured a more efficient and coordinated trade. However, producers acting alone had a very poor organization and lower sales of quinoa. Contreras (2018) determined that the CFSC of non-perishable foods manufactured in Lima and Callao produce a substantial increase in costs when distributed to supermarkets in the south of the country. Long distances restrict a quick response in case of any problems during transport, if there are shortages in the supermarket or if demand increases.

Peru's potential to combat food and nutrition insecurity

Despite the difficulties due to the pandemic and the centralization, Peru's megadiversity makes it possible to produce a large quantity and variety of foodstuffs and to regulate their cost. As shown in Figure 4, the production index has remained stable and dynamic.

The panic due to the pandemic caused people to buy essential products excessively. This increase in demand caused producers and/or merchants to raise the price of products (law of supply and demand). The price of foods such as lemons,

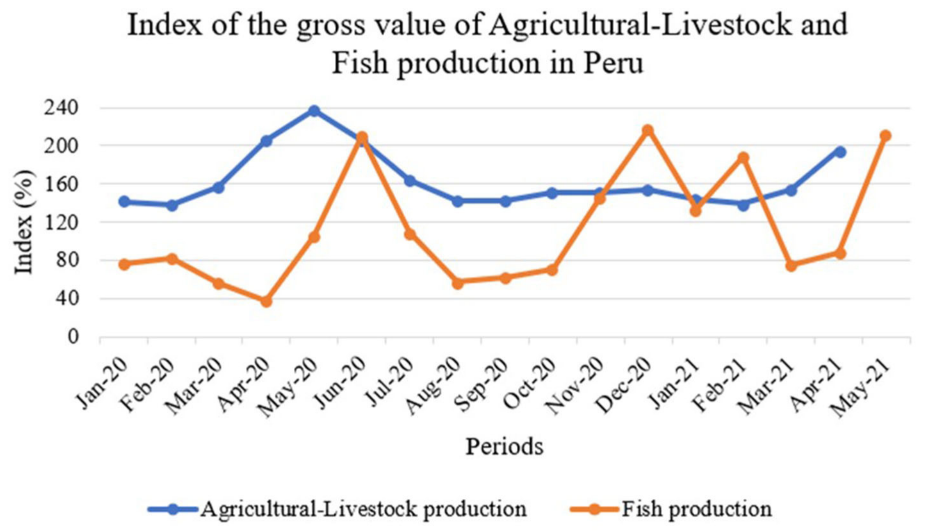

FIGURE 4
Food production indicators. Based on information from INEI (2021), provided by MINAGRI and the Ministry of Production (PRODUCE), on agricultural-livestock and fishery production, respectively.

sugar, potatoes, beans, tomatoes, spinach and peas increased from 14 to 30% (Enfoque Derecho, 2020). For price control purposes, through article 2 of Supreme Decree 044-2020-PCM, the Peruvian government guarantees the supply of food and medicines during the state of emergency. MINAGRI was in charge of monitoring the supply and price of products. Also, agricultural products were rapidly depleting due to increased exports, and as a result, decentralized production increased in fertile areas such as Olmos (Lambayeque region), Majes (Arequipa) and Chavimochic (La Libertad).

The resilience of the Peruvian food system was also due to the massive appearance of street vendors, as in the case of Arequipa. They indiscriminately distribute the products of necessity, through the modality of peasant markets, rural agricultural fairs and itinerant markets. Although sales conditions are in very poor sanitary conditions (Ramirez-Hernandez et al., 2020), this increases product availability and is reported to have influenced a 15–20% reduction in prices (Vargas et al., 2021). This information was verified in the study by Zimmerer (2020). The population of South America, specifically Peru, relied on informal traders to access a wide variety of food products. When the large markets (such as La Parada) closed in Lima, a large number of street vendors appeared and were able to supply food to the population of each locality. Even with their own funds, the vendors bought biosafety equipment to sell in the early hours of the morning, thus reducing the risk of COVID-19 infection (Coletto et al., 2021). However, informal vendors in Peru, who represent more than 50% of the population, have no benefits and are vulnerable to critical situations, especially due to the lack of health insurance (Vázquez-Rowe and Gandolfi, 2020). According to the above, emphasis is placed on supporting informal producers/traders as they represent a key point in support of decentralization. In this case, MINAGRI provided financing to small producers throughout the country to organize their itinerant markets.

Challenges and solution strategies

This COVID-19 pandemic is an opportunity to address FSC weaknesses and enhance its strengths by transitioning from CFSC to RFSCs. According to the survey conducted by Luckstead et al. (2020), with this pandemic, the U.S. population is more aware of the importance of FSC, especially at the stage of small producers. The study by Blazy et al. (2021) found that, although COVID-19 severely affected the Caribbean agricultural system, weaknesses were improved. These include the search for short marketing channels, the cultivation of more varied products according to the needs of the population and mutual assistance among farmers. To achieve this in Peru in the long term requires the support of industry, academia and other stakeholders (Ramirez-Hernandez et al., 2020). Solutions should be focused on achieving a resilient food system at local, regional, national and global scales (Han et al., 2021). Hecht et al. (2019) interviewed 26 companies and organizations in the food sector and identified 10 factors with significant influence on FSC resilience. It was concluded that the resilience and strengthening of the food industry is achieved with the active participation of government, industry, policy makers and consumers.

We must eliminate the erroneous idea that Peru is only the capital and other privileged cities (Lazo, 1984). The central government must improve and create new policies to support

RFSCs, considering their high deficit in infrastructure, logistics, experience and knowledge (Gemmill-Herren, 2020). The first step toward decentralization is to interconnect all cities, through strategic routes that allow rapid communication between all FSC agents (Bedoya-Perales and Dal' Magro, 2021).

On the other hand, labor is required in large quantities and restrictions were a limiting factor. This mainly affected countries where foreigners represent a considerable percentage of the workforce, such as the United States, Mexico, China and India. In Canada, more than 60,000 Mexicans work in agribusiness, and in India, the reduction of labor affected vegetable and fish farming, significantly reducing production (Chitrakar et al., 2021). In the case of Peru, in July 2020 there were 1.2 million Venezuelan migrants (more than 3.5% of the Peruvian population), of which a large part worked in the country's food industry [World Bank (Banco Mundial, 2020)].

Understanding the stages of FSC will allow us to identify bottlenecks and propose alternative solutions. Human (knowledge) and social (connections) capital and strong investments are required to support the community, mainly in rural areas. In a study focused on Bangladesh, Amjath-Babu et al. (2020) found that maintaining the robustness of a food system requires important components such as logistics for distribution of safe and quality inputs with circular flow. Adequate storage facilities, efficient management tools and, above all, credit opportunities to cover essential expenses, especially for small farmers, are also required (Aday and Aday, 2020). Support can also be received from international entities related to the field of food and nutrition security. An appropriate funding tool for this context is the Global Agriculture and Food Security Program, founded in response to the 2007–2008 food crisis (Cullen, 2020). It was reported that in Tunisia, Egypt and Morocco, financing was provided to workers, mainly temporary and informal workers (Hashem et al., 2020). Limited support does not allow the full potential of food products to be exploited. Ramos et al. (2021) indicate that cañihua, quinoa and kiwicha have received greater attention in the world for their nutritional quality, but deficits in seed supply, transportation, storage and packaging limit their true potential.

Use of new technologies

To improve the interconnection between each stage of the FSC and between each RFSC, Bakalis et al. (2020), García et al. (2020), Siche (2020), Vaio et al. (2020), Chitrakar et al. (2021) suggest implementing automation. This includes the application of digital and intelligent systems such as the internet of things (IoT), artificial intelligence (AI), and information and communication technologies (ICT). For example, drones can be used to deliver products, monitor and evaluate crop fields, farms, and aquaculture areas. In South Africa, an IoT system was created to manage social distancing and monitor the number of people in a facility in real time (IoT.nxt, 2020). In Shanghai, China, drones are widely used to deliver food and other products without contact (Parkhill, 2022). These technologies reduce person-to-person contact and should also be applied for e-commerce, which has increased significantly (Thilmany et al., 2021) with promising results shown in Morocco and China (Hashem et al., 2020).

Smart packaging technology (modified/controlled atmosphere packaging, active packaging and intelligent packaging) can be used in the food industry. In addition, smart detection systems (electronic tongue, electronic nose, spectroscopic techniques, machine vision and artificial intelligence) and thermal (sterilization) and non-thermal (cold plasma, pulsed electric fields, ultrasound and microwave) technologies can be used with emphasis on virus elimination (Chitrakar et al., 2021). According to the above, extensive training on these tools should be provided to FSC agents. A study assessed the effect of the pandemic on the FSC of JD.com, an Asian e-commerce giant that sells a wide variety of products, including food. Shen (2021) determined that, although JD.com did not take many actions to combat the crisis, the impact was minimal due to the proper management achieved by the smart platforms.

The importance of self-production of food

Lal (2020) recommends home production through home gardens. Another option could be hydroponics, aquaponics, small animal husbandry, which is practiced in many remote areas of Peru. Through online surveys, it was determined that due to the food impact of COVID-19, 96% of Latin American people had to carry out home farming. 90% of them indicated that their initiative contributed to preventing imminent food insecurity (Tittonell et al., 2021). In addition to home production, Castro-Bedriñana et al. (2021) indicate that more than 71% of rural families in Andean communities in Peru have farmland (potatoes, corn, barley, beans, etc.). They also raise cows, sheep, pigs, chickens/hens and guinea pigs for self-consumption and sale, in proportions greater than 44%, 34%, 29%, 40% and 63%, respectively. To this measure, the range of cultivation/breeding options can be expanded. For example, 25% of potato producers and 74% of coffee producers interviewed in Peru indicated that they would introduce new crops to improve food security (Vargas et al., 2021).

Castro (2015) evaluated the effects of these measures on the reduction of nutritional problems in children under 5 years of age in Andean communities (Acobamba, Chambará, Huamalí, Pancán and Tapo) in Peru. For a period of 3 years, assistance was provided in the development of the necessary capacities for the production of potatoes, corn, barley and mashua vegetables (in orchards and farms), the raising of guinea pigs and chickens, including their consumption and sale. This influenced the reduction in the prevalence of chronic and anemic malnutrition in ranges from 0.75% to 31.35% and from 3.2% to 20.3%, respectively.

Alternative/non-conventional food sources

It is projected that in 2050 there will be 34% more people in the world and in turn, the demand for food production will increase by 70% (Mariutti et al., 2021). In this sense, researchers are making immeasurable efforts to find new sources of food. They must be mass-produced, renewable and low-cost. It was determined that cockroach milk and flour will contribute to the prevention of food shortages due to their high protein content (Galanakis, 2020).

In the pandemic context, it was determined that the population of Cusco, Peru increased the use of edible plants such as eucalyptus, kion, garlic, matico, chamomile and coca, in proportions of 70.2%, 68.3%, 58.8%, 49.6%, 34.0% and 21.6%, respectively. These plant products have a high biological activity with potential in the prevention and possible therapeutic treatment of COVID-19 (Villena-Tejada et al., 2021). With respect to decentralization, the curious thing is that the population of the Peruvian capital has migrated to the country's marginalized cities because there is greater food potential in these areas. At the beginning of the pandemic, more than 700 people from Lima went to live in the Andean communities mainly to grow their own food and subsist (Lanza and Narváez, 2020).

Other new sources of protein-rich foods include insects (such as cockroaches), algae, and by-products of meat, fish and dairy processing (Hashem et al., 2020). The substitution of red meats such as poultry and pork for vegetable sources such as quinoa was reported (Galanakis, 2020). Other widely studied sources include pseudocereals and grains, and edible flowers. Amaranth, chia and quinoa grow in tropical and subtropical regions and have been included in the diet of the Incas for centuries. A relevant pseudocereal is kiwicha, which is cultivated in several American countries, including Peru (Mariutti et al., 2021). Other Andean grains cultivated in the country are quinoa, cañihua and tarwi, which have a high nutritional value (Padulosi et al., 2014). Regarding edible flowers, flowers of *Brassica rapa* subsp. Campestres L., *Tropaeolum dipetalum* R. et P., *T. minus* L., *T. peregrinum* L., *T. seemanni* Bush., T. *smithii* D.C., *T. tuberosum* R. & P., *Typha dominguensis* Persoon., *Carica papaya* L., *Cucúrbita moschata* Duch., *Typha angustifolia* L. are consumed in Peru (Súmar, 2004).

This measure is also aimed at animal feed. In the Amazon region of Peru, Godoy et al. (2021) evaluated the effect of supplementation with rice polishing and a new alternative supplementation based on coconut flour, cocoa husk, rice polishing and rice flour in lactating cows. Cows supplemented with the non-conventional mixture produced more milk (1.4 kg/cow/day extra) and had more weight (0.13 kg/day extra). In addition, with the alternative supplementation, there was an extra income of US$ 1.72/day (considering US$ 1 = PEN 3.846).

Does food transmit SARS-CoV-2?

Although COVID-19 has not been shown to spread through food, constant vigilance during FSC is crucial. The necessary activities to prevent the transmission of SARS-CoV-2 should be carried out (Han et al., 2021), which are more risky during the later stages due to the greater involvement of peoples (Rizou et al., 2020). According to current sanitary requirements, some strategies implemented in two food markets in Lima are shown in Table 2. In the case of La Parada market, many vendors did not continue with online sales because it was less profitable than going to the market (Coletto et al., 2021). On the other hand, in the Santa Anita Market, the measures implemented were stricter (Table 2). This was due to formality, which generates greater support from the authorities.

Although it is difficult to maintain distance under these sales conditions, these measures were necessary to prevent person-to-person transmission of the virus. At that time, measures were also aimed at preventing the presence and survival of the virus on surfaces, but currently, that is considered unlikely. Singh M. et al. (2021) did not detect the presence of SARS-CoV-2 on high-contact surfaces (n = 97) with food in retail stores in Canada.

Current recommendations for reducing the economic and public health impacts of COVID-19 in the food sector can be found in FoodCoVNET (https://foodcovnet.ces.ncsu.edu/welcome-to-foodcovnet/).

Another key element: Sustainability of the food system

The correct implementation of RFSCs must also be evaluated in terms of environmental sustainability. The strategies employed are often not sufficiently sustainable (Hashem et al., 2020). For example, artificial meat farming is not a sustainable source of protein, but it is possible to use biological and recoverable sources such as algae (Galanakis, 2020) or others previously mentioned. Likewise, although the cold chain is essential during food distribution, if the distance is very short, it is recommended to transport fresh and not frozen food to reduce energy consumption (Ramos et al., 2018).

Food sustainability is a scenario that is often overlooked, but we must be aware of its consequences. Food contributes

TABLE 2 Measures implemented in two of the most important food markets in Lima, Peru.

Market	Type of trade	Measures
La Parada	Informal street vending	Acquisition of a large number of masks and biosafety suits for personnel.
		Weekly cleaning and disinfection of the market.
		Online sales option (*via* Facebook, whatsapp, etc.), mandatory for vulnerable persons.
Santa Anita	Formal closed market	Regular COVID-19 testing.
		Acquisition of masks.
		Installation of water faucets and use of liquid soap.
		Installation of footbaths.
		Floor painting to define the distance between people.
		Temperature control of vendors and customers prior to entering the market.
		Prohibition of entry to vulnerable persons.
		Private security to prohibit the entry of informal workers who disturbed the order and established measures.
		Organization of buyers in rows.

Prepared from information from Coletto et al. (2021) obtained from February to September 2020.

approximately 17% of the total carbon footprint (Bakalis et al., 2020). According to a study on the evaluation of restaurants in Lima and Tacna, only 18% indicated that they manage organic waste (Cordova-Buiza et al., 2022). Ramirez-Hernandez et al. (2020) suggest applying sustainable strategies at each stage of the chain based on national and international standards. This will ensure food quality and safety and increase consumer confidence, as well as national and international markets.

Conclusion

COVID-19 has aggravated existing vulnerabilities in Peru's FSC due to its centralization. According to the literature, Peru has a weak food system in terms of knowledge, technology, infrastructure, logistics, transportation, interconnection routes, among other factors. In addition, the scarce support provided by the government is only directed to privileged areas, causing serious food insecurity in rural areas. However, despite the crisis generated by the interruption of the FSC, Peru remained stable due to its high agricultural and fishing potential. In addition, thanks to the support of small producers and informal vendors, food supply was ensured throughout the country. This has demonstrated the importance of decentralizing FSC, transcending to a robust, adaptable and sustainable food system at local, regional, national and global levels. The RFSC also offers the advantage of being more resistant to disturbances and of acting quickly in case of risk. The information obtained serves as a reflection to take advantage of the current situation and improve the Peruvian food system. It is suggested to implement strategies such as the use of technologies, self-production of food, ingestion of non-conventional food sources, in addition to improving hygiene measures to ensure food safety and the protection of the agents involved in the different stages of the FSC.

Author contributions

VT-K: conceptualization of the idea, bibliographic search, writing, and preparation of the original draft. WM-Z: conceptualization of the idea, writing, and preparation of the original draft. EH-M: conceptualization, drafting, preparation of original draft, and supervision. TC-R and OL-V: reviewing, drafting, and proofreading and editing. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Abdullah, D., Rahardja, U., and Oganda, F. P. (2021). Covid-19: decentralized food supply Chain management. *Syst. Rev. Pharm.* 12, 142–152. doi: 10.31838/srp.2021.3.25

Abizaid, C., Panduro, L. Á. C., and Egusquiza, S. G. (2020). Pobreza Y medios de subsistencia en la amazonía peruana en tiempos de la Covid-19. *J. Lat. Am. Geogr.* 19, 202–214. doi: 10.1353/lag.2020.0080

Aday, S., and Aday, M. S. (2020). Impact of COVID-19 on the food supply chain. *Food Qual. Saf.* 4, 167–180. doi: 10.1093/fqsafe/fyaa024

Alam, G. M. M. and Khatun, M. N. (2021). Impact of COVID-19 on vegetable supply chain and food security: empirical evidence from Bangladesh. *PLoS ONE* 16, e0248120. doi: 10.1371/journal.pone.0248120

Amjath-Babu, T. S., Krupnik, T. J., Thilsted, S. H., and McDonald, A. J. (2020). Key indicators for monitoring food system disruptions caused by the COVID-19 pandemic: Insights from Bangladesh towards effective response. *Food Secur.* 12, 761–768. doi: 10.1007/s12571-020-01083-2

Bakalis, S., Valdramidis, V. P., Argyropoulos, D., Ahrne, L., Chen, J., Cullen, P. J., et al. (2020). Perspectives from CO+RE: how COVID-19 changed our food systems and food security paradigms. *Curr. Res. Food Sci.* 3, 166–172. doi: 10.1016/j.crfs.2020.05.003

Banco de Alimentos Perú (2021). *Cada año, en nuestro país se desperdician 12,8 millones de toneladas de alimentos, el 47,6% del total con que cuenta el perú. Solo en frutas y vegetales se pierden 5,6 millones*. Available online at: https://bancodealimentosperu.org/en-el-peru-la-mitad-de-los-alimentos-termina-en-la-basura/ (accessed February 26, 2022).

Banco Mundial (2020). *Infografía: Migrantes y Refugiados Venezolanos en El Perú: El Impacto de la Crisis de la Covid-19 (#Coronavirus)*. Available online at: https://www.bancomundial.org/es/news/infographic/2020/07/22/infografia-migrantes-y-refugiados-venezolanos-en-el-peru-el-impacto-de-la-crisis-de-la-covid-19-coronavirus#:$\sim$:text=En el Perú hay 1,de migrantes y refugiados venezolanos (accessed February 26, 2022).

Barman, A., Das, R., and De, P. K. (2021). Impact of COVID-19 in food supply chain: disruptions and recovery strategy. *Curr. Res. Behav. Sci.* 2, 100017. doi: 10.1016/j.crbeha.2021.100017

Bassett, H. R., Lau, J., Giordano, C., Suri, S. K., Advani, S., and Sharan, S. (2021). Preliminary lessons from COVID-19 disruptions of small-scale fishery supply chains. *World Dev.* 143, 105473. doi: 10.1016/j.worlddev.2021.105473

Bedoya-Perales, N. S., and Dal' Magro, G. P. (2021). Quantification of food losses and waste in peru: a mass flow analysis along the food supply chain. *Sustain.* 13, 2807. doi: 10.3390/su13052807

Benítez, M. A., Velasco, C., Sequeira, A. R., Henríquez, J., Menezes, F. M., and Paolucci, F. (2020). Responses to COVID-19 in five Latin American countries. *Heal. Policy Technol.* 9, 525–559. doi: 10.1016/j.hlpt.2020.08.014

Binder, N. and Vogl, C. R. (2018). Participatory guarantee systems in Peru : two case studies in lima and apur í mac and the role of capacity building in the food chain. *Sustainability* 10, 4644. doi: 10.3390/su10124644

Blazy, J. M., Causeret, F., and Guyader, S. (2021). Immediate impacts of COVID-19 crisis on agricultural and food systems in the Caribbean. *Agric. Syst.* 190, 103106. doi: 10.1016/j.agsy.2021.103106

Briceño-Garmendia, C., Guasch, J. L., Díaz, L., Rozenberg, J., and Bozanigo, L. (2016a). *Análisis Integral de la Logística en el Perú: 5 Cadenas de Exportación. Producto Cacao.* Available online at: https://www.mincetur.gob.pe/wp-content/uploads/documentos/comercio_exterior/facilitacion_comercio_exterior/P_Cacao.pdf (accessed February 26, 2022).

Briceño-Garmendia, C., Guasch, J. L., Díaz, L., Rozenberg, J., and Bozanigo, L. (2016b). *Análisis Integral de la Logística en el Perú: 5 Cadenas de Exportación. Producto Café.* Available online at: https://www.mincetur.gob.pe/wp-content/uploads/documentos/comercio_exterior/facilitacion_comercio_exterior/Anexo2_Producto_Cafe_Final.pdf (accessed February 26, 2022).

Briceño-Garmendia, C., Guasch, J. L., Díaz, L., Rozenberg, J., and Bozanigo, L. (2016c). *Análisis Integral de la Logística en el Perú: 5 Cadenas de Exportación. Producto Quinua.* Available online at: https://cdn.http://www.gob.pe/uploads/document/file/ (accessed February 26, 2022).

Briceño-Garmendia, C., Guasch, J. L., Díaz, L., Rozenberg, J., and Bozanigo, L. (2016d). *Análisis Integral de la Logística en el Perú: 5 Cadenas de Exportación*. Available online at: https://www.mincetur.gob.pe/wp-content/uploads/documentos/comercio_exterior/facilitacion_comercio_exterior/Analisis_Integral_Logistica_Peru.pdf (accessed February 26, 2022).

Bunclark, L. and Barcellos-paula, L. (2021). Sustainability reporting for sustainable supply chain management in. *Sustain. Prod. Consum.* 27, 1458–1472. doi: 10.1016/j.spc.2021.03.013

Burlea-Schiopoiu, A., Ogarca, R. F., Barbu, C. M., Craciun, L., Baloi, I. C., and Mihai, L. S. (2021). The impact of COVID-19 pandemic on food waste behaviour of young people. *J. Clean. Prod.* 294, 126333. doi: 10.1016/j.jclepro.2021.126333

Cable, J., Jaykus, L. A., Hoelzer, K., Newton, J., and Torero, M. (2021). The impact of COVID-19 on food systems, safety, and security—a symposium report. *Ann. N. Y. Acad. Sci.* 1484, 3–8. doi: 10.1111/nyas.14482

Cañari-Casaño, J. L., Elorreaga, E. A., Cochachin-Henostroza, O., Huaman-Gil, S., Dolores-Maldonado, G., Aquino-Ramírez, A., et al. (2021). Social predictors of food insecurity during the stay-at-home order due to the COVID-19 pandemic in Peru. *medRxiv [Preprint]*. doi: 10.1101/2021.02.06.21251221

Castro, J. and Chirinos, D. (2015). Impact of a comprehensive intervention on food security in poor families of central highlands of Peru. *Food Public Heal.* 5, 213–219. doi: 10.5923/j.fph.20150506.02

Castro-Bedriñana, J., Chirinos-Peinado, D., and De La Cruz-Calderón, G. (2021). Predictive model of stunting in the Central Andean region of Peru based on socioeconomic and agri-food determinants. *Public Heal. Pract.* 2, 100112. doi: 10.1016/j.puhip.2021.100112

Cequea, M. M., Neyra, J. M. V., Schmitt, V. G. H., and Ferasso, M. (2021). Household food consumption and wastage during the covid-19 pandemic outbreak: a comparison between peru and brazil. *Sustainability* 13, 7583. doi: 10.3390/su13147583

Chenarides, L., Manfredo, M., and Richards, T. J. (2021). COVID-19 and food supply chains. *Appl. Econ. Perspect. Policy* 43, 270–279. doi: 10.1002/aepp.13085

Chitrakar, B., Zhang, M., and Bhandari, B. (2021). Improvement strategies of food supply chain through novel food processing technologies during COVID-19 pandemic. *Food Control* 125, 108010. doi: 10.1016/j.foodcont.2021.108010

Coletto, D., Jaber, L., and Vanhellemont, L. (2021). Street vendors in Lima in the time of COVID-19: guilty or oppressed? *Can. Geogr.* 65, 435–447. doi: 10.1111/cag.12712

Contreras, B. E. M. (2018). *Análisis y propuesta de mejora de la cadena de distribución de alimentos no perecederos entre las empresas de industrias alimentarias y los supermercados en el Perú (master's thesis)*. Universidad Politécnica de Cataluña, Barcelona, Spain. Available online at: https://upcommons.upc.edu/handle/2117/117480?show=full

Cordova-Buiza, F., Paucar-Caceres, A., Quispe-Prieto, S. C., Rivera-Garr,é, A. P., Huerta-Tantalean, L. N., Valle-Paucar, J. E., et al. (2022). Strengthening collaborative food waste prevention in Peru: towards responsible consumption and production. *Sustainability* 14, 1050. doi: 10.3390/su14031050

Cuenca Jaque, C. R., Osorio Tarrillo, M. L., Pastor Ramos, J. L., Peña Pasapera, G. del P., and Torres Vásquez, L. E. (2020). Economic and health aspects in times of quarantine for COVID 19 in the Peruvian population, year 2020. *Rev. la Fac. Med. Humana* 20, 630–639. doi: 10.25176/RFMH.v20i4.3067

Cullen, M. T. (2020). *COVID-19 and the Risk to Food Supply Chains: How to Respond*. Rome: Publication of the FAO. Available online at: https://www.fao.org/documents/card/es/c/ca8388en/

Curi-Quinto, K., Sánchez, A., Lago-Berrocal, N., Penny, M. E., Murray, C., Nunes, R., et al. (2021). Role of government financial support and vulnerability characteristics associated with food insecurity during the covid-19 pandemic among young peruvians. *Nutrients* 13, 3546. doi: 10.3390/nu13103546

Delgado, L., Schuster, M., and Torero, M. (2021). Quantity and quality food losses across the value chain: a comparative analysis. *Food Policy* 98, 101958. doi: 10.1016/j.foodpol.2020.101958

Enfoque Derecho (2020). *Los precios y el coronavirus:? Intervención o empatía?* Available online at: https://www.enfoquederecho.com/2020/04/10/los-precios-y-el-coronavirus-intervencion-o-empatia/ (accessed February 26, 2022).

Erokhin, V. and Gao, T. (2020). Impacts of COVID-19 on trade and economic aspects of food security: evidence from 45 developing countries. *Int. J. Environ. Res. Public Health* 17, 1–28. doi: 10.3390/ijerph17165775

FAO (2020a). *Adjusting Business Models to Sustain Agri-food Enterprises during COVID-19*. Available at: http://www.fao.org/3/ca8996en/CA8996EN.pdf (accessed February 26, 2022).

FAO (2020b). *Urban Food Systems and COVID-19: The Role of Cities and Local Governments in Responding to the Emergency*. Available online at: http://www.fao.org/3/ca8600en/CA8600EN.pdf (accessed February 26, 2022).

FAOSTAT (2021). *Suite of Food Security Indicators*. Available online at: https://www.fao.org/faostat/en/#data/FS (accessed November 25, 2021).

Galanakis, C. M. (2020). The food systems in the era of the coronavirus (COVID-19) pandemic crisis. *Foods* 9, 523. doi: 10.3390/foods9040523

García, L., Veneros, J., and Tineo, D. (2020). Severe acute respiratory syndrome (SARS-CoV-2): a national public health emergency and its impact on food security in Peru. *Sci. Agropecu.* 11, 241–245. doi: 10.17268/sci.agropecu.2020.02.12

Gemmill-Herren, B. (2020). Closing the circle: an agroecological response to covid-19. *Agric. Human Values* 37, 613–614. doi: 10.1007/s10460-020-10097-7

Godoy, D., Gonzales, J., Roque, R., Fernández, M., Gamarra, S., Hidalgo, V., et al. (2021). Use of unconventional agro-industrial by-products for supplementation of grazing dairy cattle in the Peruvian Amazon region. *Trop. Anim. Health Prod.* 53, 294. doi: 10.1007/s11250-021-02718-y

Grillo-Núñez, J., Mendo, T., Gozzer-Wuest, R., and Mendo, J. (2021). Impacts of COVID-19 on the value chain of the hake small scale fishery in northern Peru. *Mar. Policy* 134, 104808. doi: 10.1016/j.marpol.2021.104808

Han, S., Roy, P. K., Hossain, M. I., Byun, K. H., Choi, C., and Ha, S. (2021). COVID-19 pandemic crisis and food safety: implications and inactivation strategies. *Trends Food Sci. Technol.* 109, 25–36. doi: 10.1016/j.tifs.2021.01.004

Hashem, N. M., González-Bulnes, A., and Rodriguez-Morales, A. J. (2020). Animal welfare and livestock supply chain sustainability under the COVID-19 outbreak: an overview. *Front. Vet. Sci.* 7, 582528. doi: 10.3389/fvets.2020.582528

Hecht, A. A., Biehl, E., Barnett, D. J., and Neff, R. A. (2019). Urban food supply chain resilience for crises threatening food security: a qualitative study. *J. Acad. Nutr. Diet.* 119, 211–224. doi: 10.1016/j.jand.2018.09.001

Hobbs, J. E. (2020). Food supply chains during the COVID-19 pandemic. *Can. J. Agric. Econ.* 68, 171–176. doi: 10.1111/cjag.12237

INEI (2021). *Avance Coyuntural de la Actividad Económica N° 02 - Febrero 2022*. Available online at: https://m.inei.gob.pe/media/MenuRecursivo/boletines/02-informe-tecnico-avance-coyuntural-dic-2021.pdf (accessed February 26, 2021).

IoT.nxt (2020). *IoT.nxt Develops Solution to Manage Social Distancing for Retailers, Offices*. Available online at: https://www.itweb.co.za/content/xA9POvNZy6Vvo4J8 (accessed July 31, 2022).

Kerr, W. A. (2020). The COVID-19 pandemic and agriculture: short- and long-run implications for international trade relations. *Can. J. Agric. Econ.* 68, 225–229. doi: 10.1111/cjag.12230

Kumar, A., Mangla, S. K., Kumar, P., and Song, M. (2021). Mitigate risks in perishable food supply chains: learning from COVID-19. *Technol. Forecast. Soc. Change* 166, 120643. doi: 10.1016/j.techfore.2021.120643

Lal, R. (2020). Home gardening and urban agriculture for advancing food and nutritional security in response to the COVID-19 pandemic. *Food Secur.* 12, 871–876. doi: 10.1007/s12571-020-01058-3

Lanza, L. A. R., and Narváez, C. A. S. (2020). Emergencia, gestión, vulnerabilidad y respuestas frente al impacto de la pandemia COVID-19 en el Perú. *ScIELOPreprints* 1, 1–16. Available online at: https://preprints.scielo.org/index.php/scielo/preprint/view/94/version/99

Lazo, M. L. (1984). Food supply in Peru monopolies. *Food Policy* 9, 68–82. doi: 10.1016/0306-9192(84)90034-4

Luckstead, J., Nayga Jr, R. M., and Snell, H. A. (2020). Labor Issues in the Food Supply Chain Amid the COVID-19 Pandemic. *Appl. Econ. Perspect. Policy* 43, 382–400. doi: 10.1002/aepp.13090

Mahajan, K. and Tomar, S. (2021). COVID-19 and supply chain disruption: evidence from food markets in India†. *Am. J. Agric. Econ.* 103, 35–52. doi: 10.1111/ajae.12158

Malone, A., Cabana, Y. D. C., and Zegarra, A. T. (2021). Informal food systems and differential mobility during the COVID-19 pandemic in Arequipa, Peru. *Town Plan. Rev.* 92, 187–193. doi: 10.3828/tpr.2020.61

Marco, D. G. (2020). *Coronavirus: qué dice sobre la economía (y el gobierno) de Perú que el país prepare el mayor plan de estímulo de América Latina contra el covid-19 - BBC News Mundo*. Available online at: https://www.bbc.com/mundo/noticias-america-latina-52104166 (accessed February 13, 2022).

Mariutti, L. R. B., Rebelo, K. S., Bisconsin-Junior, A., de Morais, J. S., Magnani, M., Maldonade, I. R., et al. (2021). The use of alternative food sources to improve health and guarantee access and food intake. *Food Res. Int.* 149, 110709. doi: 10.1016/j.foodres.2021.110709

Marusak, A., Sadeghiamirshahidi, N., Krejci, C. C., Mittal, A., Beckwith, S., Cantu, J., et al. (2021). Resilient regional food supply chains and rethinking the way forward: key takeaways from the COVID-19 pandemic. *Agric. Syst.* 190, 103101. doi: 10.1016/j.agsy.2021.103101

Memon, S. U. R., Pawase, V. R., Soomro, M. A., and Pavase, T. R. (2021). Investigation of covid-19 impact on the food and beverages industry: China and India perspective. *Foods* 10, 1069. doi: 10.3390/foods10051069

Mercado, W. and Ubillus, K. (2017). Characterization of producers and quinoa supply chains in the Peruvian regions of Puno and Junin. *Sci. Agropecu.* 8, 251–265. doi: 10.17268/sci.agropecu.2017.03.08

MINAGRI (2020). *Perspectivas del Comercio Exterior Agrario en el Marco de la Declaración de Emergencia Nacional COVID-19*. Available online at: https://repositorio.midagri.gob.pe/handle/MIDAGRI/784 (accessed February 26, 2022).

Mukhamedjanova, K. (2020). The impact of the Covid-19 pandemic on the supply chain of agricultural products. *Asian J. Technol. Manag. Res.* 10, 49–52. Available online at: http://www.ajtmr.com/papers/Vol10Issue1/Vol10Iss1_P7.pdf

O'Hara, S. and Toussaint, E. C. (2021). Food access in crisis: food security and COVID-19. *Ecol. Econ.* 180, 106859. doi: 10.1016/j.ecolecon.2020.106859

Padulosi, S., Amaya, K., Jäger, M., Gotor, E., Rojas, W., and Valdivia, R. (2014). A holistic approach to enhance the use of neglected and underutilized species: the case of andean grains in Bolivia and Peru. *Sustain.* 6, 1283–1312. doi: 10.3390/su6031283

Parkhill, M. (2022). *Amid strict lockdown, Shanghai firefighters deliver necessities via drone*. Available online at: https://www.ctvnews.ca/health/coronavirus/amid-strict-lockdown-shanghai-firefighters-deliver-necessities-via-drone-1.5859753 (accessed July 31, 2022).

Parlamento Andino (2022). *Alternative Venting in Steam Retorts-An Approach to Energy Savings in Thermal Processing*. Available online at: https://www.parlamentoandino.org/images/actualidad/informes-covid/Peru/Principales-medidas-adoptadas-por-el-gobierno-peruano.pdf (accessed July 31, 2022).

Rahimi, P., Islam, M. S., Duarte, P. M., Tazerji, S. S., Sobur, M. A., El Zowalaty, M. E., et al. (2021). Impact of the COVID-19 pandemic on food production and animal health. *Trends Food Sci. Technol.* 121, 105–113. doi: 10.1016/j.tifs.2021.12.003

Ramirez-Hernandez, A., Galagarza, O. A., Álvarez Rodriguez, M. V., Pachari Vera, E., Valdez Ortiz, M. del C., Deering, A. J., et al. (2020). Food safety in Peru: a review of fresh produce production and challenges in the public health system. *Compr. Rev. Food Sci. Food Saf.* 19, 3323–3342. doi: 10.1111/1541-4337.12647

Ramos, E., Coles, P. S., Chavez, M., and Hazen, B. (2021). Measuring agri-food supply chain performance: insights from the Peruvian kiwicha industry. *Benchmarking An Int. J.* 29, 1484—1512. doi: 10.1108/BIJ-10-2020-0544

Ramos, E., Espichan, K., Rodriguez, K., Lo, W. S., and Wu, Z. (2018). Blueberry supply chain in Peru: planning, integration and execution. *Int. J. Supply Chain Manag.* 7, 1–12. Available online at: https://core.ac.uk/download/pdf/230751452.pdf

Requena-Sanchez, N., Carbonel-Ramos, D., Moonsammy, S., Klaus, R., Punil, L. S., and Ng, K. T. W. (2022). Virtual methodology for household waste characterization during the pandemic in an urban district of Peru: citizen science for waste management. *Environ. Manage.* 69, 1078–1090. doi: 10.1007/s00267-022-01610-1

Rizou, M., Galanakis, I. M., Aldawoud, T. M. S., and Galanakis, C. M. (2020). Safety of foods, food supply chain and environment within the COVID-19 pandemic. *Trends Food Sci. Technol.* 102, 293–299. doi: 10.1016/j.tifs.2020.06.008

Romero, T. H. and Reys, A. (2020). Empobrecimiento de los Hogares y Cambios en el Abastecimiento de Alimentos por la COVID-19 en Lima, Perú. *Ar@cne* 24, 243. doi: 10.1344/ara2020.243.31627

Sanchez, A., Cueto, S., and Penny, M. (2020). *Listening to young lives at work in Peru: first call.* Available online at: https://www.younglives.org.uk/sites/default/files/migrated/YOL-Peru-Headlines-FirstPhoneSurvey-Aug20_0.pdf (accessed February 26, 2022).

Sharma, M. (2020). Conceptualizing the nexus of migration and food security during COVID-19. *J. Agric. Food Syst. Community Dev.* 9, 1–5. doi: 10.5304/jafscd.2020.094.036

Shen, Z. M. and Sun, Y. (2021). Strengthening supply chain resilience during COVID-19: a case study of JD.com. *J. Oper. Manag.* doi: 10.1002/joom.1161

Shrestha, N., Shad, M. Y., Ulvi, O., Khan, M. H., Karamehic-Muratovic, A., Nguyen, U. S. D. T., et al. (2020). The impact of COVID-19 on globalization. One Heal. 11, 100180. doi: 10.1016/j.onehlt.2020.100180

Siche, R. (2020). What is the impact of COVID-19 disease on agriculture? *Sci. Agropecu.* 11, 3–9. doi: 10.17268/sci.agropecu.2020.01.00

Singh, M., Sadat, A., Abdi, R., Colaruotolo, L. A., Francavilla, A., Petker, K., et al. (2021). Detection of SARS-CoV-2 on surfaces in food retailers in Ontario. *Curr. Res. Food Sci.* 4, 598–602. doi: 10.1016/j.crfs.2021.08.009

Singh, S., Kumar, R., Panchal, R., and Tiwari, M. K. (2021). Impact of COVID-19 on logistics systems and disruptions in food supply chain. *Int. J. Prod. Res.* 59, 1993–2008. doi: 10.1080/00207543.2020.1792000

STATISTA (2021). *Revenue of the Food Market Worldwide Between 2012 to 2025(in Billion U.S. Dollars)*. Available online at: 15daafde01110eb1faa7d35784d76 (accessed February 26, 2022).

Súmar, H. E. D. (2004). *Plantas Alimenticias del Perú*. Available online at: file:///C:/Users/user/Documents/2017/Referencias de TESIS ETNOBOTANICA/UNALM-Etnobotánica-Chota.pdf (accessed February 26, 2022).

Thilmany, D., Canales, E., Low, S. A., and Boys, K. (2021). Local food supply chain dynamics and resilience during COVID-19. *Appl. Econ. Perspect. Policy* 43, 86–104. doi: 10.1002/aepp.13121

Tittonell, P., Fernandez, M., El Mujtar, V. E., Preiss, P. V., Sarapura, S., Laborda, L., et al. (2021). Emerging responses to the COVID-19 crisis from family farming and the agroecology movement in Latin America – a rediscovery of food, farmers and collective action. *Agric. Syst.* 190, 103098. doi: 10.1016/j.agsy.2021.103098

UNICEF (2019). *Estado Mundial de la Infancia 2019 incluye a Perú entre las experiencias exitosas de lucha contra la desnutrición crónica infantil*. Available online at: https://www.unicef.org/peru/nota-de-prensa/estado-mundial-infancia-nutricion-alimentos-derechos-peru-experiencias-exitosas-desnutricion-cronica-infantil-reporte (accessed February 26, 2022).

Useche, P. and Twyman, J. (2016). Sugar, fat, or protein: are all food insecure households eating the same? The case of small rice producers in Peru. *Front. Econ. Glob.* 16, 115–132. doi: 10.1108/S1574-871520150000016005

Vaio, A. D., Boccia, F., Landriani, L., and Palladino, R. (2020). Artificial intelligence in the agri-food system: rethinking sustainable business models in the COVID-19 scenario. *Sustainability* 12, 4851. doi: 10.3390/su12124851

van der Ploeg, J. D. (2020). From biomedical to politico-economic crisis: the food system in times of Covid-19. *J. Peasant Stud.* 47, 944–972. doi: 10.1080/03066150.2020.1794843

Vargas, R., Fonseca, C., Hareau, G., Ordinola, M., Pradel, W., Robiglio, V., et al. (2021). Health crisis and quarantine measures in Peru: Effects on livelihoods of coffee and potato farmers. *Agric. Syst.* 187, 103033. doi: 10.1016/j.agsy.2020.103033

Varona, L. and Gonzales, J. R. (2021). Dynamics of the impact of COVID-19 on the economic activity of Peru. *PLoS ONE* 16, e0244920. doi: 10.1371/journal.pone.0244920

Vázquez-Rowe, I., and Gandolfi, A. (2020). Peruvian efforts to contain COVID-19 fail to protect vulnerable population groups. *Public Heal. Pract.* 1, 13–15. doi: 10.1016/j.puhip.2020.100020

Velásquez-Quispe, L. S., Ortiz-Meza, C. A., Calizaya-Mamani, U. G., Zapana-Calderón, A. A., and Chire-Fajardo, G. C. (2021). Energética nutricional en tiempos de pos COVID-19 en el Perú. *Enfoque UTE* 12, 1–28. doi: 10.29019/enfoqueute.761

Villena-Tejada, M., Vera-Ferchau, I., Cardona-Rivero, A., Zamalloa-Cornejo, R., Quispe-Flórez, M. M., Frisancho-Triveño, Z., et al. (2021). Plantas medicinales y alimentos funcionales usados como recursos contra Covid-19 en una población andina del Perú. *Ambient. Comport. y Soc.* 4, 62–81. doi: 10.51343/racs.v4i1.819

WHO (2022). *WHO Coronavirus (COVID-19) Dashboard*. Available online at: https://covid19.who.int/ (accessed July 31, 2022).

Worldometer (2022). *COVID-19 Coronavirus Pandemic*. Available online at: https://www.worldometers.info/coronavirus/?utm_campaign=homeAdvegas1#countries (accessed July 31, 2022).

Zimmerer, K. S. and de Haan, S. (2020). Informal food chains and agrobiodiversity need strengthening—not weakening—to address food security amidst the COVID-19 crisis in South America. *Food Secur.* 12, 891–894. doi: 10.1007/s12571-020-01088-x

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EDITED BY
Paraskevi Detopoulou,
General Hospital Korgialenio Benakio, Greece

REVIEWED BY
Shalander Kumar,
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India
Olufunke A. Alaba,
University of Cape Town, South Africa

*CORRESPONDENCE
Richard Sidebottom
ris25@cam.ac.uk;
sidebottom@hotmail.com

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A longitudinal investigation of dietary diversity during the COVID-19 pandemic in Mandinka households in Kanifing, Brikama, and the West Kiang region in The Gambia

Richard Sidebottom[1]*, Solomon Bizuayehu Wassie[2], Carla Cerami[3], Momodou W. Jallow[3], Shailaja Fennell[1] and Sarah Dalzell[4]

[1]Department of Land Economy, University of Cambridge, Cambridge, United Kingdom, [2]Department of Agricultural Economics, Bahir Dar University, Bahir Dar, Ethiopia, [3]Nutrition Unit, MRC Gambia at London School of Hygiene and Tropical Medicine, Banjul, Gambia, [4]MRC Nutrition and Bone Health Research Group, University of Cambridge, Cambridge, United Kingdom

The Covid pandemic has exposed fissures of inequality through heightened food insecurity and nutritional deficiency for vulnerable social cohorts with limited coping mechanisms. Given the multi-dimensional pathways through which its effects have been felt, several researchers have highlighted the need to analyse the pandemic in specific contexts. Using random and fixed effect regression models, this study analyzed longitudinal survey data collected from 103 Mandinka households in rural and urban Gambia. The study employed convenience and snowball sampling and involved the monthly collection of detailed income, food consumption, expenditure, sourcing, migration, health, and coping mechanism data through mobile phone interviews which yielded 676 observations. Food insecurity was manifest in terms of quality, not quantity, and spread unevenly across food types and households. Dietary outcomes and sourcing strategies were associated with location, improved sanitation, household size, changes in monthly income, Covid policy stringency, and Covid cases but these associations varied by food group. Staples were the most frequently consumed food group, and dark green vegetables were the least. Rural communities were more likely to eat more healthy millets but much less likely to consume dairy products or roots and tubers. Access to own production was also important for Vitamin A-rich foods but higher incomes and markets were key for protein and heme-iron-rich foods. Tighter Covid policy stringency was negatively associated with dietary diversity and, along with fear of market hoarding, was positively associated with reliance on a range of consumption and production coping mechanisms. Resilience was higher in larger households and those with improved water and sanitation. The number of Covid cases was associated with higher consumption of protein-rich foods and greater reliance on own produced iron-rich foods. Very few households received Government aid and those that did already had access to other income sources. Our findings suggest that the nature of food insecurity may have evolved over time during the pandemic. They also reiterate not only the importance of access to markets and employment but also that the capacity to absorb affordability shocks and maintain food choices through switching between sources for specific nutritious food groups varied by household and location.

KEYWORDS

nutrition, COVID-19, dietary diversity, food security, coping mechanisms

Introduction

The impacts of the COVID-19 pandemic have been routed via *direct* pathways to physical and mental well-being and *indirect* ones through reduced employment, income, and consumption (1–4). Their magnitude, nature, and duration have exposed pre-existing fissures of inter and intra-country economic and health inequality most vividly manifest in heightened food insecurity (5–9). The pandemic has highlighted the need for policy makers to focus on the links between nutritional diversity and health (10, 11) and livelihood resilience during external shocks (12).

From the outset of the pandemic, many countries witnessed changes in food supply and demand. Early impacts were often contingent upon state support, food markets, social networks, and nutritional knowledge (9). Thereafter, food insecurity evolved along with country-specific pathways (13). Several studies have highlighted a preference for online food sourcing and home cooking in developed countries (14). The pandemic has also been associated with healthier diets in Mexico (15) but not in Italy (16) or the United Kingdom (5, 17) in Ethiopia, the immediate effects of policy restrictions appear to have been short-lived (18), but elsewhere in Sub-Saharan Africa (SSA) lockdown restrictions may have exacerbated food insecurity through income shocks, poor targeting of social welfare, and the undermining of long-term resilience (19).

In many countries, income and food effects persisted long after policy easing (20). Subsequent pandemic phases saw a shift to less expensive foods with shorter supply chains (13) as many countries reported restrictions on specific food choices but not overall availability (14). Irrespective of policy regime or food system disruption, the impacts of the pandemic have been unevenly distributed across numerous divides. Dou et al. (14) have highlighted varying resilience capacity *within* social and income cohorts, not simply across them. In Bangladesh, income and diet deterioration were most evident amongst rural residents, informal workers, and the less well-educated (21). Further research highlighted the importance of age, occupation, and gender, rather than location, as these are associated with pre-existing food insecurity (22).

One driver of such resilience is access to alternative food sources. There is voluminous literature on the relative attributes of production, income, or market pathways to dietary diversity under normal circumstances (23). However, spatial and temporal fluidity suggest that people switch between complementary sources depending on food type, season, and the nature of the external shocks (24). In India and SSA, pandemic coping mechanisms included the use of agriculture as an income and food source substitute (25, 26). In Burkina Faso, Nigeria, and Ethiopia, Madzorera et al. (27) found that crop production was associated with stable dietary diversity in the pandemic, whilst non-producers' diets were more vulnerable to affordability shocks.

The incomplete separation between urban and rural spaces and livelihoods ties in with the idea "migration-food security nexus" (28, np), which allows for fluidity of people, occupations, money, and food as part of food security coping strategies. The potency of the pandemic's multi-dimensional employment, income, and expenditure impact pathways (14) is therefore likely to be linked with household-specific livelihood and sourcing strategies, not just food environments or lockdown regimes. To appreciate the dynamic and intricate nature of these interactions requires an understanding of specific contexts (20).

Method

Study background

The Migration, Nutrition and COVID-19 (MNC19) study sought to contribute to this understanding through a longitudinal investigation of the indirect impacts of the pandemic in The Gambia from November 2020 to September 2021. Impacts were assessed in terms of perceived threat, coping strategies, and nutritional outcomes. The study was an interdisciplinary collaboration as part of the Research on Millets and Nutritional Enhancement Traits for Iron bioavailability project (MillNET_i)[1]. Design, training, and coordination were

1 MillNET_i was funded by the Biotechnology and Biological Sciences Research Council (BBSRC)-Global Challenges Research (GCRF) from

led by researchers from the Department of Land Economy at the University of Cambridge and the MRC Nutrition and Bone Health Research Group in the United Kingdom, and the survey was conducted by members of the Nutrition Theme in the MRC Gambia at London School of Hygiene and Tropical Medicine, The Gambia. Data analysis was completed through co-operation between the Universities of Cambridge and Bahir Dar, Ethiopia.

The Gambia's socio-economic geography makes it an informative case study. Ranked 174th in terms of the Human Development Index (HDI), The Gambia is a relatively urbanized service-driven economy reliant upon tourism and remittances (29). The country's predominantly Muslim population of 2.3 million is made up of several large ethnic groups – Mandinka, Fula, Wolof, and Jola (30). With significant levels of domestic and international mobility, there is a high dependence upon remittances of food and money but foreign cashflows were expected to fall by 20% during the pandemic (31, 32). This was expected to exacerbate a pre-existing triple burden of malnutrition that was manifest in the form of dietary insufficiency, excess, and low quality. This has contributed to a high incidence of diabetes, hypertension, and iron deficiency (33, 34). With a semi-arid climate and low agricultural capacity, the Gambia imports 40% of its cereals, especially rice (34). In terms of health, reliance on transport, employment, incomes, and diets, the country was therefore vulnerable to an external shock (32, 35–38).

The Gambia saw a spike in reported COVID-19 cases from July to September 2020, a smaller rise from January to April 2021 and another spike after June 2021 (39). During the period of the MNC19 study, there was 260% increase in cumulative cases. By 30 September 2021, there had been 9,935 cases and 338 fatalities (40). However, according to the Oxford COVID-19 Government Response Stringency Index[2], Gambian restrictions were never as severe as those in India or parts of Europe and were relaxed after September 2020, despite a rising number of Covid cases (41) (Figure 1).

In early 2020, the national incidence of food insecurity rose from 5% in 2016 (33, 34) to 25% (6). By July 2020, this fell to 20% (42), in part due to the provision of government food aid. The easing of policy restrictions allowed children to return to school but subsequent phases of the pandemic have seen the continued erosion of incomes through job losses, enforced job switching, or lower remittances. Seasonal factors temporarily eased employment concerns but the rural poor remained three times more likely to be food insecure due to low affordability (43).

Study design

Our research objective was to unpack the drivers of these pockets of food insecurity as the pandemic unfolded in terms of perceived threats, coping strategies, and nutritional outcomes. To realize our objective, monthly household food consumption, income, expenditure, and migration data were collected from November 2020 to September 2021. Data collection began *after* initial Gambian lockdown restrictions began to ease but *before* case numbers started to accelerate. With a high dependence upon remittances, imported food, and foreign tourism, we hypothesized that the effects of the pandemic were as likely to come via indirect pathways (both perceived and actual) and direct ones. Given the initial spread of the pandemic was concentrated outside The Gambia, indirect effects were likely to *precede* direct ones.

Sampling, data collection, and ethics

Our unit of analysis was the household which we defined as those who regularly shared cooking facilities in accordance with Gambian government surveys (44, 45)[3]. Our design sought to reflect the "multi-nodal" nature of these households, which requires researchers to rethink the notion of location and context (28). We, therefore, surveyed both urban and rural households and those that we had reason to believe contained members who were geographically mobile. We recruited Mandinka households through randomized selection from an urban convenience sample previously used by one of the authors[4] in Brikama and Kanifing. This was supplemented by adopting a snowballing technique from urban contacts to identify rural respondents in the West Kiang District of Central River Region. Snowballing within one ethnic group enabled us to identify intra-group interlinkages and control for inter-group dietary variations. As the survey was conducted remotely, we were restricted to those who had mobile phone access and whose numbers were still in use.

April, 2019 to October, 2021 (Grant Reference BB/S013954/1). Additional funding was received October, 2021 – March, 2022 from the Transforming India's Green Revolution by Research and Empowerment for Sustainable food Supplies research project (TIGR2ESS) also funded by the Global Challenges Research Fund (Grant reference BB/P027970/1).

2 Measured from 0 to 100, this scale of pandemic measures includes school and work closures, public event and travel bans, information, testing and vaccination campaigns (41).

3 We are aware that, as a consequence, we do not address intra-household inequities.

4 Kiang West Women's Migration Study (WMS) ((SCC1389v2) and a Feasibility study (SCC1222v2 L2013.56)) conducted by Dr Sarah Dalzell at the MRC Gambia unit.

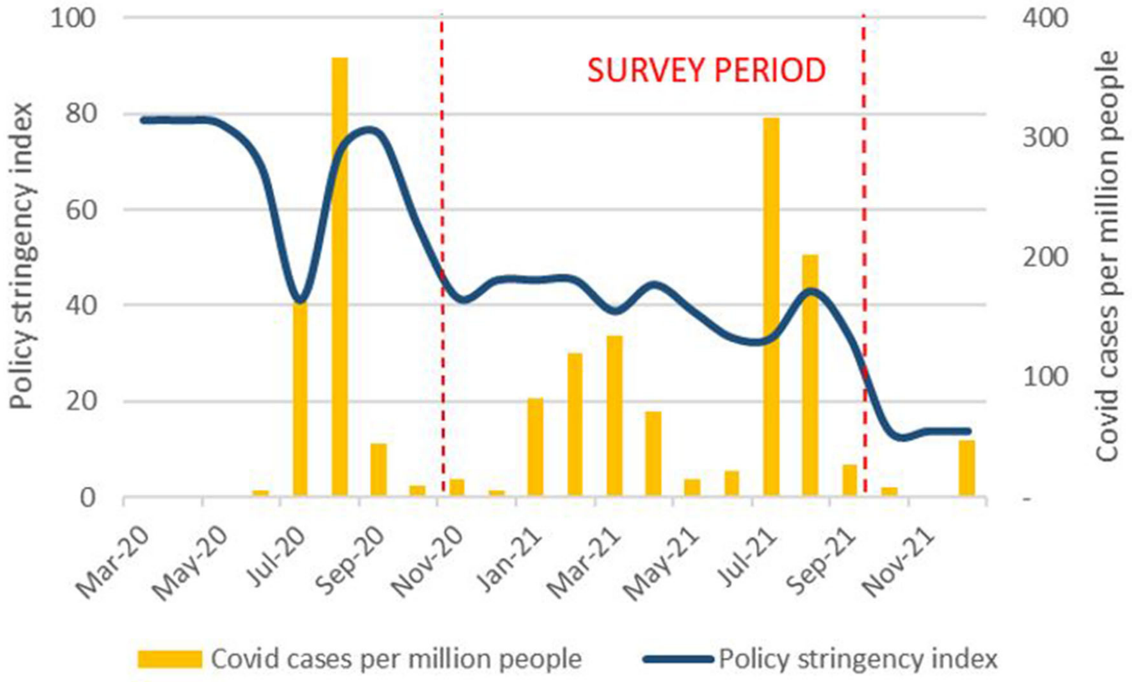

FIGURE 1
Policy stringency and Covid cases [Own graph, data sources (40, 41)].

Prior to data collection, households were informed they would be called approximately once a month for up to 12 months. They were advised that there was no reward for participation or penalty for non-participation or non-completion. Respondents were given 24 h to consider their participation before the survey commenced. If they agreed[5], audio-recorded informed consent was obtained from both the household head and any other nominated adult respondent who would complete all or part of the survey. A total of 106 households were recruited but three dropped out (due to sickness or migration) after the initial call, leaving 60 urban households and 43 rural. We collected data[6] on household composition, income, migration and expenditure, coping strategies and consumption, and the sourcing of 35 food items chosen and categorized in accordance with FAO guidelines (46) (Table 1). Recruitment and questionnaires were completed remotely by mobile phone throughout the entire study. Data were collected on tablets using Redcap survey software (47). Enumerator training was conducted remotely by lead researchers and in person by local supervisors under appropriate social distancing protocols. Training involved seminars, discussions, and pilot interviews which provided feedback on the list of foods and question content and ordering. All procedures were approved by the Scientific and Ethical committees of MRC Gambia/London School of Hygiene and Tropical Medicine, the Gambia Government/MRC Joint Ethics Committee, and by the Department of Land Economy at the University of Cambridge.

5 There were no refusals.

6 Household composition data was collected on the first call and updated for any changes in health or employment status and household entrants or exits on each subsequent visit. In accordance with WFP guidelines (48), consumption data was collected on the basis of the previous 7 days and all other data was based on the previous month.

Data analysis

Data cleaning

Due to a range of pandemic-related problems and the nature of the snowballing process, recruitment lasted from mid-November, 2020 until the start of March 2021. We started recording income and consumption data immediately and not all households could be reached at every round or each call made in a particular calendar month. To address these unbalanced panel data, we applied two sets of filters. As there were only 26 recruits prior to 31 December 2020, we excluded income and consumption data before then but included household background information. For all others, we excluded calls less than 20 days apart. Of 779 surveys completed, this left us with

TABLE 1 Food list for consumption questions.

	Food group		Food item
1	*Staples*	1	Rice (Mano): mono, nyakatango, fajiringo, benechin, other rice
		2	Millets (Sanyo/Suno)
		3	Fonio (Findo)
		4	Maize (tubanyo): cob, roasted, futo, nyelengo
		5	Sorghum (kinto): nyelengo, futo
		6	Bread
		7	Pasta
2	*Roots & Tubers*	8	White roots and tubers
3	*Nuts, Pulses, legumes*	9	Groundnuts
		10	Pulses
		11	Nuts and seeds
4	*Dairy*	12	Milk and other dairy products
5	*Eggs*	13	Eggs: from Chicken, duck, guinea fowl or other
6	*Fish*	14	White fish
		15	Bony fish
		16	Canned fish
		17	Shellfish: Oyster (Nganya), mussels, sea snail, crabs, shrimps, lobster
7	*Meat*	18	Flesh meat
		19	Canned meat
		20	Organ meat: liver, kidney, heart and/or other organ meats
8	*Vegetables*	21	Orange Veg and Tubers rich in Vitamin A: Carrot, Red pepper, Pumpkin, Orange Sweet potatoes, orange vegetables
		22	Dark green leafy vegetables: Baobab leaf (naa/lalo), sorrel (kucha/domoda), amaranth (morongo), spinach, water leaf, cassava leaf, okra (kanjo), Moringa (nebedayo) and/or other dark green leaves
		23	Other vegetables
9	*Fruit*	24	Orange fruits rich in Vitamin A
		25	Other Fruits
10	*Sweets*	26	Tea/coffee with sugar
		27	Sugary drinks
		28	Cakes, biscuits/cookies, pastries
		29	Other sweets
11	*Oils & Fats*	30	Groundnut oil
		31	Palm oil
		32	Palm kernel oil
		33	Vegetable oil
		34	Margarine/butter
12	*Condiments/ Spices*	35	Condiments/Spices

676 observations across 103 households. We had at least five observations for 97 households but with some time gaps. Of the six with only three or four valid observations, four were uncontactable after May and the other two were infrequently available (Table 2).

Variable specification

Dependent variables

We used a range of nutritional proxies to test the robustness of our findings (Table 3). The *Household Food Insecurity Access Scale (HFIAS)* assesses a household's psychological experience of food access over the previous 4 weeks (48). Although open to response bias (49), questions on *perceived* food insecurity form a useful complement to other indices measuring *actual* consumption behavior within a given socio-cultural context. Respondents were asked how frequently they worried about food availability; a number of questions about dietary diversity (including whether they had not been able to eat preferred foods, forced to eat non-preferred foods, or eat a more limited variety); and questions regarding the impact of having insufficient food (50). In terms of actual consumption over the previous 7 days, we calculated *Food Consumption (FCS)*[7] and *Food Consumption Nutrition* scores *(FCS-N)*. FCS categorizes food item frequencies into eight groups weighted in accordance with their calorific and nutritional content (50). FCS-N provides a more direct indication of Vitamin A, protein, and heme-iron (He) intake (51). We also used our food sourcing data to calculate FCS and FCS-N scores by market and own production.

Independent variables

We defined an income trend variable which had a value of 1 if income had risen compared to the previous month, or 0 otherwise. Each of employment, business, and remittance income was assigned a value of 1 if it was cited as a top 3 source in the previous month, or 0 otherwise[8]. For expenditure, we adopted the Gambian concept of "fish money" that was a commonly used indicator of a household's monthly disposable cash for spending on food. This was normalized by dividing by the number of household members in each round. We used the absolute sum of in- and out-migration to gauge population fluidity and changes in household dependency ratios. Perceived and actual external risks were measured using the number of times food hoarding was cited as perceived impact[9], the Oxford COVID-19 Government Response Stringency Index

7 These were preferred to the Household Dietary Diversity (HDDS) score as gauge of nutrition (50).

8 We had insufficient observations to use government aid.

9 Other responses had insufficient variability (e.g., prices) or overlapped other variables (e.g., jobs).

TABLE 2 Phone call schedule.

Data collection period	Households (HH) recruited					Total calls	Households called
	Start	New	Drop outs with data	Drop-outs no data	Net		
Nov–Dec 2020	0	26		1	25	0	0
Jan-21	25	17		2	40	43	38
Feb-21	40	47			87	85	73
Mar-21	87	16	1		102	110	93
Apr-21	102		2		100	90	90
May-21	100		1		99	97	91
Jun-21	99		10		89	89	84
Jul-21	89		12		77	52	52
Aug-21	77		16		61	45	42
Sep-21	61		0		61	65	61
		106		3	103	676	103

Phone call frequency distribution

Number of calls per household		Percentage of sample	Cumulative
3 or 4	6	5.8%	6%
5	13	12.6%	18%
6	26	25.2%	44%
7	37	35.9%	80%
8	14	13.6%	93%
9	7	6.8%	100%

(41), and the official number of national Covid cases per million (40). We also used a number of control variables – household head characteristics (gender, age, education); location (rural or urban); and services (improved water and sanitation). For health, we allowed for pre-existing self-reported health conditions of the household head and the incidence of changed health conditions for any household member each month. We also included a specific control variable for observations during Ramadan (12 April to 12 May).

Econometric model specification

We acknowledge issues of endogeneity and causality. According to Holland (52), x is said to have an effect on y if the following three conditions are met (i) y follows x temporally, (ii) y changes as x changes (relationship is statistically significant), and (iii) no other causes should eliminate the relation between x and y, referred in the literature as an omitted variable (53). While the first two conditions are arguably accounted for in the study, we did not roll out the third condition associated with model specification. To this end, we have included location dummies and months in the regression to account for location and time-specific factors that are not observable and referred to in the literature as unobserved heterogeneity. However, we acknowledge that there may be other factors that may, for example, affect covid cases and outcome variables simultaneously.

Panel data allow control for unobservable intra-household factors or variables that change over time but not inter-household heterogeneity. The most commonly used techniques to analyse panel data are fixed effects and random effects models (54). A fixed effects model assumes that household level factors may influence the outcome variable and hence need to be controlled. Once the effect of time-invariant characteristics has been accounted for to avoid omitted variable bias, we can assess the net effect of the predictors on the outcome variable. A fixed effects model also assumes that the time-invariant features are unique to a household and should not be correlated with other household characteristics. More formally, a fixed effects model can be specified as:

$$Y_{it} = \beta_1 X_{it} + \alpha_i + u_{it} \tag{1}$$

where Y_{it} the dependent variable; X represents explanatory variables; α_i $(I = 1, 2, 3, \ldots\ n)$ is unknown household-specific intercept and n is the number of households; β are coefficients to be estimated; i indexes households and t indexes time; and u_{it} is the error term. Unlike the fixed effects model, a random effects model assumes that the variation across entities is random and uncorrelated with the explanatory variables. The advantage of a

TABLE 3 Variable specifications.

Data type	Description	Specification	Variable name
Control	Location	Urban yes /no	Location
	Gender household head	Male Yes/no	HHHgender (male)
	Age household head	Numeric	HHHAge
	Education household head	None yes/no	Educdummy
	Health household head	Self-reported diabetes or hypertension	HHHhealthstart
	Improved water supply	Yes/no	HHImpwaterdummy
	Improved sanitation	Yes/no	HHImptoiletdummy
Independent	Household size	Total number of residents	Hhsize
	Household dependency ratio	Ratio non-working age residents to working age residents	Depratio
	Resident health change	Self-reported any new health conditions for any resident	Anyresidentsick
	Resident migration	Absolute migration in and out	Mobility
	Cash expenditure	Fish money per resident (Dalasi)	Fishmoney (GMD)
	Income change	Income up yes/no	Income up
	Income source: employment	Cited as a top 3 income source	Employment
	Income source: business	Cited as a top 3 income source	Business
	Income source: remittances	Cited as a top 3 income source	Remittance
	Covid policy measures	Oxford Policy stringency index monthly data	Policystring
	Covid cases	Monthly National cases per million John Hopkins data	covidcases
	Covid perceived impact	Hoarding cited yes/no	Hoarding
Dependent	Household Food Insecurity Access Scale	Each of nine questions scored (0–3) depending on the frequency of response (Never, rarely, sometimes, often). Sum is HFIAS score (0–27)	HFIAS
	Food Consumption score (FCS) all sources	Sum of Staples (2); Pulses (3); Veg (1); Fruit (1); Meat/Fish (4); Milk (4); Sugar (0.5); Oil (0.5) all sources. Max 7 each group; weights in brackets	FCS[1]
	FCS market sources	As FCS, market sources only	FCSmarket
	FCS own production sources	As FCS, own production only	FCSown
	FCS-Nutrition (FCS-N) Protein all sources	Pulses; Milk and dairy; organ meat; flesh meat; fish; and eggs	Protein
	FCS-N Protein Market sources	As FCS-protein, market sources	Proteinmkt
	FCS-N Protein[2] own production	As FCS-protein, own production	Proteinown
	FCS-N Vitamin A[3] all sources	Milk, dairy; Organ meat; eggs; Orange vegetables; dark green leafy vegetables; Vitamin A rich orange fruits	VitA
	FCS-N Vitamin A Market sources	As FCS-VitA, market sources	VitAmkt
	FCS-N Vitamin A own production	As FCS-VitA, own production	VitAown
	FCS-N Heme[4] iron all sources	Flesh meat and fish	Iron
	FCS-N Heme iron Market sources	As FCS-iron, market sources	Ironmkt
	FCS-N Heme iron own production	As FCS-iron, own production	Ironown

[1] Food Consumption Score is calculated for foods sourced from own production and the market, as well as the total.
[2] Food consumption Nutrition Score for Protein is calculated for foods sourced from own production and the market, as well as the total.
[3] Food consumption Nutrition Score for vitamin A is calculated for foods sourced from own production and the market, as well as the total.
[4] Food consumption Nutrition Score for Heme iron is calculated for foods sourced from own production and the market, as well as the total.
GMD, is the official currency of the Republic of Gambia; HFIAS, Household Food Insecurity Access Scale; FCS, Food Consumption Score; FCS-N, Food Consumption Nutrition Score; FCS-Protein, Food Consumption Nutrition score for Protein-rich foods; FCS-VitA, Food Consumption Nutrition score for Vitamin A rich foods; FCS-Iron, Food Consumption Nutrition score for Heme-iron rich foods.

random effects model is that you have a chance to include time-invariant or household level variables in the regression (53). However, this may lead to omitted variable bias.

Formally, the model can be specified as:

$$Y_{it} = \beta X_{it} + \alpha + \xi_{it} + e_{it} \quad (2)$$

where ξ_{it} is between household error term, e_{it} is within household error term, and others as defined above.

The estimation procedure depends on the outcome variable. We used multiple linear regression for continuous outcome variables and negative binomial models for count outcome variables. Although Poisson regression models could be used for the latter, the negative binomial model does not restrict the variance to be equal to the mean. This is referred to as "overdispersion" and measured by "alpha" in the estimation model. If 'alpha' is significant, the negative binomial is preferred.

Our selection of random or fixed effects models was guided by a Hausman specification test, which adopts a null hypothesis that the household level error term (ξ_{it}) is not correlated with the regressors, in which case a random effects model is used (53).

Results

Descriptive statistics

Household backgrounds

The total number of 1,406 residents meant that the average initial household size was just under 14 (Table 4). Urban households were 40% larger than rural households but dependency ratios were lower; 98% of residents were Mandinka, 2% Fula, and 53% female; 46% were born in the Mandinka region of Kiang West and a further 30% in the Brikama and Kanifking urban districts; 47% were under 16 years old and only 4% over 65; 68% lived in a compound occupied by a single dwelling and most had water piped to the dwelling or compound and private sanitation.

A total of 85 households had a sole male head, 12 had a sole female head and in three households headship was shared between one male and female[10]. Most heads had no education, especially in rural areas; 97% were married – two-thirds of marriages were polygamous. The self-reported incidence of hypertension or diabetes was especially evident in urban household heads (23.3%)[11]. Of those who specified a sector, most household heads worked in business, service, construction, or farming. Nearly 40% had multiple occupations, but 17% were unpaid (unemployed or housewives).

10 Three male heads were absent during the survey but were consented prior to consenting their wives.

11 During subsequent calls, we found 84 instances of a new health condition – 18 percent of which related to hypertension, diabetes, respiratory illness or obesity.

TABLE 4 Descriptive data.

Household data	All	Urban	Rural
Location (*n*)	103	60	43
Location (%)	100%	58%	42%
Households with improved water (%)	82.5%	73.3%	95.3%
Households with improved toilet (%)	83.5%	81.7%	76.7%
Initial household size (mean)	13.7	15.7	11.0
Initial dependency ratio (mean)	1.1	0.8	1.6
Household head male[1] (%)	87%	87%	84%
Household head age (mean)	57.0	59.3	53.8
Household head education none/primary (%)	56%	50%	65%
Household head education secondary or higher (%)	44%	50%	35%
Household head health condition at start (%)	19.4%	23.3%	14.0%

[1] Includes three households with both a male and female head.

Pandemic awareness

To avoid over-attribution of dietary behavior to the pandemic, we were careful not to lead respondents and asked a number of questions regarding perceived household exposure to all types of external shock. 30% of households experienced food shortages during the previous year, usually in July and August. In terms of the current shock, awareness remained high throughout the survey period. Initial fears of the market and school closures and reduced employment eased over time but food prices were a consistent worry and concerns of hoarding rose with the number of Gambian Covid after April 2021 (Figure 2). These patterns reflect the relatively few government restrictions and reliance on food markets (32, 34).

Consumption

Our food frequency results were similar to those of the most recent one-off national surveys (33, 34, 42) but also showed variation over time (Table 5). Staples were the most frequently consumed food group, and dark green vegetables were the least. Rice and bread were the most popular staples but more healthy options, such as millets, regularly consumed in Wolof and Fula communities (42) were noted mainly in rural households during harvest periods. Consumption of Vitamin A-rich fruit and vegetables peaked between May and July and was lowest in February and March. Rural consumption of dairy products and roots and tubers was much lower than in urban areas.

All male household heads ate full meals outside the house on average 3 three times a week throughout the survey period. Markets were visited just over 6 days a week and were the main household food source (Table 6). Market reliance was highest in urban areas but visit frequency was lower, especially before

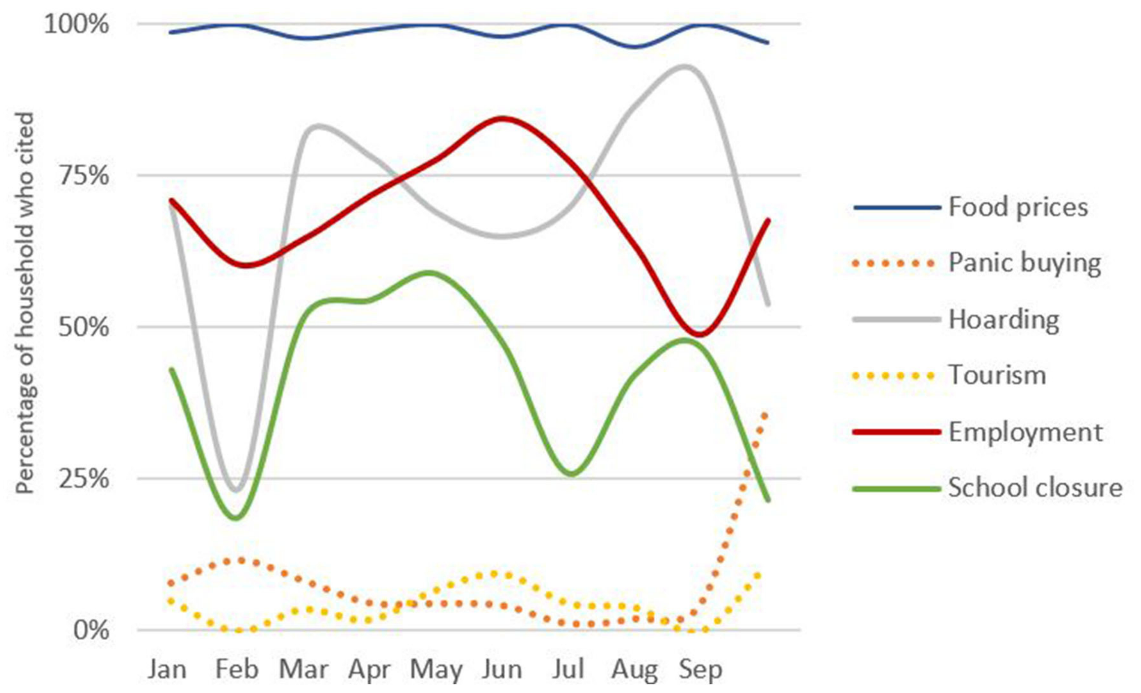

FIGURE 2
Perceived Covid impacts by month (Own graph, data source Survey data).

the relaxation of policy in March and as Covid cases began to rise after July. Own production was intermittently important for fruit, vegetables, and millets, especially in rural areas and gifting was only noted in urban Vitamin A-rich fruit.

We used the data for foods consumed at home over the previous 7 days to calculate a number of food security indices (Table 7). Average *FCS* scores were 12% lower in rural areas (especially in February and March), but average FCS-N rural protein and heme-iron scores were 25% lower and FCS-N Vitamin A scores 29% lower. August saw below-average intakes of Vitamin A and heme-iron-rich foods but not of protein-rich foods. Spatial disparities were most evident in February to March but the widest inter-household dispersion from May to July may also reflect non-locational factors.

These consumption and sourcing patterns suggest that pandemic impacts may vary by season, location, and food group. This was also evident in our *HFIAS* scores. Our results reveal constraints on food *choice* rather than *quantity*. These were addressed most frequently through the use of savings or borrowing food or money, rather than cutting non-food expenditure or begging. Urban HFIAS scores were higher, especially in February and March but only 3% of observations had a score greater than 4. HFIAS scores were lowest during April (the period of Ramadan) and after July.

However, these scores may reflect a greater ability to borrow cash or food to maintain consumption patterns, not necessarily a greater need.

Income and expenditure

Sixty-seven percent of calls witnessed no change in household monthly income and only 14% witnessed declines. February and September saw the highest incidence of falling incomes but the distribution was skewed in favor of net gains in all other months, especially June. However, income falls were concentrated in 47% of households. This was evenly split by location but rural households were nearly twice as likely to experience *multiple* monthly declines and were particularly affected June to September. The most commonly cited reason was usually lower production (irrespective of location) but declining remittances were also significant in July and September.

Employment and business were the most frequently cited income sources[12] but urban households were twice as likely as rural households to cite business. The importance of remittance receipts (from domestic or international sources) rose after May

12 As we were wary of difficulties in estimating numbers in a remote survey and our pilot surveys indicated some reluctance, households were not asked to quantify income, only to cite top three sources.

TABLE 5 Main Food consumption patterns by location and month.

Average number of days consumed per week											
Food	**All**	**Urban**	**Rural**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Rice	6.1	6.8	6.5	6.2	5.9	7.0	6.7	6.9	6.9	4.2	7.0	7.0
Millets	2.0	2.3	2.7	2.9	1.7	2.9	1.9	2.0	3.2	0.8	2.7	2.5
Roots/Tubers	2.9	3.7	1.9	3.7	3.3	3.2	3.2	2.7	2.8	2.1	3.7	2.8
Pulses	1.5	1.7	1.1	1.4	1.4	1.4	1.3	1.5	1.5	1.4	2.3	1.5
Dairy	5.2	5.5	3.7	5.0	3.7	4.2	5.0	5.8	4.9	5.9	5.6	6.1
Eggs	2.5	2.4	1.4	1.8	1.6	1.8	2.0	2.1	2.0	3.9	2.6	3.0
Dark green Vegetables	1.7	1.7	1.5	1.9	1.8	1.8	1.6	1.5	1.6	1.9	1.4	1.6
Vitamin A-rich vegetables	3.6	3.4	1.8	2.8	2.3	2.4	3.3	3.8	2.8	5.7	3.1	3.1
Vitamin A-rich fruit	2.7	3.1	2.7	0.6	0.5	1.2	3.1	5.7	6.3	2.7	2.8	0.7
Other fruit	5.7	6.2	6.2	6.0	6.3	5.9	6.2	6.4	6.0	4.1	6.3	6.4
Flesh meat	1.7	2.3	1.7	1.8	1.3	1.6	2.3	2.7	1.8	1.0	2.6	1.9
Fish	6.2	6.8	6.5	6.9	6.0	7.0	6.8	7.1	7.2	5.1	4.8	6.0
Oils & Fats	5.7	5.7	5.2	5.3	5.2	5.1	6.2	6.2	5.6	6.1	5.3	5.3

TABLE 6 Main food sourcing patterns by location.

Food	**Totals**			**Urban**			**Rural**		
	Market[1]	**Own production[2]**	**Gift[3]**	**Market**	**Own production**	**Gift**	**Market**	**Own production**	**Gift**
Rice	97%	3%	0%	99%	1%	0%	92%	8%	0%
Millets	84%	13%	2%	95%	4%	2%	67%	30%	3%
Roots/Tubers	84%	15%	0%	91%	9%	0%	69%	30%	1%
Pulses	83%	15%	2%	90%	8%	2%	71%	26%	3%
Dairy	97%	2%	1%	99%	0%	1%	94%	5%	1%
Eggs	95%	5%	0%	99%	1%	0%	89%	11%	1%
Dark green Vegetables	56%	44%	1%	72%	27%	1%	30%	70%	0%
Vitamin A rich vegetables	91%	9%	0%	96%	4%	0%	83%	17%	0%
Vitamin A rich fruit	38%	56%	6%	45%	50%	5%	26%	68%	6%
Other fruit	86%	13%	2%	89%	10%	1%	77%	19%	5%
Flesh meat	88%	9%	3%	90%	7%	2%	82%	13%	5%
Fish	99%	0%	0%	100%	0%	0%	99%	1%	0%
Oils and fats	100%	0%	0%	100%	0%	0%	100%	0%	0%

[1] Refers to food purchased at the market.
[2] Refers to food sources from own production.
[3] Refers to foods sourced from friends or family with no monetary exchange.

in urban areas and after July in rural areas. These were usually in monetary form (rather than goods or food) and used to buy food. As such, their receipt may be a key factor in dietary diversity, especially during the lean period and when Covid cases begin to reaccelerate.

However, a diverse range of income sources was not universal. Whilst 74% of households received remittances, 35% of recipients received only once. Government aid was received by <9% of households and accounted for only 2% of observations. Moreover, all households who received aid also received remittances. Income and remittance reliance may also be related to the movement of people; 43% of households had instances of new people entering the household and 57% of people leaving. All 72% of households (especially in urban areas) had some type of resident mobility. This confirms our prior expectation of household fluidity.

Household budgets were also subject to fluctuations on the expenditure side; 42% of calls recorded increased monthly

TABLE 7 Food consumption indices.

Month	HFIAS			FCS			FCS-N Protein			FCS-N Vit A			FCS-N Heme iron		
	TOT	URB	RUR	TOT	URB	RUR	TOT	URB	RUR	TOT	URB	RUR	TOT	URB	RUR
Jan	1.1	1.1	1.4	88.5	89.8	79.2	23.3	24.2	17.0	12.3	13.0	7.2	11.0	11.3	8.2
Feb	1.4	1.6	1.0	85.2	93.0	72.9	21.2	25.0	15.1	10.2	12.4	6.9	9.4	11.2	6.6
Mar	0.9	1.1	0.8	87.4	94.3	79.4	22.7	27.0	17.8	10.7	13.5	7.5	10.4	12.1	8.3
Apr	0.5	0.4	0.6	94.2	98.5	88.9	23.7	26.5	20.3	14.6	17.6	10.8	10.7	11.7	9.4
May	0.6	0.6	0.6	99.7	101.5	97.4	25.9	27.2	24.1	19.2	19.4	18.8	11.7	12.4	10.9
Jun	0.7	0.8	0.6	95.7	102.3	88.4	24.6	28.5	20.4	17.2	20.0	14.1	10.8	12.4	9.0
Jul	0.3	0.2	0.4	98.7	102.1	93.2	26.1	27.6	23.7	17.5	19.4	14.4	10.7	10.9	10.3
Aug	0.6	0.9	0.1	98.8	104.2	90.6	25.7	28.4	21.8	14.5	17.3	10.4	8.7	9.9	6.9
Sep	0.7	0.7	0.6	93.0	101.3	83.8	24.4	28.4	19.9	13.9	16.2	11.3	9.1	10.5	7.5
Mean	0.8	0.8	0.7	93.1	98.1	86.1	24.0	26.9	20.0	14.4	16.4	11.6	10.4	11.6	8.7
SD	1.58	1.71	1.36	16.7	13.7	17.9	9.3	8.4	9.1	6.8	6.3	6.4	4.5	4.3	4.3

TOT, Total sample; URB, Urban sample; RUR, Rural sample; HFIAS, Household Food Insecurity Access Scale; FCS, Food Consumption Score; FCS-N Protein, Food Consumption Nutrition score for Protein-rich foods; FCS-N Vit A, Food Consumption Nutrition score for Vitamin A rich foods; FCS-N Heme iron, Food Consumption Nutrition score for Heme-iron rich foods; SD, Standard deviation.

expenses, especially in August. This was usually attributed to higher rice prices (69%) but also to cooking oil. The affordability of nutritious foods, such as dairy or fish, was seldom mentioned. Based on historical price data (55), the 67% rise in vegetable oil prices since March 2020 appears to be more of a pandemic-specific effect (Figure 3). By contrast, the 14% rise in rice prices is not extraordinary by historical standards and has been offset by the falling cost of millets which to some degree are a staple substitute. However, this did not appear to impact the consumption frequency of either.

The impact of these budgetary fluctuations was gauged by analyzing the Gambian concept of "fish money" – a household's monthly disposable cash. As this was a clearly understood local concept, it was one of the few variables we asked respondents to quantify. As respondents sometimes could not remember or were unwilling to reveal the amount, we collected only 642 estimates but had data for all households. The average of these (normalized for household size) was 449 Gambian Dalasi (GMD) and peaked at 549 GMD in August. However, dispersion around the mean was significant (standard deviation of 391 GMD). The urban average (531) was 1.6 times the rural average (327) and those in the top quintile had more than three times as much fish money as those in the bottom quintile.

Each of our consumption, income, and expenditure indicators, therefore, suggested a degree of spatial, temporal, and inter-household variation.

Regression analysis

Table 8 summaries the descriptive data for our regression variables, and Table 9 shows our tests of association between 20 independent variables and our 13 dependent variables. They identify a number of significant associations (especially for HFIAS, Vitamin A, Vitamin A market, and Protein market) but the explanatory power is weaker for own production and iron-rich food.

The most frequently significant independent variables are location, improved sanitation, household size, changes in monthly income, Covid policy stringency, and Covid cases but there was some variation by the dependent variable. Contrary to our *a priori* expectations, we found no association between migration and most dietary metrics which may be attributable to variable specification.

Household Food Insecurity Access Scale was significantly negatively associated with being a male household head (though the number of female heads was small); positive income changes; income from any source; and Ramadan. Although the number of Covid cases had no effect, case numbers only began to rise in August so may not affect all observations. A link between personalized perception of risk and behavior was more apparent in the positive relationship between HFIAS and any resident

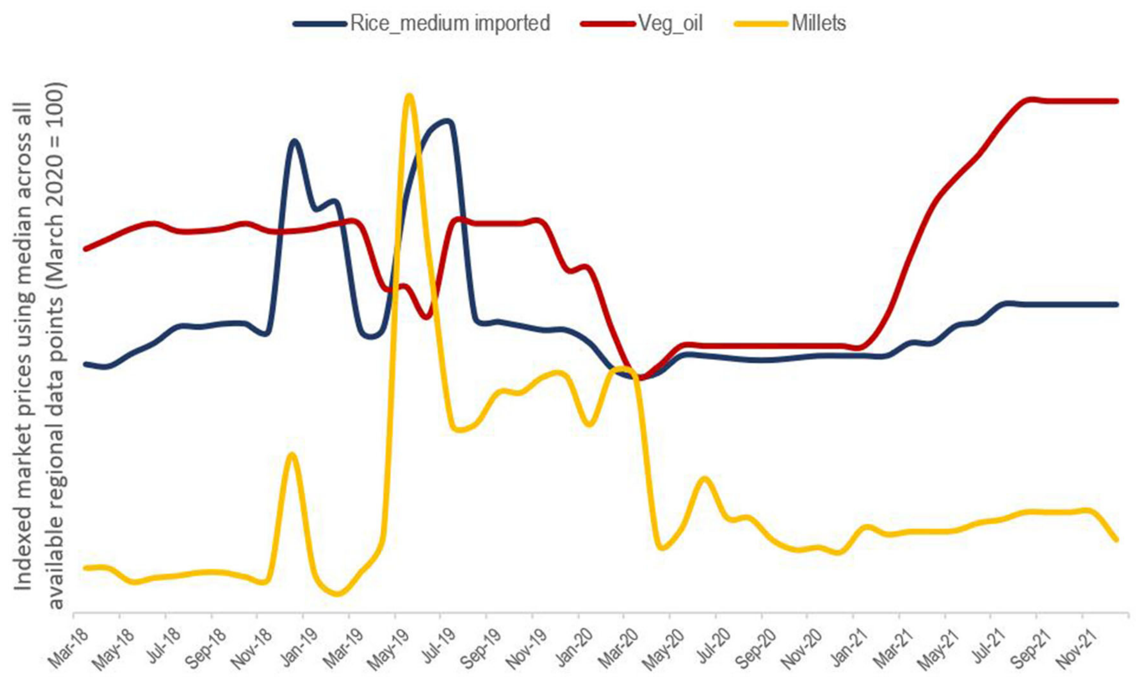

FIGURE 3
Market food prices [Own graph, date source (55)].

becoming sick, the fear of hoarding, and the education of the household head.

Food Consumption associations with income changes, Ramadan, policy stringency, business, and remittance income sources mirrored those of HFIAS as expected. Income from employment and hoarding was not significant but we did identify additional positive associations with location, improved sanitation, and household size. However, the direction and magnitude of these associations varied by food source. The negative association between own production sources and location is intuitive but our results also showed a negative relationship with household head age and education, improved sanitation, and Covid policy stringency and a positive one with Covid cases. FCS market was positively associated with location, improved sanitation, household size, positive income changes, and Ramadan but negatively associated with Covid cases.

These relationships may suggest a degree of switching between food sources, as well as a number of household-specific choice constraints, such as age, income, and location. The indirect effects of the pandemic are also implied through the negative association between stringency measures and own production (possibly attributable to restrictions on movement or higher costs of transport back to farms). However, higher Covid cases seem to encourage more reliance on own production. The perceived effects of hoarding do not seem to have a bearing on consumption patterns, only coping mechanisms to maintain them.

Our nine FCS-N nutritional intake variables provided corroboration of our HFIAS and FCS findings that indicated the importance of location, household services (sanitation or water supply), Covid policy stringency, and cases. However, there was some variation by nutrient type. We found a positive association between location and market sourcing for all nutrients and for protein and iron scores but not Vitamin A scores. Covid policy stringency had a negative association with all but two of our FCS-N variables – protein own and iron market[13].

Covid cases were associated with nutrient sourcing but not nutrient scores. Moreover, the impact was inconsistent. Covid cases had a negative association with Vitamin A rich food consumption from either source and with iron rich foods sourced from the market. This may reflect the seasonal availability of own produced Vitamin A-rich food. By contrast, Covid cases were positively associated with protein scores from both own production and markets (possibly due to people trying to improve health resilience).

We also found a positive association between Vitamin A scores and male household heads, improved water supply, positive income changes, business income, and Ramadan and a

13 Protein rich food sourced from own production and iron rich food sourced from markets respectively.

TABLE 8 Variable data for regression model.

Control variables			Independent variables			Dependent variables		
Name[1]	Mean	SD	Name	Mean	SD	Name	Mean	SD
Location[2]	58%	0.5	Anyresidentsick	13%	0.3	HFIAS	0.8	1.6
Household head (male)[3]	88%	0.3	Mobility	14%	0.5	FCS	93.1	16.7
Household head age	57.0	12.0	Fishmoney(GMD)	449	391	FCSmarket	76.0	17.3
Education dummy	53%	0.5	Incomeup	20%	0.4	FCSown	7.3	9.2
Health household head	19%	0.5	Employment	68%	0.5	Protein	24.0	9.3
HHImpwaterdummy	83%	0.3	Business	51%	0.5	Proteinmkt	22.4	9.8
HHImptoiletdummy	83%	0.3	Remittance	33%	0.4	Proteinown	1.4	2.6
Hhsize	13.9	6.6	Policystring	39.6	5.3	VitA	14.4	6.8
Depratio	1.1	0.9	covidcases	110.3	98.9	VitAmkt	11.1	6.4
			Hoarding	70%	0.4	VitAown	3.2	3.8
						Iron	10.4	4.5
						Ironmkt	10.0	4.6
						Ironown	0.3	1.3

[1] Refer to Table 3 for variable specifications.
[2] 58% for location means that 58% of the respondents used in the regression are from urban area (please refer to Table 3 for reference group of dummy variables). Others can also be interpreted with the same fashion.
[3] Household head data Includes three households with both a male and female head.
SD, standard deviation; GMD, Gambian Dalasi the official currency of the Republic of Gambia; HFIAS, Household Food Insecurity Access Scale; FCS, Food Consumption Score.

negative association with age. Male household heads and larger households with improved water supply were more likely to rely on market sources of Vitamin A, but female-led households those who feared market hoarding were more likely to rely on their own production. However, it should be noted that the number of female-led households was relatively small.

Protein scores were also positively associated with higher monthly income, access to business and remittance income, improved water supply, and household size but not with the gender, age, and education of the household head. Each of the latter variables was positively associated with market sourcing of protein-rich foods. Reliance on own production had a negative association with urban location, age, and health of household heads, improved sanitation, fish money but was positively associated with reliance on employment income and Covid cases.

The patterns for iron-rich food were rather different. As for other nutrients, urban living, improved sanitation, household size, and positive income changes were positively associated with higher iron intake and reliance upon markets. However, there were no significant associations with income sources, household head gender, age or education, Covid cases, or Covid-induced hoarding. We found a negative relationship between Covid policy stringency and iron-rich food intake but this seems to be driven through own production, not market sourcing. This particular effect is also suggested by the positive association between Covid cases and own production and a negative association with market sourcing. Reliance on own production is also positively associated with a deterioration in the health of a household resident.

The positive relationship between the Ramadan dummy and FCS, iron, and Vitamin A and the negative association with HFIAS can be attributed to households trying to ensure they maintained a diversified diet during a period of fasting but this did not seem to include protein.

Discussion

The primary strengths of this study are its longitudinal nature and its analysis of food indices disaggregated by source within a particular social group. This enables our results to identify specific dimensions of inequality (such as household resources) that limit the resilience of households in the face of the pandemic shock. Our findings, therefore, corroborate many of those from the literature and provide some contextual nuances.

We found that functioning food markets and adoption of a range of production and consumption coping mechanisms were paramount (13). As only 9% of households in our survey received government aid, we were unable to rigourously test previous findings on the importance of social safety nets in the early stages of the pandemic (9). We simply note the small number of recipients and that all of these also received remittances. To the extent that pandemic restrictions impair markets or coping strategies, they may limit dietary diversity (19), especially

TABLE 9 Regression model results.

Variable	HFIAS Scale	FCS			Vitamin A			Protein			Heme-Iron		
		FCS score	Own production sources	Market sources	FCS-N Vitamin A score	Own production sources	Market sources	FCS-N Protein score	Own production sources	Market sources	FCS-N Heme-iron Score	Own production sources	Market sources
Location	0.049	6.421***	−5.439***	12.548***	0.662	−0.947***	1.925***	0.804**	−2.187***	1.095***	0.162***	−0.488	0.186***
Gender household head	−0.695***	3.879	2.3	1.697	1.106**	−0.673*	1.119***	0.451	0.955	0.154	0.008	−0.019	0.003
Age household head	0.012	0.044	−0.130**	0.127	−0.026*	−0.001	−0.003	−0.009	−0.048**	0.003	0.000	−0.016	0.001
Education household head	0.461***	−0.072	−2.558**	2.093	−0.156	−0.232	0.234	−0.124	−0.367	0.078	0.005	0.021	0.009
Health household head	0.068	−1.489	−1.013	−1.607	0.17	−0.154	0.052	−0.378	−0.978***	−0.166	−0.063	−0.052	−0.071
Improved water supply	0.077	2.328	0.316	2.451	0.933**	0.43	1.112***	0.713**	−0.677	0.461	0.03	0.855*	0.011
Improved sanitation	−0.018	4.092*	−4.910***	7.301***	0.287	0.066	1.152***	0.444	−1.252**	0.671**	0.241***	0.203	0.219***
Household size	0.002	0.355**	0.053	0.263*	0.051***	−0.029	0.030*	0.043***	0.048	0.031**	0.014***	0.009	0.015***
Household dependency ratio	0.025	−0.918	0.253	−0.716	0.022	0.039	0.014	−0.006	−0.014	0.007	−0.033	−0.209	−0.021
Resident health change	0.485**	0.942	0.497	0.148	0.048	−0.121	0.021	−0.028	0.079	−0.048	−0.062	0.575*	−0.090*
Resident migration	0.004	1.038	0.019	0.431	0.016	0.023	0.063**	0.014	0.096	0.021	0.002	0.134	−0.002
Cash expenditure	−0.028	0.249	−0.093	0.233	−0.005	0.019	−0.008	−0.009	−0.102***	−0.007	0.002	−0.001	0.004
Income change	−0.225***	3.497***	0.685	3.032**	0.102**	−0.024	0.059	0.087***	−0.158	0.095**	0.091**	−0.261	0.106**
Income source: employment	−0.746***	0.207	0.005	−0.172	−0.004	0.119	0.063	0.006	0.349*	−0.011	−0.034	−0.052	−0.041
Income source: business	−0.436**	4.141***	0.528	1.378	0.092**	0.039	0.113**	0.077**	0.086	0.064**	0.014	0.045	−0.007
Income source: remittances	−0.861***	3.957***	−0.321	1.668	0.036	0.019	0.172***	0.117***	0.085	0.115***	−0.023	−0.008	−0.047
Covid policy measures	0.031*	−0.547***	−0.247***	−0.177	−0.016*	−0.075***	−0.008**	−0.005*	−0.018	−0.006*	−0.006*	−0.061*	0.0004
Covid cases	−0.001	−0.007	0.007**	−0.020***	0.001	−0.001**	−0.001***	0.0001	0.002***	0.0003**	0	0.008***	−0.001***

(Continued)

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TABLE 9 (Continued)

Variable	HFIAS Scale	FCS			Vitamin A			Protein			Heme-Iron		
		FCS score	Own production sources	Market sources	FCS-N Vitamin A score	Own production sources	Market sources	FCS-N Protein score	Own production sources	Market sources	FCS-N Heme-iron Score	Own production sources	Market sources
Covid perceived impact	0.875***	−0.018	−0.723	−1.144	−0.008	0.209*	−0.032	0.008	−0.096	0.011	−0.012	0.17	−0.004
Ramadan	−0.499*	5.036***	−0.228	2.943*	0.243***	0.283*	0.125**	0.053	0.11	0.045	0.086**	0.13	0.054

HFIAS, Household Food Insecurity Access Scale; FCS, Food Consumption Score; FCS-N, Food Consumption Nutrition Score; FCS-Protein, Food Consumption Nutrition score for Protein-rich foods; FCS-VitA, Food Consumption Nutrition score for Vitamin A rich foods; FCS-Iron, Food Consumption Nutrition score for Heme-iron rich foods.
***Significance at a 99% confidence level.
**Significance at a 95% confidence level.
*Significance at a 90% confidence level.

in rural areas (21). This may be through more restricted food choices or higher costs of transport in rural areas to find work.

Although we found some suggestions of gender-specific associations with coping mechanisms and Vitamin A consumption, we could not replicate findings elsewhere in the literature (20) that gender was more widely associated with vulnerability, as our dataset had only a small number of sole female household heads (Table 4). However, we did confirm the continued importance of agriculture as an income source and food source (Table 6) (25–27). The maintenance of dietary diversity through seasonal switching between own and market sources is well-documented (24), but our results highlight which particular households and for which particular food groups (Table 9).

Our descriptive results also suggest a range of household, spatial and temporal factors that drive dietary behavior over time. All households were from the Mandinka social group and frequently featured large, mobile and polygamous households usually led by male household heads with a low level of education and a poor state of health (Table 4). Diets were heavily dependent upon staples across all locations and market food sources, especially in urban areas (Tables 5, 6). As Kundu et al. (21) found in Bangladesh, we found that Gambian rural micronutrient intake was consistently lower than in urban households (Table 7). Whilst this echoes findings of higher food insecurity in rural areas of The Gambia (43), growing inter-household dispersion from May to July was not location specific (Table 7).

Our findings did not suggest the same degree of food insecurity in terms of availability identified in national Gambian surveys conducted earlier in the pandemic (6, 42). Food security in our survey was manifest in terms of restricted food choice, rather than quantity (Tables 5, 7), but households employed coping strategies to ensure stable nutritional intake during Ramadan. Income falls occurred mainly in February and September and were concentrated in a sizeable minority of the survey population. Rural households were more reliant upon employment and production income and susceptible to multiple monthly declines, especially after June. Less than 50% of households received remittances more than once and less than 9% received Government aid (Table 8). The wide dispersion of disposable spending money suggests that some household budgets were more squeezed by rising food prices than others. This may mirror Dou et al.'s (14) finding of varying resilience capacity within income cohorts, not just across them though we were not able to replicate Crush and Si's (22) finding that this dispersion may reflect pre-existing food insecurity driven by age, gender, and occupation.

This array of factors highlights the multi-dimensional pandemic impact pathways (20) and had a strong bearing on our regression results. We identified significant associations between dietary behavior and six key variables: location, improved sanitation, household size, changes in monthly income, Covid policy stringency, and Covid cases (Table 9). These associations are suggestive of spatial, temporal, and pandemic effects but the magnitude of these varied by dietary metric and the specific Covid impact. These findings echo those of Teachout and Zipfel (19), which suggest that lockdown restrictions may have exacerbated food security issues for some households and those of Egger et al. (20) which suggest these effects persisted long after policy easing. We found that food insecurity was manifest in terms of restricted choices (14), rather than availability or affordability (13).

In terms of psychological effects, our HFIAS results (Table 7) suggested that tighter policy stringency and fear of pandemic-induced hoarding encouraged wider use of dietary coping mechanisms to maintain food choices. As Covid cases did not rise until toward the end of the study, they had less effect on most dependent variables but were associated with greater reliance on own production for some food types. This echoes the findings of Madzorera et al. (27). The positive association between the incidence of household illness and coping strategies and reliance on own produced iron-rich foods may suggest that behavioral change actually occurs only when a health risk is perceived to be personal.

Policy stringency had a negative association with most dietary diversity scores and with reliance on own production of all food types as found elsewhere in SSA (27), except those rich in protein where market sources were negatively associated (Table 9). This appears to confirm Teachout and Zipfel's (19) finding that policy restrictions may undermine long-term resilience. Increased national Covid cases were associated with own production of protein and iron-rich food scores and perceived fears of market hoarding Covid was also positively associated with own production of Vitamin A-rich food scores. These differences may not only reflect seasonality to some extent but also suggest that the impact of each different aspect of Covid needs to be assessed by a specific food group.

Income changes were also significantly associated with several dependent variables (Table 9) but it is unclear if these can be attributed directly to the pandemic. Although our variables may not explain changes in the intake of nutrients, they may indicate changes in food sourcing. An important finding is that the associations were not consistent by nutrient type or location. Urban location was associated with improved dietary outcomes using all metrics (21), except Vitamin A-rich foods, which were largely sourced from own production. Iron-rich food intake was not associated with income source or Covid cases but reliance on own production sources for iron was positively associated with household sickness and Covid cases. Although we found that female-headed households were more likely to eat Vitamin A-rich foods and adopt more coping strategies, the small number of observations does not allow us to definitively determine a gender effect (22).

As well as spatial factors, the ability to adapt dietary and sourcing habits appears to be subject to household-specific constraints (14). Households with improved services (which may be deemed a wealth proxy) and larger households (which may be deemed an income-earning capacity proxy) were more resilient in terms of diversity and nutritional outcomes, though most households took steps to ensure stable food intake during Ramadan (Table 9). Although we found no relationship between migration and dietary outcomes *per se*, it is possible that migration had an indirect income effect through remittances.

Our results suggest that Covid policy restrictions and the rise in cases have had a negative effect on dietary outcomes and altered food sourcing behavior to some degree (19, 20). However, neither Covid policy nor cases appear to have affected the frequency of market visits (especially in rural areas) or of eating out (Tables 6, 9). In the face of the pandemic, households have adopted a range of food-specific coping strategies (Tables 6, 7), including dynamically switching between sources as available (13). Therefore, the effects of the pandemic have been filtered through location and household-specific wealth and income proxies that have constrained household resilience.

In terms of policy implications, our findings reiterate those from elsewhere in SSA (19) that there is scope for more sophisticated targeted of Government aid as it does not appear to have reached most households and certainly not those most in need, particularly those with higher dependence on employment income and no access to remittances. We do not try to suggest that the absence of social safety nets was a cause of dietary hardship (due to insufficient data) simply that not many received any aid and those who did had alternate safety nets. The fact that there is some inconsistency across food groups may also suggest that a strategy to address one dimension of micronutrient deficiency is not necessarily one that can address others.

We acknowledge a number of limitations in our study. Our findings are limited by the size of our sample population, reliance on those with regular access to a mobile phone, the use of convenience and snowballing techniques, and the small number of female household heads, as well as the fact that Covid incidence was relatively low and local policy relaxed for most of the survey period. Nevertheless, circumstances did make collection and co-ordination rather problematic. We had hoped to follow-up on some of the questions raised in our survey through individual interviews and focus groups but resources, timing, and Covid restrictions precluded this. We also recognize that we relied on nutritional frequency proxies in terms of dietary intake at the household level, rather than measuring individual intake or nutritional outcomes directly. We have tried to take reasonable steps to address issues in our dataset but recognize that as not all potential causes of error can be fully mitigated (54), these may limit the robustness of our results.

Conclusions

This longitudinal study examines the multi-dimensional impact pathways of the Covid pandemic within one ethnic group located in urban and rural areas of The Gambia. It thereby contributes to the literature in terms of improved understanding of the interaction between food environments, lockdown policy regimes, and household coping strategies in specific contexts (20).

Food insecurity was manifest during the 9-month survey period mainly in terms of lack of choice and nutritional variety, rather than quantity. Our regression analysis demonstrates that dispersion of household dietary outcomes and sourcing strategies were associated with location, improved sanitation, household size, changes in monthly income, Covid policy stringency, and Covid cases. An important finding is that there were variations in food group consumption by location and by food nutrient group. Rural communities were more likely to eat more healthy millets (sourced from own production) but much less likely to consume dairy products or roots and tubers. Access to own production was important for Vitamin A-rich foods but higher incomes and markets were key for protein and hem-iron-rich foods. Tighter policy stringency was negatively associated with dietary diversity and positively associated with increased reliance on a range of coping mechanisms. Resilience was higher in larger households and those with access to improved water and sanitation. Higher consumption of protein-rich foods and greater reliance on own produced iron-rich foods was associated with the number of Covid infections.

As well as reaffirming findings from other contexts, this paper highlights how different aspects of the pandemic affect dietary diversity in different ways and that impact pathways are contingent upon an array of spatial and household-specific variables. Through further research, these findings can hopefully serve as a platform through which targeted policy measures can be designed to address food-specific deficiencies and the inequalities in resilience capacity that has been so widely exposed by the pandemic.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

All procedures including the use of recorded audio consent and social distancing protocols were approved by the Scientific and Ethical committees of MRC Gambia / London School of Hygiene and Tropical Medicine, the Gambia Government/MRC Joint Ethics Committee, and by the Department of Land Economy at the University of Cambridge.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

1. Gordon, D. Covid-19 and Poverty in the UK. *Bristol Poverty Institute and the Townsend Centre for International Poverty Research. University of Bristol, UK. Bristol Poverty Institute COVID-19 Webinar series: Poverty Dimensions of the COVID-19 pandemic in the UK*. (2020). Available online at: http://www.bristol.ac.uk/media-library/sites/poverty-institute/documents/Davidpercent20Gordonpercent20presentation.pdf (accessed September 3, 2021).

2. House of Lords Library Briefing. *Covid-19: Impact on People Living in Poverty*. (2020). Available online at: https://researchbriefings.files.parliament.uk/documents/LLN-2020-0093/LLN-2020-0093.pdf (accessed September 13, 2021).

3. Karas H. *The impact of COVID-19 on global extreme poverty*. Brookings Institution. The impact of COVID-19 on global extreme poverty. (2020). Available online at: brookings.edu (accessed September 11, 2021).

4. United Nations. *Impacts of COVID-19 disproportionately affect poor and vulnerable*. (2020). Available online at: https://news.un.org/en/story/2020/06/1067502 (accessed September 1, 2021).

5. Loopstra R. *Vulnerability to food insecurity since the COVID-19 lockdown Preliminary report*. King's College London (2020). Available online at: https://foodfoundation.org.uk/sites/default/files/2021-10/Report_COVID19FoodInsecurity-final.pdf (accessed March 15, 2022).

6. World Food Programme. *Risk of hunger pandemic as coronavirus set to almost double acute hunger by end of 2020*. (2020). Available online at: https://www.wfp.org/stories/risk-hunger-pandemic-coronavirus-set-almost-double-acute-hunger-end-2020 (accessed January 31, 2022).

7. Nikoloski Z, Alqunaibet, AM, Alfawaz RA, Almudarra SS, Herbst CH et al. Covid-19 and non-communicable diseases:evidence from a systematic literature review. *BMC Public Health*. (2021) 21:1068. doi: 10.1186/s12889-021-11116-w

8. World Bank Poverty and Equity global practice. *Covid-19 and inequality. How unequal was the recovery from the initial shock?* (2021). Available online at: https://openknowledge.worldbank.org/bitstream/handle/10986/35867/COVID-19-and-Inequality-How-Unequal-Was-the-Recovery-from-the-Initial-Shock.pdf?sequence=1 (accessed October 21, 2021).

9. O'Meara L, Turner C, Coitinho DC, Oenema S. Consumer experiences of food environments during the Covid-19 pandemic: Global insights from a rapid online survey of individuals from 119 countries. *Glob Food Sec*. (2022) 32:100594. doi: 10.1016/j.gfs.2021.100594

10. Aburto N. *Dietary Diversity to Address Anemia. Food and Agriculture Organization of the United Nations*. (2020). Available online at: https://www.who.int/docs/default-source/anaemia/areacop-webinar-24-september-2020/areacop-webinar-nancyaburto-presentation.pdf?sfvrsn=7abd1427_4&msclkid=21c6167aa5c411ec82b4664e89a39acd (accessed March 17, 2022).

11. Lanham-New SA, Webb AR, Cashman KD, Buttriss JL, Fallowfield JL, Masud T, et al. Vitamin D and SARS-CoV-2 virus/COVID-19 disease. *BMJ Nut Prev Health*. (2020) 3:106–10. doi: 10.1136/bmjnph-2020-000089

12. African Green Revolution Forum Summit Report. *Pathways to recovery and Resilient Food systems*. (2021). Available online at: https://agrf.org/wp-content/uploads/2021/12/AGRF-2021-Summit-Report-FINAL.pdf (accessed February 3, 2022).

13. Picchioni F, Goulao LF, Roberfroid D. The impact of COVID-19 on diet quality, food security and nutrition in low and middle income countries. a systematic review of the evidence. *Clin Nutr*. (2021) 27:S0261-5614(21)00395-2. doi: 10.1016/j.clnu.2021.08.015

14. Dou Z, Stefanovski D, Galligan D, Lindem M, Rozin P, Ting C, et al. Household food dynamics and food system resilience amid the COVID-19 pandemic. A cross-national comparison of China and the United States. *Front Sustain Food Syst*. (2021) 4:577153. doi: 10.3389/fsufs.2020.577153

15. Batis C, Irizarry L, Castellanos-Gutiérrez A, Aburto TC, Rodríguez-Ramírez S, Stern D, et al. Factors associated with dietary quality during initial and later stages of the COVID-19 pandemic in Mexico. *Front Nutr*. (2021) 8:758661. doi: 10.3389/fnut.2021.758661

16. Scarmozzino F, Visioli F. Covid-19 and the subsequent lockdown modified dietary habits of almost half the population in an Italian sample. *Foods*. (2020) 9:675. doi: 10.3390/foods9050675

17. O'Connell M, Smith K and Stroud R. The dietary impact of the COVID-19 pandemic. Institute for Fiscal Studies Working Paper 21/18 (2021). Available online at: https://ifs.org.uk/uploads/WP202118-The-dietary-impact-of-the-COVID-19-pandemic.pdf (accessed March 17, 2022).

18. World Bank. *LSMS-Supported High-Frequency Phone Surveys on COVID-19*. (2021). Available online at: https://www.worldbank.org/en/programs/lsms/brief/lsms-launches-high-frequency-phone-surveys-on-covid-19#2 (accessed February 21, 2022).

19. Teachout M, Zipfel C. *The economic impact of COVID-19 lockdowns in Sub-Saharan Africa*. International Growth Centre Policy brief. (2020). Available online at: https://www.theigc.org/wp-content/uploads/2020/05/Teachout-and-Zipfel-2020-policy-brief-.pdf (accessed February 1, 2022).

20. Egger D, Miguel E, Warren SS, Shenoy A, Collins E, Karlan D, et al. Falling living standards during the COVID-19 crisis. Quantitative evidence from nine developing countries. *Sci Adv*. (2020) 7:eabe0997. doi: 10.1126/sciadv.abe0997

21. Kundu S, Banna MHA, Sayeed A, Sultana MS, Brazendale K, Harris J, et al. Determinants of household food security and dietary diversity during the COVID-19 pandemic in Bangladesh. *Public Health Nutr*. (2021) 24:1079–87. doi: 10.1017/S1368980020005042

22. Crush J, Si Z. COVID-19 containment and food security in the Global South. *J Agri Food Syst Commun Dev*. (2020) 9:149–51. doi: 10.5304/jafscd.2020.094.026

23. Nandi R, Nedumaran S, Ravula P. The interplay between food market access and farm household dietary diversity in low and middle income countries. A systematic review of literature. *Glob Food Secur*. (2021) 28:100484. doi: 10.1016/j.gfs.2020.100484

24. Zanello G, Shankar B, Poole N. Buy or make? Agricultural production diversity, markets and dietary diversity in Afghanistan. *Food Policy*. (2019) 87:101731. doi: 10.1016/j.foodpol.2019.101731

25. Harris J, Depenbusch L, Pal AA, Nair RM, Ramasamy R. Food system disruption: initial livelihood and dietary effects of COVID-19 on vegetable producers in India. *Food Secur*. (2020) 12:841–51. doi: 10.1007/s12571-020-01064-5

26. Akuffo A, Gourlay S, Zezza A. *Agriculture as a buffer in COVID-19 crisis: Evidence from five Sub-Saharan African countries*. (2021). Available online at: https://blogs.worldbank.org/opendata/agriculture-buffer-covid-19-crisis-evidence-five-sub-saharan-african-countries (accessed February 1, 2022).

27. Madzorera S, Ismail A, Hemler EC, Korte ML, Olufemi AA, Wang D, et al. Impact of COVID-19 on nutrition, food security, and dietary diversity and quality in Burkina Faso, Ethiopia and Nigeria. *Am J Trop Med Hyg*. (2021) 105:295–309. doi: 10.4269/ajtmh.20-1617

28. Crush J, Caesar M. Introduction: cultivating the migration-food security nexus. *International Migration*. (2017) 55:10–7. doi: 10.1111/imig.12360

29. United Nations Development Programme. *Human Development Report 2020. The next frontier, Human Development and the Anthropocene*. (2020). Available online at: https://hdr.undp.org/content/human-development-report-2020 (accessed September 7, 2021).

30. Central Intelligence Agency. *World Factbook*. (2020). Available online at: https://www.cia.gov/the-world-factbook/countries/gambia-the/ (accessed November 13, 2020).

31. Global Nutrition Report. (2018). Available online at: https://globalnutritionreport.org/reports/#::text=2018%20Global%20Nutrition%20Report%20The%202018%20Global%20Nutritionlate%20to%20end%20malnutrition%20in%20all%20its%20forms (accessed November 1, 2020).

32. United Nations Development Programme. *A Report on the Short-Term Socioeconomic Effect of COVID 19 on The Gambia*. (2020). Available online at: https://gambia.un.org/index.php/en/97946-report-socioeconomic-effects-covid-19-gambia (accessed September 2, 2021).

33. World Food Programme. *Gambia Comprehensive Food Security & vulnerability analysis*. (2016). Available online at: https://documents.wfp.org/stellent/groups/public/documents/ena/wfp290335.pdf? (accessed November 29, 2020).

34. National Nutrition Agency (NaNA)-Gambia, UNICEF, Gambia Bureau of Statistics. *Gambia National Micronutrient Survey 2018*. Banjul, Gambia: National Nutrition Agency (2019).

35. Food and Agricultural Organisation of the United Nations. *Gambia at a glance*. (2019). Available online at: https://www.fao.org/gambia/gambia-at-a-glance/en/ (accessed December 12, 2021).

36. United Nations Development Programme. *Brief #2 The Tourism Sector in The Context of the Covid-19 Outbreak in The Gambia*. (2020). Available online at: https://gambia.un.org (accessed September 2, 2021).

37. United Nations Development Programme. *Brief #4 The Impact of the Covid-19 Outbreak on Employment in The Gambia*. (2020). Available online at: https://gambia.un.org (accessed September 2, 2021).

38. United Nations Development Programme. *Brief #6 The Impact of the Covid-19 Outbreak on The Transport Sector in The Gambia*. (2020). Available online at: https://gambia.un.org (accessed September 2, 2021).

39. Ministry of Health Epidemiology and Disease Control Unit. *The Gambia Covid-19 outbreak Situational report # 363*. (2021). Available online at: GMB-COVID-19-Situational-Report_2021_29th_August_No-363.pdf (gov.gm) (accessed August 31, 2021).

40. Gambia - COVID-19 Overview. *Data from: John Hopkins Coronavirus Resource Centre*. John Hopkins University and Medicine (2021). Available online at: https://www.nature.com/articles/s41562-021-01079-8 (accessed September 12, 2021).

41. Hale T, Angrist N, Goldszmidt R, Kira B, Petherick A, Phillips T, et al. A global panel database of pandemic policies (Oxford COVID-19 Government Response Tracker). *Nat Hum Behav*. (2021) 5:529–38. doi: 10.1038/s41562-021-01079-8

42. National Nutrition Agency, Gambian Ministry of Agriculture, Gambian Bureau of Statistics. *P2RS evaluation Joint Food & Nutrition Survey in The Gambia*. Banjul, The Gambia: National Nutrition Agency (2020).

43. World Bank, The Gambia Bureau of Statistics. *High Frequency Phone Survey 2020-2021 Gambia*. (2021). Available online at: https://microdata.worldbank.org/index.php/catalog/4245/related-materials (accessed February 2, 2022).

44. The Gambia Bureau of Statistics and ICF International. *Gambia Demographic & Health Survey*. Banjul, The Gambia and Rockville, MD (2013).

45. *Gambia Bureau of Statistics, Gambia Integrated Household Survey*. Banjul (2016).

46. Food and Agricultural Organisation of the United Nations and World Health Organisation. *Global Individual Food consumption data Tool (GIFT)*. (2022). Available online at: https://www.fao.org/3/cb8809en/cb8809en.pdf (accessed March 17, 2022).

47. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap) - a metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform*. (2009) 42:377–81. doi: 10.1016/j.jbi.2008.08.010

48. Coates J, Swindale A, Bilinsky P. *Household Food Insecurity Access Scale (HFIAS) for Measurement of Household Food Access: Indicator Guide (v3). Food and Nutrition Technical Assistance Project*. (2007). Corpus ID: 221158599. Available online at: https://www.fao.org/fileadmin/user_upload/eufao-fsi4dm/doc-training/hfias.pdf (accessed September 1, 2020).

49. Tadesse G, Abate GT, Zewdie T. Biases in self-reported food insecurity measurement: a list experiment approach. *Food Policy*. (2020) 92:101862. doi: 10.1016/j.foodpol.2020.101862

50. INDDEX Project. *Data4Diets: Building Blocks for Diet-related Food Security Analysis*. Boston, MA: Tufts University. (2018). Available online at: https://inddex.nutrition.tufts.edu/data4diets (accessed August 31, 2021).

51. World Food Programme. *Food Consumption Score Nutritional Quality Analysis (FCS-N)*, 1st ed. Rome. (2015).

52. Holland PW. Statistics and causal inference. *J Am Stat Assoc*. (1986) 81:945–60. doi: 10.2307/2289064

53. Hill AD, Johnson SG, Greco LM, O'Boyle EH, Walter SL. Endogeneity: a review and agenda for the methodology-practice divide affecting micro and macro research. *J Manag*. (2021) 47:105–43. doi: 10.1177/0149206320960533

54. Torres-Reyna O. *Panel Data Analysis Fixed and Random Effects Using Stata (v. 4.2). Data & Statistical Services*, Vol. 112. Wooldridge: Princeton University (2007), p. 49.

55. World Food Programme (WFP). *VAM Food security analysis*. (2022). Available online at: https://dataviz.vam.wfp.org/economic_explorer/prices?adm0=155 (accessed March 3, 2022).

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EDITED BY
Rachel Bezner Kerr,
Cornell University, United States

REVIEWED BY
Charlie Shackleton,
Rhodes University, South Africa
Sinead Boylan,
Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia
Shalander Kumar,
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India

*CORRESPONDENCE
Christine G. K. Chege
c.chege@cgiar.org

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Effects of COVID-19 on dietary behavior of urban consumers in Nairobi, Kenya

Christine G. K. Chege[1]*, Kevin Onyango[1], Joram Kabach[2] and Mark Lundy[3]

[1]Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT), Nairobi, Kenya, [2]Twiga Foods Limited, Nairobi, Kenya, [3]Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT), Regional Office for the Americas, Cali, Colombia

The disruptions wrought by the COVID-19 pandemic on food systems worldwide have endangered food and nutrition security for many consumers. The resource-poor, especially those in urban areas, are more susceptible to pandemic-related disturbances. This study uses primary data collected from 2,465 households located in and outside of informal settlements (slums) in Nairobi, Kenya to assess how COVID-19 and related public-health measures have influenced diets of urban consumers, their purchasing patterns and overall food security. Questions about food security and consumption behavior, including household dietary diversity scores, were used to capture the pre- and mid-pandemic situation. The data show that low-income households in the informal settlements were more affected than middle-income households. About 90% of slum households reported dire food insecurity situations, including being unable to eat preferred kinds of food, eating a limited variety of foods, consuming smaller portions than they felt they needed, and eating fewer meals in a day. With a score of four food groups out of nine, household in the informal settlements have lower dietary diversity than middle-income households, whose score is five out of nine. The consumption of nutritious foods, including fruits, vegetables, and animal products, fell among people living in slums during the pandemic. In addition to assessing dietary changes, this study highlights the factors associated with quality food consumption during the pandemic period such as household income levels and male-vs-female headed households. Our research demonstrates the need to attend to slums and vulnerable, poor consumers when enacting mitigation measures or designing and implementing policy.

KEYWORDS
COVID-19, urban poor consumers, consumption, diets, nutrition, Africa, Kenya

Introduction

Food and nutrition security are ongoing concerns for global public health. The FAO's State of Food Security and Nutrition in the World 2019 report showed that an estimated 821 million people were undernourished between 2016 and 2018, most in low-income countries (FAO, 2019). In addition, undernourishment, micronutrient malnutrition, and rates of obesity are increasing rapidly in

Africa, especially in urban areas, driven by dependence on markets and increases in food prices (Ruel et al., 2010). In Kenya, a large portion of the population is undernourished, with 26% of children under five stunted, 11% underweight, and 4% wasted (KNBS, 2014). Among women of reproductive age (15–49 years old), 27% are anemic. In urban informal settlements (slums), the prevalence of stunting among children under five and among women can exceed 40% (Olack et al., 2011; Kimani, 2014; Kimani-Murage et al., 2015). Inadequate nutrition harms the development and health of children and women. A recent study of the informal settlements in Nairobi indicated that 87% were food-insecure, with 46% severely insecure (Wanyama et al., 2019).

Food and nutrition insecurity is expected to rise significantly because of the COVID-19 pandemic; those who are already vulnerable, such as the urban poor, are likely to face the worst consequences (HLPE, 2020; U. N. Habitat, 2020). Governments are putting various measures in place to mitigate the spread and the effect of the COVID-19 pandemic. In Kenya, the government has been adopting several measures (Center for Policy Impact in Global Health., 2020). During the first 6 months of the pandemic, government restrictions included social distancing; a nationwide dusk-to-dawn curfew; border closures; the closure of traditional markets, learning institutions, and places of worship; and mandatory quarantine for international travelers (Quaife et al., 2020). The government also identified "hot spots" where higher numbers of infections were reported and restricted movement into and out of those regions. Nairobi, Mombasa, Kilifi, and Kwale were all identified as hotspots.

While public health measures are critical to mitigate the spread of COVID-19, they can pose a significant threat to livelihoods and food and nutrition security, especially in low- and middle-income countries (Demeke et al., 2020; International Labour Organization, 2020; UN Habitat and World Food Programme, 2020). Likewise, they disproportionately affect the urban poor, who often rely on low-wage, casual employment and depend on frequent market purchases for food (Wanyama et al., 2019; Bundervoet and Arden, 2020; Hirvonen et al., 2020). Social distancing and stay-at-home orders significantly limit the informal employment sector and the restriction or closure of traditional markets reduces food access and security (FAO, 2019; Wanyama et al., 2019; Wertheim-Heck et al., 2019; IPES Food, 2020; Wertheim-Heck, 2020). Income and food access disruptions may cause households to change their consumption behavior, for instance, addressing their immediate hunger needs with cheaper but nutritionally poor, less diversified diets. These changes curtail on-going initiatives to promote nutritious foods. The COVID-19 crisis is expected to increase demand for nutrient-poor foods while reducing demand for high-value, nutritious foods like fruits, vegetables, and animal products (Headey and Marie, 2020). Restrictions on food supply chain logistics, increased transaction costs, and speculative hording could all exacerbate this trend (Reardon et al., 2020).

Existing evidence shows that while food remained generally available in most low- and middle-income countries, COVID-19 restrictions limited consumers' access (GAIN, 2020). Urban, lower-income, and migrant populations face greater affordability and access barriers (GAIN, 2020). In Ethiopia and India, preliminary findings demonstrated declining consumption of high-value, nutritionally rich foods like fruits, vegetables, and animal products (Harvard University, 2020; Hirvonen et al., 2020; Tamru et al., 2020). Income loss, which ties directly to consumption patterns, has also been reported in 70% of households across nine countries in Africa, Asia, and Latin America (Egger et al., 2021). A study on urban consumers in Ethiopia showed that income loss was more likely to be reported by less-wealthy households than wealthier households (Hirvonen et al., 2020). Results from a nationwide telephone survey conducted in Kenya showed that about 30% of the respondents were absent from work because of temporary layoffs or reductions for technical or economic reasons (KNBS, 2020).

While these broad findings provide important insights, there is still limited understanding of the ways in which COVID-19 and the measures put in place to reduce its spread influence household diets, purchasing patterns, and overall food security in Kenya. This paper provides early evidence of these changes, with a focus on households in urban informal settlements (slums), using primary data collected in April and May of 2020. The study surveyed 2,465 households in and outside of slums in Nairobi, Kenya. The data allow us to analyze consumption and purchasing behavior for nutritious foods—especially fresh fruits and vegetables—and to assess effects of the COVID-19 in the early months of the pandemic, on food security and nutrition. These findings identify potential entry points for food and nutrition interventions targeting vulnerable households and can help policy makers to prioritize the needs of poor urban consumers.

Materials and methods

This study was conducted in urban Nairobi, focusing on households living in urban informal settlements and those living in middle income areas of Nairobi. The goal of the study was to understand how COVID-19 has affected the two consumer groups and document evidence on the early effects of the pandemic on consumption behavior and diets of low-and-middle income urban consumers in Nairobi. We conduct comparative analysis with the two groups to gain a better understanding of the similarities and differences on the effects so that targeted solutions can be formulated to address dietary challenges by policy makers and programs.

Sample selection and data collection

The study uses primary data collected between 26 April and 13 May 2020 in Nairobi, Kenya. The survey period falls within the first national COVID-19 lockdown in Kenya which began on March 25th, 2020. Within this period, the government of Kenya put in place several measures to reduce the spread of the disease, such as social distancing, nationwide dusk-to-dawn curfew, border closures, closure of traditional markets, learning institutions and places of worship, and mandatory quarantine for travelers from foreign countries, among others.

Respondents of the study were resource-poor consumers in urban informal settlements and middle-income consumers from urban areas. More than 50% of the urban population in Nairobi city lives in slums (World Bank, 2016). A multi-stage sampling strategy was used to select respondents for this study. Based on official data (KNBS, 2014) and information from the government administration, a list of residential estates and slums in Nairobi was developed and ordered by average incomes as a proxy indicator for living standard. Next, the estates were grouped according to low, middle and upper income. From the low income category, the Kibera and Mathare slums were chosen because they have the highest poverty levels in Nairobi based on national statistics (KNBS, 2014). Then, six middle-income residential estates—Nairobi West, Embakasi, Kaloleni, Waiyaki Way, Langata, and Dagoretti Corner—were randomly selected from the middle income category. Due to resource constraints, not every household in the selected estates could be interviewed. The study sought to interview 2,600 households, 1,300 from each group category. However, about 5% of the respondents refused to be interviewed so we ended with a total sample of 2,465 households: 1,298 in slums and 1,167 in non-slum sites. Within each residential estate, households were selected for interviews using a systematic sampling procedure. Starting from the center of each slum, every fifth household in all directions (north, south, east and west) was selected.

Physical interviews were conducted using Swahili language, the country's national language that is spoken by the vast majority of the population and each interview took about 1 h. The government of Kenya's ministry of health COVID-19 recommendations to reduce spread of the virus such as wearing masks and use of sanitizers were observed. The target respondent at the household level was the main decision-maker on household food consumption; in most but not all cases, this was the main female in the household.

The study tool captured household demographics and asked questions about food security; consumption behavior, including the diversity of foods like fresh fruits and vegetables eaten; and the impact of the COVID-19 pandemic on household consumption behavior. The study has a special focus on fruits and vegetable owing to their importance in improving diet quality of consumers. FAO (2020b) affirms that consumption of fresh fruits and vegetables is essential for healthy lives, better mental health, and lower obesity risks among other benefits. Data on food consumption during COVID-19 period were collected with a reference period of the past 4 weeks to capture the COVID-19 lockdown period by the government of Kenya. Household Food Insecurity Access Score (HFIAS) questions were modified, adapted and used to measure the effects of the pandemic on household food security. Due to the pandemic and recommendations by the Kenyan ministry of health to reduce human interactions to avoid the spread of COVID-19, the study questionnaire was shortened to give a quick understanding of the consumption behavior during the pandemic using selected HFIAS questions. As such, the study does not compute the HFIAS index because not all HFIAS questions were asked. Ethical clearance for this study (#2020-IRB02) was obtained from the International Center for Tropical Agriculture (CIAT) Institutional Review Board.

Dietary diversity score

Using a 7-day recall period, food consumption data were collected to generate dietary diversity scores. A seven day recall period was used instead of the 24 h recall to ensure that certain food groups that are consumed once or twice a week by poor households, such as animal products, are captured. Dietary diversity scores from 7-day recall data are likely to be systematically higher than those from 24 h recall because more of the day-to-day variation in food consumption is captured. Therefore, results from studies using 7-day recall may not be directly comparable with those using 24 h recall.

Dietary diversity scores offer a simple count of the number of food groups consumed by an individual or household within a specified recall period (Gina et al., 2010). A household dietary diversity score indicates the economic ability of a household to access a variety of foods; individual dietary diversity scores can also be collected (Gina et al., 2010). Previous analyses have shown that the correlation between household and individual dietary diversity scores is significant (Sibhatu and Qaim, 2018; Wanyama et al., 2019). Since households typically try to satisfy food energy needs before diversifying their diets, these scores are used as a food security proxy (Headey and Ecker, 2013; Vhurumuku, 2014).

The household dietary diversity score was originally developed by the Food and Nutrition Technical Assistance II project as a measure of household food access and it has been widely used since then (Swindale and Bilinksy, 2006; Headey and Ecker, 2013; Chege et al., 2015; Fongar et al., 2019). Scores can be generated using nine, 12, or 16 food groups; the higher the number of indicators, the higher the demands are for the data collection process (Gina et al., 2010; Martin-Prevel et al., 2015). Studies using only nine food groups have nevertheless been robust, as they exclude food groups with low micronutrient density: oils and fats; sweets; and spices, condiments, and beverages (Sibhatu et al., 2015). For this study, we generated scores based on nine food groups: cereals; white roots and tubers; vegetables; fruits; meat; eggs; fish and other seafood; legumes, nuts, and seeds; and milk and its products. While a higher score indicates higher dietary diversity, there is no consensus on a household dietary diversity score threshold that would mark households as food secure (Gina et al., 2010). These scores do not take into account the quantities of foods consumed, but it is easy to collect the data required to generate them and they are easy to measure.

Statistical analyses

We conducted descriptive and econometric analyses to understand the socioeconomic, demographic, and food security and dietary situation in households located in slums and non-slum areas. Descriptive analyses present the diet characteristics and consumption behavior of sampled households. We computed mean values, percentages, and *t*-tests to describe the consumption levels of different food groups; the effects of COVID-19 on the diversity, frequency, and quantity of foods consumed; and the frequency with which preferred foods were eaten. Further analyses explore the effect of COVID-19 on the consumption of nutritious foods, especially fresh fruits and vegetables by slum and non-slum consumers using the Difference-in-Difference model.

To show the influence of various factors on household diets, we estimated a simple regression model of

$$HDDS = \alpha + \beta X + \varepsilon \tag{1}$$

where HDDS is the household dietary diversity indicator based on nine food groups, α and β are estimated parameters, and ε is the random error term. X is a vector of controlled variables including the head-of-household's gender, education, and occupation; household size; consumption of fresh fruits and vegetables; and the location of the household in a slum or non-slum area.

Results

Descriptive results

Households in the slums constituted slightly more than half of the sample size, at 52% (Table 1). Overall, 62% of the study households were headed by a male. In the aggregate, household heads had an average of 12.7 years of formal education; with 14.9 years of education, non-slum heads outperformed the 10.7 years of their peers living in the slums. At the time of the survey, most household heads were working as casual laborers, salaried workers, or were self-employed. Employment varied by group: nearly 48% of household heads living in the slum areas were employed as casual workers, while 34% of those in non-slum areas were salaried, and 34% were self-employed. Although most heads of household were working, at the time of the survey 16% of those in the slums were not, compared to only just over 5% from the non-slum areas.

Households in the slum areas were larger than those in the non-slum locations. In addition, the average monthly income of a household in the slums, USD 78, was significantly lower than in the non-slum households, where the average was USD 382. The wide difference between the two income groups is expected given that the low income residents mainly obtain their incomes from casual employment, which is informal employment on a short-term basis and have lower wages (Wanyama et al., 2019). Residents in the non-slum locations have relatively higher incomes, mainly from formal employment and businesses, and are more likely to off-set their income risks from the pandemic (Kansiime et al., 2021). At four out of nine groups, the mean household dietary diversity score in the slums was significantly lower than for middle-income households, which averaged five of nine groups.

To understand how the food security situation of households has been affected by the current pandemic, we used a range of questions adopted from the Household Food Insecurity Access Scale to elicit respondents' perceptions of their food security or insecurity over a four-week recall period (Coates et al., 2007). More than 65% of all respondents reported reduced food security, with households located in the slums reporting at a much higher rate than those in non-slum locations (Table 2). In total, 90% of households in the slums were not able to eat their preferred foods during the recall period, compared to 56% in non-slum households. Moreover, 92% of households in the slums reported having to eat a limited variety of foods, compared to just 53% for households in the non-slum locations; 89% of households in the slums and 42% of non-slum households had to eat smaller quantities at meals; and 88% of households in the slums ate fewer meals, compared to 46% of non-slum households.

In terms of the types of foods consumed, consumption behavior varied depending on the location of households (Table 3). Almost all the study households consumed cereals and fresh vegetables. However, 89% of non-slum households consumed fresh fruits, compared to 52% within slum areas. Likewise, only 23% of households in slum areas consumed meat, compared to 46% of non-slum households. Patterns for eggs and dairy products replicate these trends: in middle-income areas, 57% reported eating eggs and 82% consumed dairy products, compared to 37 and 51%, respectively, in slum areas. Conversely, fish consumption was higher, at 57%, among households in the slums, compared to 43% in non-slum areas. The most consumed fish was silver fish, locally known as *omena*; it is relatively cheap and frequently consumed in low-income areas.

TABLE 1 Demographic characteristics of the study sample.

Variables	Overall ($n = 2,465$)	Slum ($n = 1,298$)	Non-slum ($n = 1,167$)
Male household head (dummy)	62.2 (48.5)	61.5 (48.7)	63.1 (48.3)
Household head education (years)	12.8 (8.1)	10.8 (9.4)	15.0 (5.5)***
Occupation of the head			
None	11.5 (31.9)	16.8 (37.4)***	5.7 (23.1)
Salaried employment	23.3 (42.3)	13.4 (34.1)	34.3 (47.5)***
Casual laborer	37.2 (48.4)	47.9 (50.0)***	25.4 (43.5)
Self-employment	28.0 (44.9)	21.8 (41.4)	34.7 (47.6)***
Household size	3.8 (2.0)	4.3 (1.9)***	3.3 (1.9)
Average Monthly income (USD)	222.4 (2,267.1)	78.8 (145.4)	382.2 (3,284.7)***
Mean household dietary diversity score during COVID-19 (out of 9 scores)	5.3 (1.7)	4.9 (1.8)	5.8 (1.6)***
Study sites			
Kibera	32.3 (46.8)	61.3 (48.7)	0 (0.0)
Mathare	20.4 (40.9)	38.67 (48.7)	0 (0.0)
Nairobi West	0.1 (2.9)	0 (0.0)	0.8 (4.1)
Embakasi	11.3 (31.7)	0 (0.0)	23.9 (42.7)
Kaloleni	12.6 (33.2)	0 (0.0)	26.6 (44.2)
Wayiaki Way	11.2 (31.6)	0 (0.0)	23.7 (42.6)
Langata	2.6 (14.5)	0 (0.0)	4.5 (20.8)
Dagoretti Corner	9.98 (30.0)	0 (0.0)	21.1 (40.8)

Means are presented with the standard deviation in parentheses; the USD–KES exchange rate used was the rate at the time of the survey of KES 107.11 = 1USD; HDDS stands for household dietary diversity score; mean differences between slum and non-slum locations were tested for statistical significance; *** $P < 0.01$.

TABLE 2 Percentage of households facing various food insecurity challenges.

Variables	Overall	Slum	Non-slum
In the past 4 weeks, household members were not able to eat the kinds of foods they preferred because of the COVID-19 pandemic	74.3 (43.7)	90.6*** (29.2)	56.1 (46.6)
In the past 4 weeks, household members had to eat a limited variety of foods due to a lack of resources occasioned by the COVID-19 pandemic	74.0 (43.9)	92.4*** (26.6)	53.6 (49.9)
In the past 4 weeks, household members had to eat a smaller meal than they felt they needed because there was not enough food due to the COVID-19 pandemic	67.4 (46.9)	89.8*** (30.2)	42.5 (49.5)
In the past 4 weeks, household members had to eat fewer meals in a day because there was not enough food due to the COVID-19 pandemic	68.7 (43.4)	89.0*** (31.3)	46.2 (49.9)
Number of observations	2,465	1,298	1,167

Means are presented with the standard deviation in parentheses; mean differences between slum and non-slum locations were tested for statistical significance; *** $P < 0.01$.

To further understand changes in diet quality, indicated by changes in fresh fruit and vegetable use in the study areas, we asked households how their behavior differed relative to the four weeks prior to the study (Table 4). Almost all the households in the slums reported reduced consumption of fruits and vegetables; at 92%, their reduction was almost double the 55% in non-slum households. Additionally, while 42% of the non-slum households reported no change in the frequency and quantity of their fruit and vegetable consumption, only 7% of households in the slum areas reported the same. The respondents who reported reduced consumption were further asked about the reasons for this change. Among middle-income households, 89% indicated that fruits and vegetables had become more expensive; 95% of households in the slums attributed the shift to reduced incomes. Very few households indicated low supply or non-availability as a reason.

TABLE 3 Consumption of various foods groups in seven days prior to interview.

Food groups	Overall	Slum	Non-slum
Cereals	97.7 (14.9)	97.6 (15.3)	97.8 (14.5)
Roots and tubers	32.0 (46.7)	32.7 (46.9)	31.3 (46.4)
Nuts and pulses	33.1 (47.1)	35.2 (47.8)*	30.7 (46.1)
Fresh vegetables	99.4 (7.2)	99.7 (5.5)	99.1 (8.8)
Fresh fruits	69.6 (46.0)	52.2 (50.0)	89.0 (31.2)***
Meats	34.4 (47.5)	23.9 (42.7)	46.2 (49.9)***
Eggs	46.7 (49.9)	37.4 (48.4)	57.1 (49.5)***
Milk and dairy products	66.3 (47.3)	51.4 (50.0)	82.9 (37.6)***
Fish (including omena)	50.99 (50.00)	57.9 (49.4)***	43.4 (49.6)
Sample size	2465	1298	1167

Means are presented with the standard deviation in parentheses; mean differences between slum and non-slum locations were tested for statistical significance; * P < 0.1, *** P < 0.01.

Econometric model results

In addition to the descriptive analysis, we conducted two econometric analysis; (1) to understand consumption of fruits and vegetables by the slums and non-slum households using Difference-in-Difference analysis (Tables 5, 6), and (2) to understand the factors that may be associated with higher or lower household dietary diversity during the COVID-19 pandemic using simple econometric regressions (Table 7).

To understand the changes in consumption of fruits and vegetables by all households, an indicator of diet quality, respondents were asked to indicate the three fresh fruits and vegetables they primarily consumed before and during the pandemic period. The results were analyzed using Difference-in-Difference approach comparing consumption of fruits and vegetables by the slum and non-slum households before and during the pandemic, Results are presented in Tables 5, 6. Table 5 shows that relative to non-slum households, there was a significant increase in the proportion of slum households that did not consume any fruits as part of their diet during the pandemic period compared to the period before. Results also show a significant decline in the proportions of slum households consuming other fruits such as mangoes, bananas, citrus fruits, watermelon, pineapple, pawpaw, guava, avocado, and apple relative to non-slum households. For example, relative to non-slum households, there was a 0.55 decline in the proportion of slum households who consumed mangoes during the COVID-19 period compared to the period before. The decline was 0.75 for ripe bananas, 0.66 for citrus fruits, 0.37 for watermelon and 0.35 for pineapples.

The story is similar for the consumption of vegetables. Overall we observe a decline in the proportion of slum households that consumed various vegetables relative to the non-slum households, before and during the pandemic (Table 6). There was a significant decline in the proportions of slum households consuming Tomatoes, Amaranthus leaves, Black night shade, Spider plant, Spinach and Carrots. On the other hand, results show a significant increase in the proportions of slum households consuming Kales and Onions during the pandemic relative to non-slum households. Kales are the most available and affordable leafy vegetables in Nairobi.

Table 7 shows results of the simple econometric regressions used to analyze factors that may be associated with higher or lower household dietary diversity during the COVID-19 pandemic. Households headed by males tended to have higher dietary diversity scores than those headed by females. The education level of the household head was only significant among the non-slum households, where increased educational levels corresponded to higher dietary diversity. Likewise, where the head was either salaried or self-employed, the household was likely to have a higher dietary diversity score; stable employment corresponds to higher diversity.

Decreased consumption of fruits and vegetables is positively associated with lower diet diversity scores in the overall model and in households in the slums. Increased food prices are also associated with reduced dietary diversity for these households. In sum, the overall model indicates that households in the slums have a lower and more precarious dietary diversity than those in the non-slum locations.

Discussion and policy recommendations

In this paper we have analyzed effects of COVID-19 on diets in slum and non-slum areas in Nairobi, Kenya. Our descriptive analysis illustrates the pandemic's effects on households in terms of socioeconomic factors, food security, and nutrition. We also assessed the factors with the greatest influence over diets during the pandemic period using household dietary diversity scores.

The initial descriptive results show that around 5% of households in non-slum areas experienced unemployment during the study period, compared to 16% in slum areas. Other studies conducted in developing countries in 2020 also found a decline in employment during the COVID-19 period compared to the period before. Egger et al. (2021) in their study conducted in 2020 found that in Kenya, there was a 37% decline in employment at the national level, and 17% for low income groups in the rural areas. Kansiime et al. (2021) through their online survey with both rural and urban respondents also reported job losses and reduction in incomes in Kenya and Uganda. Similar findings have been reported by other studies (ILO (2020);U. N. Habitat, 2020; World Bank, 2020). Unemployment and a divergence of working situations, with casual labor more common in the slums than in the non-slum areas, could explain the low monthly incomes reported. Furthermore, pandemic-related movement

TABLE 4 Changes to consumption of fresh fruits and vegetables (FFV).

Variables	Category	Overall	Slum	Non-slum
Over the past 4 weeks, how has the frequency or quantity of household fresh fruits and vegetables consumption changed?	No change	24.9 (43.2)	7.7 (26.7)	44.0*** (49.7)
	Increased	0.5 (7.0)	0.0 (0.0)	1.0*** (10.1)
	Reduced	74.7 (43.5)	92.3*** (26.7)	55.0 (49.8)
Reasons for reduced frequency or quantity of fresh fruit and vegetable consumption	FFV not available	0.4 (6.2)	0.0 (0.0)	1.1*** (10.4)
	FFV became expensive	34.1 (47.4)	4.3 (20.2)	89.7*** (30.4)
	Reduced incomes	64.8 (47.8)	95.7*** (20.2)	7.0 (25.6)
	Low supply	0.8 (8.7)	0.0 (0.0)	2.2*** (14.6)
Reasons for increased frequency or quantity of fresh fruit and vegetable consumption	More household members	91.7 (28.9)	0.0 (0.0)	91.7 (28.9)
	Own supply from rural home	8.3 (28.9)	0.0 (0.0)	8.3 (28.9)
Number of observations		2,465	1,298	1,167

Means are presented with the standard deviation in parentheses; mean differences between slum and non-slum locations were tested for statistical significance; *** $P < 0.01$.

TABLE 5 Difference-in-difference model results on household fruit consumption before and during COVID-19 in slum and non-slum areas.

Commodities	Residence * time Coef	SE	Constant	SE	Observations	Model Prob > chi2
None	0.474***	0.131	−2.214***	0.099	4,930	0.000
Mango	−0.551***	0.081	0.048***	0.037	4,930	0.000
Ripe bananas	−0.75***	0.074	0.366***	0.038	4,930	0.000
Citrus - Lemon, Orange, Tangerine	−0.664***	0.073	0.242***	0.037	4,930	0.000
Plums	−0.244	0.381	−2.384***	0.116	4,930	0.020
Watermelon	−0.366***	0.086	−0.169***	0.037	4,930	0.000
Pineapple	−0.351***	0.104	−0.825***	0.042	4,930	0.000
Pawpaw	−0.364***	0.130	−1.461***	0.055	4,930	0.000
Guava	−0.870**	0.374	−2.566***	0.141	4,930	0.000
Avocado	−0.478***	0.083	−0.732***	0.040	4,930	0.000
Wild fruits (wild berries, zambarau)	−0.160	0.281	−2.422***	0.121	4,930	0.041
Apple	−0.363**	0.153	−1.237***	0.049	4,930	0.000
Passion fruit	0.192	0.261	−2.512	0.133	4,930	0.211

** $P < 0.5$, *** $P < 0.01$; reference group is non-slum households and reference time is before COVID-19.

restrictions and curfews enacted by the government could have further endangered the economic situation of households that derive their income from casual labor. Generally low dietary diversity scores were attributed by study participants to reduced income and increased food prices.

Using self-reported information about food insecurity during the pandemic period, we found that about 90% of households in the slums were not able to eat the kinds of foods they preferred; most also reported eating a limited variety of foods, smaller meals, and fewer daily meals due to the pandemic. Food insecurity measures were considerably lower in non-slum locations, ranging between 42 and 56%. While all households in the study indicated food insecurity, households in the slums were more vulnerable, exacerbating their general levels of precarity. These findings are in line with other studies conducted with both urban and rural households in Kenya where food insecurity of 88% of the population during COVID-19 period was reported compared to 50% before COVID-19 (Kansiime et al., 2021). Previous studies conducted in the slums of Nairobi before COVID-19 showed that only 13% of the sampled households were food secure, 46% were severely food insecure, and 41% were moderately or mildly food insecure (Wanyama et al., 2019). The high rates of food insecurity may be due to reduction in incomes and food supply disruptions due to government restrictions during the lockdown period FAO, 2020a; Reardon et al., 2020). In addition, increased food prices due to disruptions in the supply chains could also lead higher food insecurity.

TABLE 6 Difference-in-difference model results on household vegetable consumption before and during COVID-19 in slum and non-slum areas.

Commodities	Residence * time Coef	SE	Constant	SE	Observations	Model Prob > chi2
Kales/Sukuma wiki	0.225***	0.073	−0.048	0.037	4,930	0.0000
Onions	0.165**	0.072	−0.035	0.037	4,930	0.0000
Cabbage	−0.055	0.077	−0.687***	0.040	4,930	0.3428
Tomato	−0.182**	0.073	0.089**	0.037	4,930	0.0000
Amaranth leaves	−0.248**	0.096	−0.701***	0.040	4,930	0.0000
Cowpea leaves	−0.146	0.090	−0.840***	0.042	4,930	0.0000
Black night shade	−0.178**	0.078	−0.313***	0.037	4,930	0.0000
Spider plant	−0.316***	0.084	−0.704***	0.040	4,930	0.0000
Egg plant	−0.222	0.183	−2.009***	0.081	4,930	0.0207
Pumpkin	−0.222	0.341	−2.348***	0.112	4,930	0.0000
Pumpkin leaves	−0.200	0.171	−1.963***	0.078	4,930	0.0000
Spinach	−0.509***	0.082	−0.696***	0.040	4,930	0.0000
Carrot	−0.616***	0.201	−1.607***	0.060	4,930	0.0000

** P < 0.5, *** P < 0.01; reference group is non-slum households and reference time is before COVID-19.

TABLE 7 Poisson regression for determinants of household dietary diversity.

Variables	Model 1 (Overall)		Model 2 (Slum)		Model 2 (Non–slum)	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
Male household head (dummy)	0.058***	0.019	0.127***	0.027	0.000	0.026
Household head education (years)	0.002	0.001	0.001	0.001	0.005**	0.002
Occupation of the head (base = none)						
Salaried employment	0.166***	0.034	0.092*	0.047	0.150**	0.058
Casual laborer	0.032	0.032	0.024	0.038	0.000	0.060
Self-employment	0.138***	0.033	0.120***	0.042	0.097*	0.058
Household size	0.001	0.005	−0.006	0.007	0.009	0.007
Decrease in consumption of fruits (dummy)	−0.055**	0.024	−0.120***	0.034	−0.021	0.033
Decrease in consumption of vegetable (dummy)	−0.042*	0.022	−0.077**	0.030	−0.012	0.033
Increase in food prices (dummy)	−0.015	0.023	−0.083**	0.039	0.008	0.028
Slum dweller (dummy)	−0.089***	0.020				
Constant	1.632***	0.042	1.687***	0.062	1.575***	0.071
LR chi2(9)	184.970		93.220		38.300	
Prob > chi2	0.000		0.000		0.000	
Log likelihood	−4,922.062		−2,574.092		−2,327.8804	
Number of observations	2,465		1,298		1,167	

* P < 0.1, ** P < 0.5, *** P < 0.01.

Analyzing the consumption of various food groups, constituting the household consumer behavior, we found that 98% of all study households consumed cereals in the 7 days prior to interview. However, 89% of non-slum households consumed fresh fruits in the same period, compared to 52% in the slums, a significant difference. Further, we found that animal products, which usually offer higher-quality nutrition but are also more expensive, were consumed more by non-slum households than households in the slums. The small share of animal products eaten by households in the slums could be attributed to high prices and low incomes. Fish was an exception, as it was more commonly consumed within the slums than outside of them, but the wide availability and low cost of omena, or sliver fish, explains this finding (Cornelsen et al., 2016).

Our findings also show that 99% of study households consumed fresh vegetables, although the specific varieties changed due to the pandemic. While kales and onions were widely eaten prior to the pandemic, their share rose considerably during the study period. Conversely, the consumption of nutritious indigenous vegetables fell significantly during the pandemic period across all study locations. Other vegetables, such as tomatoes, spinach, eggplants, cucumbers, and carrots, were also eaten significantly less frequently during COVID-19 in all study households. These trends could be attributed to the availability and costs of various kinds of vegetables.

An analysis of changes in fresh fruit and vegetable consumption patterns during the study period found that 92% of households in slums and 55% of those outside ate fresh fruits and vegetables less frequently and in smaller amounts under pandemic conditions. Most households in slum areas noted reduced incomes as the main reason for this shift, as reported in other studies (World Bank, 2020; Kansiime et al., 2021). Government measures to control COVID-19, including market closures, stay-at-home orders, and social distancing, have more drastic effects on the types of casual income-generating opportunities on which these households rely. Insufficient day labor opportunities cut incomes and purchasing power. However, 90% of the non-slum households also cited financial considerations, noting increased prices as the reason for eating fewer fresh fruits and vegetables.

In addition to changes in quantity, the variety of fruits consumed also narrowed. Households reported consuming almost all fruits less frequently during the pandemic period, with greater changes in the slum-based households compared to those in non-slum areas. The Difference-in-Difference models show a decrease in the proportion of slum households consuming fruits and vegetables during COVID-19 relative to the non-slum households. This included the nutrient-dense fruits, such as mangoes and paw paws—both rich in vitamin A. However, it is important to note that mangoes were out of season locally, which may have rendered them less available and more expensive. The decreased consumption could be attributed to increase in prices and decreased household incomes FAO (2022).

The econometric regression analysis, which assesses determinants of household dietary diversity, confirms the descriptive results. We found that in the slum model, male-headed households had higher dietary diversity than female-headed households, perhaps because men tend to have more diverse income portfolios, and if one of them is affected by a shock, others may remain unaffected (Kansiime et al., 2021). At the same time, because women do considerable work in the informal sector (and are less likely to be employed formally as wage workers), they are quite exposed to COVID-19 health controls. Furthermore, during the pandemic male heads of household could generate income from casual jobs, while female heads may be kept from such employment by the need to care for children. Government-mandated school closures meant that all children were at home during the study period; households with young children were likely to have assumed greater child-care responsibilities and increased cost of food with more mouths to feed. For the low income neighborhoods, school also provides an opportunity for students to eat healthily through the school feeding programs (Van Lancker and Parolin, 2020). Our analysis also shows that that the education level of the head of household was associated with improved diet diversity, but only in non-slum households. This result could be due to greater opportunities outside of slum areas for salaried or self-employed work that requires higher levels of education. Further, we found that decreased consumption of fruits and vegetables was associated with lower diet diversity scores for the households in the slums. While the non-slum households may have replaced fresh fruits and vegetables with other foods, it is possible that households in the slums did not, instead lessening the diversity of their diets. Increased food prices were also associated with reduced dietary diversity for the slum households, perhaps due to meager household incomes. Overall, our analysis showed that households in the slums had a lower household dietary diversity score than non-slum households. Ongoing income shocks from COVID-19 control measures mean that the dietary quality of households in slums will likely continue to be suboptimal; the implications for health and wellbeing, especially among children and women, are troubling.

Several conclusions can be drawn from our findings. First, in terms of food security, nutrition, and economic factors, the COVID-19 pandemic has affected resource-poor consumers in the urban slums more than middle-income consumers in non-slum locations. Employment opportunities in the slums tend to be in casual labor; the pandemic disrupted these jobs, and household incomes shrunk. Second, households in slum areas significantly lessened their consumption of nutritious foods—especially fruits, vegetables, and animal products—during the pandemic compared to those in the non-slum areas. These changes indicate a reduction in diet quality which increases their risk of chronic and non-communicable diseases and other nutrition related challenges. Third, increased prices for fresh fruits and vegetables are at the root of dietary pattern changes among all households in the study, with diminished incomes in the slums presenting an additional constraint.

These findings can inform policy development. First, food and nutrition security policies need to be responsive to the needs of different income segments of the population. We find that slum and non-slum households were affected differently by the COVID-19 pandemic. Differentiated policies and solutions could address the food and nutrition security challenges of poor and middle-income groups simultaneously. For example, given that higher prices during the pandemic were a limiting factor on the consumption of fresh fruits and vegetables in both middle- and low-income households, interventions aimed at reducing food prices such as production cost reducing strategies at farm level, strategies for improved post-production value chain efficiencies to ensure unconstrained supply of commodities to consumer markets, and price subsidies to cushion consumers from shocks, will help to improve their food security and nutrition. However, such interventions would not necessarily guarantee improved food security and nutrition for resource-poor households, who first need economic empowerment solutions to access nutritious foods. A generalized approach to policy formulation and implementation my not be effective.

A second insight generated by the study is the stark gender differences in experience of the impacts of the pandemic. We find that male- and female-headed households were affected differently by COVID-19. Women, who have lower formal employment opportunities and are also generally assigned more productive and reproductive roles in the household, may find it harder to achieve food and nutrition security when they head their households. This general situation was exacerbated by the pandemic and concurrent movement restrictions, which together reduced casual labor opportunities, and market and school closures that limited physical access to food and increased their workload. Further analysis of the gender impacts of COVID-19 is however required for a clear understanding of how different genders are affected by the pandemic.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by CIAT Institutional Review Board (IRB). The participants provided their written informed consent to participate in this study.

Author contributions

Conceptualization and writing—review and editing: CC, KO, ML, and JK. Methodology: CC, KO, and ML. Formal analysis and writing—original draft preparation: KO and CC. Investigation: CC and ML. Resources and funding acquisition: ML, CC, and JK. Investigation: CC. All authors have read and agreed to the published version of the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

Author JK was employed by the company Twiga Foods Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Bundervoet, T., and Arden, F. (2020). "Ethiopia Poverty Assessment: What Can It Tell Us about Likely Effects of the Coronavirus?" *Africa Can End Poverty (blog).* Available online at: https://blogs.worldbank.org/africacan/ethiopia-poverty-assessment-what-can-it-tell-us-about-likely-effects-coronavirus (accessed August 2020).

Center for Policy Impact in Global Health. (2020). "Kenya's Policy Response to COVID-19." *D Driving Health Progress during Disease, Demographic, Domestic Finance, and Donor Transitions.* Available online at: https://centerforpolicyimpact.org/wp-content/uploads/sites/18/2020/08/Kenya-Policy-Response-to-COVID.pdf (accessed August 2020).

Chege, C., Camilla, G. K., Andersson, I. M., and Matin, Q. (2015). Impacts of supermarkets on farm household nutrition in Kenya. *World Dev.* 72, 394–407. doi: 10.1016/j.worlddev.2015.03.016

Chege, C. G. K., Onyango, K., Kabach, J., and Lundy, M. (2020). *Impact of COVID-19 on Diets of Poor Consumers in Africa: Evidence from the Slums of Nairobi, Kenya.* Cali, Colombia: International Center for Tropical Agriculture (CIAT). p. 18.

Coates, J., Swindale, A., and Bilinsky, P. (2007). "Household Food Insecurity Access Scale (HFIAS) for Measurement of Food Access: Indicator Guide: Version

3." *Food and Nutrition Technical Assistance Project*. Washington, DC: Academy for Educational Development. doi: 10.1037/e576842013-001

Cornelsen, L., Pablo, A., Barbara, H., Djesika, D. A, Elaine, F., Eric, M., et al. (2016). Cross-sectional study of drivers of animal-source food consumption in low-income urban areas of Nairobi, Kenya. *BMC Nutr.* 2. doi: 10.1186/s40795-016-0109-z

Demeke, M., Kariuki, J., and Wanjiru, M. (2020). *"Assessing the Impact of COVID-19 on Food and Nutrition Security and Adequacy of Responses in Kenya."* Rome: FAO.

Egger, D., Miguel, E., Shana, S. W., Ashish, S., Elliott, C., Dean, K., et al. (2021). Falling living standards during the COVID-19 crisis: quantitative evidence from nine developing countries. *Sci. Adv*. 7, eabe0997. doi: 10.1126/sciadv.abe0997

FAO (2020a). *COVID-19 Pandemic - Impact on Food and Agriculture*. Rome, Italy: Food and Agriculture Organisation of the United Nations (FAO).

FAO (2020b). *Fruit and Vegetables – Your Dietary Essentials*. Rome: The International Year of Fruits and Vegetables, 2021. background paper.

FAO, IFAD, UNICEF, WFP, and WHO. (2019). *The State of Food Security and Nutrition in the World 2019: Safeguarding Against Economic Slowdowns and Downturns*. Rome: FAO.

Fongar, A., Theda, G., Aseta, A., and Qaim, M. (2019). How well do different dietary and nutrition assessment tools match? Insights from rural Kenya. *Public Health Nutr*. 22, 391–403. doi: 10.1017/S1368980018002756

GAIN (2020). *Impact of COVID-19 on Food Systems: A Situation Report*. Available online at: https://www.gainhealth.org/sites/default/files/publications/documents/impact-of-covid-19-on-food-systems-a-situation-report-edition-3.pdf (accessed May 13, 2020).

Gina, K., Terri, B., and Marie-Claude, D. (2010). *Guidelines for Measuring Household and Individual Dietary Diversity.* Rome: FAO.

Harvard University. (2020). *Impact of the COVID-19 Pandemic on Agriculture and Food Security in India: Baseline Survey Results*. Available online at: https://www.facebook.com/watch/live/?v=3017821198256672&ref=watch_permalink (accessed August 2020).

Headey, D., and Marie, T. R. (2020). *The COVID-19 Nutrition Crisis: What to Expect and How to Protect.* Washington, DC: International Food Policy Research Institute. doi: 10.2499/p15738coll2.133762_08

Headey, D., and Olivier, E. (2013). Rethinking the measurement of food security: from first principles to best practice. *Food Secur*. 5, 327–43. doi: 10.1007/s12571-013-0253-0

Hirvonen, K., Belay, M., Bart, M., and Seneshaw, T. (2020). *Food Marketing Margins During the COVID-19 Pandemic: Evidence from Vegetables in Ethiopia*. Washington, DC: International Food Policy Research Institute. doi: 10.2499/p15738coll2.133931

HLPE (2020). *Impacts of COVID-19 on Food Security and Nutrition: Developing Effective Policy Responses to Address the Hunger and Malnutrition Pandemic*. Rome: FAO.

ILO (2020a). *COVID-19 and the world of work: Impact and policy responses. ILO Monitor (1st Ed.).* Geneva: International Labour Organization.

ILO (2020b). *Survey on Socio Economic Impact of COVID-19 on Households Report: Wave 1*. Available online at: https://s3-eu-west-1.amazonaws.com/s3.sourceafrica.net/documents/119956/COVID-19-Survey-Key-Indicators-Report.pdf.

International Labour Organization (2020). *COVID-19 and the World of Work: Impact and Policy Responses*. Available online at: https://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/documents/briefingnote/wcms_738753.pdf (accessed August 2020).

IPES Food (2020). *COVID-19 and the Crisis in Food Systems: Symptoms, Causes, and Potential Solutions*. Available online at: http://www.ipes-food.org/pages/covid19.

Kansiime, M. K., Tambo, J. A., Mugambi, I. , Bundi, M., Kara, A., and Owuor, C. (2021). COVID-19 implications on household income and food security in Kenya and Uganda: Findings from a rapid assessment. *World Dev*. 137, 105199 doi: 10.1016/j.worlddev.2020.105199

Kimani, E. (2014). "The Nutrition Paradox in Kenya: What Are We Doing?" *Global Nutrition Report (blog).* Available online at: https://globalnutritionreport.org/blog/nutrition-paradox-kenya-what-are-we-doing/ (accessed July 18, 2014).

Kimani-Murage, Elizabeth, W., Muthuri, K. S., Oti, O. S., Mutua, K. M., van de Vijver, S., and Kyobutungi, C. (2015). Evidence of a double burden of malnutrition in urban poor settings in Nairobi, Kenya. *PLoS ONE.* 10, 6. doi: 10.1371/journal.pone.0129943

KNBS (2014). *2014 Demographic and Health Survey Key Findings.* Nairobi, Kenya. Available online at: https://www.dhsprogram.com/pubs/pdf/sr227/sr227.pdf (accessed January 2020).

KNBS (2020). *Survey on Socio-economic Impact of COVID-19 on Household Report*. Kenya National Bureau of Statistics, Nairobi, Kenya. Available online at: https://bit.ly/3gjgS0c (accessed June 2020).

Martin-Prevel, Y. P., Allemand, D., Wiesmann, M., Arimond, T., Ballard, M., Deitchler, M. C., et al. (2015). *Moving Forward on Choosing a Standard Operational Indicator of Women's Dietary Diversity.* Food and Agriculture Organization of the United Nations. Available online at: https://cgspace.cgiar.org/handle/10568/72450 (accessed January 2020).

Olack, B., Heather, B., Leonard, C., Sapna, B., Kathleen, D., Daniel, R., et al. (2011). Nutritional status of under-five children living in an informal urban settlement in Nairobi, Kenya. *J. Health Popul. Nutr.* 29, 357–363. doi: 10.3329/jhpn.v29i4.8451

Quaife, M., van Zandvoort, K., Gimma, A., Kashvi, S., McCreesh, N., Kiesha, P., et al. (2020). The Impact of COVID-19 control measures on social contacts and transmission in Kenyan informal settlements. *BMC Med.* 18, 316. doi: 10.1186/s12916-020-01779-4

Reardon, T., Marc, F. B., and Zilberman, D. (2020). *How COVID-19 May Disrupt Food Supply Chains in Developing Countries. 0 ed.* Washington, DC: International Food Policy Research Institute. doi: 10.2499/p15738coll2.133762_17

Ruel, M. T., James, L. G. Corinna, H., and Marc, J. C. (2010). The food, fuel, and financial crises affect the urban and rural poor disproportionately: a review of the evidence. *J. Nutr.* 140, 170S-6S. doi: 10.3945/jn.109.110791

Sibhatu, K. T., and Qaim, M. (2018). Review: meta-analysis of the association between production diversity, diets, and nutrition in smallholder farm households. *Food Policy.* 77, 1–18. doi: 10.1016/j.foodpol.2018.04.013

Sibhatu, K. T., Vijesh, V. K., and Qaim, M. (2015). Production diversity and dietary diversity in smallholder farm households. *Proc. Natl. Acad. Sci. U.S.A.* 112, 10657–62. doi: 10.1073/pnas.1510982112

Swindale, A., and Bilinksy, P. (2006). *Household Dietary Diversity Score (HDDS) for Measurement of Household Food Access: Indicator Guide Version 2.* Washington, DC: FHI 360/Food and Nutrition Technical Assistance Project. p. 15.

Tamru, S., Kalle, H., and Bart, M. (2020). *Impacts of the COVID-19 Crisis on Vegetable Value Chains in Ethiopia.* Washington, DC: International Food Policy Research Institute. doi: 10.2499/p15738coll2.133762_18

U. N. Habitat, and World Food Programme. (2020). *Impact of COVID-19 on Livelihoods, Food Security, and Nutrition in East Africa: Urban Focus*. Available online at:https://docs.wfp.org/api/documents/WFP-0000118161/download/?_ga=2.44879076.1580116148.1621545297-2003143752.1621545297.

Van Lancker, W., and Parolin, Z. (2020). COVID-19, school closures, and child poverty: a social crisis in the making. *Lancet Public Health.* 5, e243–e244. doi: 10.1016/S2468-2667(20)30084-0

Vhurumuku, E. (2014). "Food Security Indicators." in *Presented at the Integrating Nutrition and Food Security Programming for Emergency Response Workshop, February*. Available online at: http://www.fao.org/fileadmin/user_upload/food-security-capacity-building/docs/Nutrition/NairobiWorkshop/5.WFP_IndicatorsFSandNutIntegration.pdf (accessed January 2020).

Wanyama, R., Theda, G., and Qaim, M. (2019). Food security and dietary quality in African Slums. *Sustainability.* 11, 5999. doi: 10.3390/su11215999

Wertheim-Heck, S. (2020). "The Impact of the COVID-19 Lockdown on the Diets of Hanoi's Urban Poor," in *International Institute for Environment and Development (blog).* Available online at: https://www.iied.org/impact-covid-19-lockdown-diets-hanois-urban-poo (accessed April 8, 2020).

Wertheim-Heck, S., Jessica, E. R., and Oosterveer, P. (2019). Food safety and nutrition for low-income urbanites: exploring a social justice dilemma in consumption policy. *Env. Urbanizat.* 31, 397–420. doi: 10.1177/0956247819858019

World Bank (2016). *Republic of Kenya: Kenya Urbanization Review*. Available online at: https://documents1.worldbank.org/curated/en/639231468043512906/pdf/AUS8099-WP-P148360-PUBLIC-KE-Urbanization-ACS.pdf (accessed February 2016).

World Bank (2020). *Assessing the Economic Impact of COVID-19 and Policy Responses in Sub-Saharan Africa*. Africa's Pulse. Washington, DC: World Bank Group.

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Claire Kremen,
University of British Columbia, Canada

REVIEWED BY
Guillaume Fournié,
Royal Veterinary College (RVC),
United Kingdom
Aditya Parmar,
University of Greenwich,
United Kingdom

*CORRESPONDENCE
Lian Francesca Thomas
l.thomas@cgiar.org

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Foodborne zoonoses control in low- and middle-income countries: Identifying aspects of interventions relevant to traditional markets which act as hurdles when mitigating disease transmission

Eithne Leahy[1], Florence Mutua[1], Delia Grace[1,2], Elisabetta Lambertini[3] and Lian Francesca Thomas[1,4*]

[1]Department of Biosciences, International Livestock Research Institute, Nairobi, Kenya, [2]Natural Resource Institute, University of Greenwich, Kent, United Kingdom, [3]Global Alliance for Improved Nutrition (GAIN), Washington, DC, United States, [4]Institute of Infection Veterinary and Ecological Sciences, University of Liverpool, Liverpool, United Kingdom

Globally, foodborne zoonoses are responsible for approximately one third of all foodborne disease burden and this picture is likely to worsen if consumption of animal source foods continues to rise with insufficient attention to risk mitigation. Traditional markets represent highly important nodes that can be targeted for risk mitigation; in this series of case studies, we discuss food safety interventions relevant to this nexus. We illustrate that to improve food safety within traditional markets it is essential to consider some of the motivations and incentives of the stakeholders involved and the cultural, social, and economic context in which interventions are undertaken, highlighting barriers, enablers future interventions should aim to avoid, embrace. We also conclude that a holistic approach to foodborne zoonoses control will require the institutionalization of One Health across food systems of which traditional markets are part.

KEYWORDS

foodborne zoonoses, traditional markets, LMICs, food safety, interventions, One Health

1. Introduction

Consumption of animal source food (ASF) is rapidly increasing especially in low- and middle-income counties (LMIC), driven by population growth, urbanization, and increased income (De Balogh et al., 2013; Abebe et al., 2020). ASFs supply calories, along with multiple bioavailable nutrients, lacking in plant-based diets, such as Vitamin B12 (Watanabe, 2007), providing the nutrients required for healthy human development and growth (Adesogan et al., 2020). ASFs contain high quantities of protein and more bioavailable nutrients including vitamin A, folic acid, vitamin D3, iron, and zinc, than many plant-based foods. Simultaneous consumption of animal and plant-sourced foods can synergistically enhance overall nutritional bioavailability and improve health outcomes (Adesogan et al., 2020). Livestock value chains also have numerous other roles in livelihoods, culture, and human wellbeing (Randolph et al., 2007; Alders et al., 2021). ASFs, however, are also closely associated with foodborne disease, harboring numerous bacterial, viral, and parasitic foodborne hazards (Li et al., 2019).

The One Health concept acknowledges the interconnectedness of the health of humans, animals, and the environment, and advocates for multi-disciplinary collaboration and the engagement of multiple sectors (multi-sectoral) for the enhancement of health across these three domains. Food safety, especially the control of foodborne zoonoses (FBZ), sits at the nexus of the human and veterinary spheres and as such is an exemplar of a "One Health" challenge, in which multi-sectoral and multi-disciplinary collaboration is imperative for their control. The environment here may relate both to the health of the physical environment in which food systems operate as well as a healthy enabling institutional and governance environment in which the food system actors operate. One Health interventions implemented to date have focused more on surveillance and disease control in the animal host, with little consideration of other One Health issues. We believe, however, that a One Health lens can be applied to interventions at multiple nodes along the food-system, and acknowledging the need for multi-disciplinary collaboration is critical in ensuring this is achieved.

The majority of ASF products in LMICs are sold through traditional markets, where many vendors congregate with official recognition and governance structure, or through informal street vendors (Smit, 2016; Grwambi, 2020), with the proportion of food sold through modern formal retail (supermarkets and convenience chain stores) remaining low, even in large cities (Kang'ethe et al., 2020). This is especially the case for perishable foods such as ASF. Traditional markets are important hubs of trade and commerce; they supply the growing ASF demand to urban populations and are a source of employment for small-scale livestock owners and all those who ensure the products are delivered and sold through these markets (Roesel and Grace, 2014), including women and youth. Infrastructure in many of these markets is poor and this makes food safety issues within them a matter of concern (Grwambi, 2020). Traditional markets are often located close to where low-income earners live, especially those in urban areas, and are characterized by no or irregular provision of electricity, lack of piped water, poor drainage and sanitation, poorly built structures and floors, all of which increase the risk for food contamination and foodborne diseases (Resnick, 2017). Some of these markets operate outside in open air, either partially or entirely (King et al., 2000; Muyanja et al., 2011).

It should be kept in mind that traditional markets play a vital role in fragile food systems in LMIC (Béné, 2020), as they are important for the food security and livelihoods of many of the most vulnerable populations, and as such merit protection and support through integrated safe food approaches. Despite high foodborne disease burdens, caution against demonizing traditional markets just because they belong to an unregulated sector must be observed (Chukwuocha et al., 2009). Firstly, informal market food is often safe for consumption and foodborne hazards, which are very common in traditional markets, do not necessarily always translate into foodborne risks at the point of consumption (Roesel and Grace, 2014). Secondly, supermarket food, commonly believed to be safer than informal market food, is sometimes no better (and sometimes worse) at meeting standards than food sold in the informal sector (Grace, 2015).

In addition to the risks related to the traditional markets in which ASF are sold, the inherent nature of ASF has the potential to increase the risk to consumers from specific foodborne zoonotic hazards. Vertebrate animal species are natural reservoirs for many zoonotic pathogens, which can be transmitted through food (Abebe et al., 2020), as well as non-zoonotic pathogens resulting from contamination. The human health burden of FBZ increases as consumption of food of animal origin increases (Carrique-Mas and Bryant, 2013). The burden from just 13 zoonoses in ASF is estimated to be 168 (137–219) DALYs lost per 100,000 of the population, or ∼35% of all foodborne disease burden (Li et al., 2019) with three hazards found to be responsible for 70% of this burden: non-typhoidal *Salmonella* spp., *Taenia solium,* and *Campylobacter* spp., and Africa is the continent with the highest burden of FBZ (Li et al., 2019). As the analysis took into account only 13 FBZ and did not consider several other pathogens commonly found in or contaminating ASF such as *Listeria, Clostridium, Yersinia* spp., *Coxiella burnetti*, or Echinococcus, it under-estimates the actual burden of this important subset of food safety hazards. Country-level studies have hinted at under-estimation, as 78 and 71% of foodborne disease burden in the UK and India is attributed to ASF (Grace, 2015). It can be argued, therefore, that consumers of ASF in LMIC face a double-edged sword scenario: while they stand to gain nutritional benefits from high-quality animal-sourced protein, they also run the risk of becoming infected with foodborne zoonoses, with negative health consequences. Table 1 outlines the health burden associated with some of the main ASF zoonotic pathogens in LMIC. Consumers of non-ASF may also be at risk of the same diseases, for example, vegetables can become cross-contaminated by zoonotic pathogens when they get irrigated with contaminated water or through poor vendor storage and hygiene practices (Desiree, 2019; Schwan et al., 2021).

In higher-income countries (HIC), an effective method used to mitigate risks associated with FBZ is a "farm to fork" system of surveillance, allowing full traceability and transparency along

TABLE 1 Key foodborne zoonoses of particular relevance to LMICs in Africa and Asia.

Foodborne zoonotic pathogen	Global burden (DALYs/100,000) with 95% uncertainty interval attributable to ASF*	Animal source food and approximate % of burden attributable to ASF*	Details on transmission
Campylobacter spp.	27 (19–40)	Poultry, Beef, Pork, Small ruminant meat, Dairy (90%)	Recognized as the leading cause of bacterial foodborne diarrheal disease. Infections with *Campylobacter* spp. are commensals of many vertebrate species, but infections are most commonly associated with poultry meat. Other sources of infection is consumption of water contaminated with animal feces (Hall et al., 2004)
Non-typhoidal *salmonella enterica*	49 (30–76)	All ASFs (80%)	Fecal pathogens of animals which can cross-contaminate ASF at many points of the value chain. Cause a generally self-limiting gastroenteritis with complications in the young, old, and immunocompromised (Roesel and Grace, 2014)
Brucella spp.	2 (0.6041)	Dairy, Beef, Pork, Small ruminant meat, (95%)	Predominately transmitted to humans through unpasteurised milk or through direct contact with infected animals. Human infections lead to an undulant fever, joint pain, and weakness (Li et al., 2019)
Toxoplasma gondii	9 (6–14)	Beef, Pork, Small ruminant meat, Poultry, Dairy, eggs (70–80%)	One of the most ubiquitous zoonoses. Humans become infected through consumption of cysts from undercooked meat or through contact with food and water contaminated by the sporulated oocysts from cats, the definitive host. Toxoplasmosis is generally sub-clinical, but adverse outcomes can arise in the fetuses of pregnant women and in the old and immune-compromised (Roesel and Grace, 2014)
Taenia solium	41 (31–52)	Pork (100%)	The parasitic zoonoses *T. solium* has pigs as its intermediate host. Consumption of undercooked pork meat leads to infection with the definitive stage of the tapeworm (Taeniosis) yet subsequent fecal-oral transmission can result in an aberrant intermediate stage infection in humans, resulting in neurocysticercosis, a leading cause of epilepsy in endemic areas (Khan et al., 2017)
Mycobacterium bovis	9 (7–33)	Dairy (100%)	*M. bovis* is transmitted to humans from cattle predominately *via* unpasteurised milk. Symptoms in humans are indistinguishable from those of *M. tuberculosis.* The highest burden of zoonotic TB is assumed to be borne by Africa given the prevalence in cattle and lack of pasteurization for the majority of milk consumed (Barlow et al., 2015)
Fishborne trematodes	13 (10–15)	Finfish (100%)	Metecercaiae are harbored in the muscles of fish which are then consumed by humans and can cause chronic liver disease, pancreatitis and cholangitis in some people, These trematodes are common across South East Asia (Carrique-Mas and Bryant, 2013)
Paragonimus spp.	15 (11–21)	Shellfish (100%)	Humans acquire this zoonotic parasite through the consumption of raw/undercooked shellfish. The immature flukes migrate to the lungs where they are responsible for pulmonary signs linked to inflammation, through aberrant migrations including to the CNS can occur. The parasite is most commonly distributed across Asia where cultural practices relating to the consumption of raw shellfish propagate the life-cycle (Grace, 2015)

*Li et al. (2019).

the supply chain (Jaffee et al., 2018). Unfortunately, such systems, which would identify how and where ASFs become contaminated, have thus far proven too costly in LMIC (Thomas et al., 2020) and may not be feasible in what is largely an informal sector. At present, hygiene-improving interventions addressing infrastructure, resources, and knowledge of the multiple actors along the ASF supply chain, necessary for successful food safety (Aiyar and Pingali, 2020), are scarce. Given the significant role that traditional markets have in food security and food safety (Roesel and Grace, 2014), and the growing consumption of ASF (Grace et al., 2012b), investigating how FBZ transmission risk changes and evolves before, at, and after the informal market nexus, is increasingly becoming important, from a public health perspective.

In this review of selected case studies the traditional market is presented as the interface where a vendor and a producer of an ASF producer meet the consumer (a key moment in understanding transmission pathways for ASF-borne diseases). Approaches at local, regional, and governmental and multi-sectoral levels, sourced from literature previously identified through two bodies of work (Grace et al., 2018; Global Alliance for Improved Nutrition, 2021) and supplemented by a non-systematic literature search focusing on the infrastructure of informal markets, their vendors, consumers and their governance are reviewed. The aim is to gain a better understanding of how interventions to reduce FBZ and other foodborne pathogens, have been applied specifically at the traditional market level, and to highlight barriers or enablers to successful implementation.

2. Interventions focused on infrastructure

The working environment of ASF vendors in traditional markets is often responsible for major breaches in food safety, vendors operate within challenging occupational settings, often without electricity, clean potable water, waste disposal, and sanitation facilities (Grwambi, 2020). The lack of refrigeration provides opportunities for cross-contamination for highly perishable ASF (Muyanja et al., 2011), especially when leftover raw materials are retained for the next day‘s use without appropriate storage facilities (Alimi, 2016). Vendors use open-air, crude structures such as push carts, wooden display tables, or chop bars, to display goods, thus facilitating contamination and transmission of foodborne pathogens (Alimi, 2016). Poor market infrastructure, specifically inadequate sanitation and water supply is linked to increased foodborne disease burden. In a study in Uganda, lack of public sanitary facilities within an informal market was linked to poor personal hygiene among meat vendors (Muyanja et al., 2011), predisposing both the vendors and their food products, to foodborne pathogens. Lack of running water forced milk vendors in a Tanzanian market to wash their utensils in basins designed for hand washing, thus increasing the risk of food contamination (Kilango, 2011). In Vietnam, meat workers reportedly used unclean water to wash utensils and this increased opportunities for cross-contamination of meat products (Thi Nguyen et al., 2019).

Given this context, it is assumed that infrastructural development is a highly influential mechanism for improving food safety, yet despite substantial investment in infrastructural development, these are often the interventions least often evaluated. Lack of evaluation is partly because infrastructure investments are regarded as a development rather than a research activity and hence do not lead to scientific evaluations published in journals. Examples of such investments are: building/upgrading market infrastructure, building abattoirs, building dairy chilling plants, sewage, and waste disposal, building/upgrading laboratories, electrification, improvement of roads, and other transport. It is often assumed that such interventions can only produce benefits, an assumption that makes research evaluations less common. However, as the following case studies show, investments in modern infrastructure may result in under-utilized equipment lying dormant, or worse still, have unintended negative consequences on food safety.

In Uganda, more than 90% of milk is sold in the informal sector without treatment. A development project installed 3 dairies in Gulu district, two of which had cooling tanks, to improve milk quality. A study of the milk value chain observed that of these cooling tanks only one was used, the other was never used as the dairy staff considered it too expensive and slow, consumers generally wanted to purchase milk immediately upon delivery without waiting for the cooling process, therefore such equipment demonstrated a poor return on capital investment (Rock et al., 2016).

Abattoirs are a major point of contamination as animals are often slaughtered and skinned on the floor which is covered in feces allowing cross contamination. A study in one of the largest abattoirs in Nigeria, built in 1986 with poor maintenance history, found that 98% of meat failed to meet standards for total aerobic bacterial counts (indicators of potential presence of pathogenic organisms) (Thi Nguyen et al., 2019). A participatory, peer-to-peer, low-cost intervention that took the form of an interactive training workshop for Butchers Associations' representatives was found to reduce unsafe meat by 15% (Grace et al., 2012a). Despite this successful intervention, in 2014 the government initiated a public-private partnership to build a new modern abattoir, citing unhygienic practices. However, this abattoir was far from customers and butchers found the fees charged unacceptable. They returned to the previous abattoir which did not benefit from meat inspection. Authorities tried to remove them by force resulting in riots, nine people were shot dead in the street and a police station was burnt to the ground. Meat in the old abattoir was less safe than before the relatively successful intervention (Grace et al., 2019).

Similarly, street vendors in Zambia who were moved into new and hygienic premises were soon found to have returned to their former market location; the improved market, despite having better environmental conditions, meant less accessibility to customers and higher transaction costs for vendors (Ndhlovu, 2011). In Mozambique, as in most of Africa, women usually own, are responsible for, and slaughter chickens. However, only men are employed in the modern slaughterhouses highlighting how when food systems modernize, women are displaced from their traditional roles (Roesel and Grace, 2014), an important consideration when developing inclusive food safety interventions.

Infrastructural development is by its nature expensive and difficult to test under formal experimental conditions. The examples above, however, illustrate the need to consider unexpected and unintended consequences of infrastructural investments aiming to improve food safety. We would highly recommend investors, be they public or private sector, to first ensure that the needs and concerns of the end-users are fully considered and invest time and effort in managing the change and adoption process by ensuring stakeholders are prepared, supported, and equipped and by reducing the friction involved in adopting new ways of working (Thaler and Sunstein, 2008).

3. Interventions targeting vendors of animal source foods in traditional markets

Vendors are important players in the etiology of FBZ outbreaks (Grwambi, 2020). How vendors prepare and handle food can lead to cross-contamination and promote the transmission of foodborne zoonosis (Alimi, 2016). One study in an informal market in Vietnam, showed how *Salmonella enterica*, a bacterium from cattle and poultry, had contaminated multiple food products across the market due to the poor sanitation practices among the market vendors, unaware of the impact of their actions (Schwan et al., 2021). Understanding and improving vendor awareness regarding FBZ has been one area of focus for interventions.

Studies have demonstrated a widespread lack of knowledge in LMIC settings, among vendors of ASF, leading to the perpetuation of unsafe practices (Chukwuocha et al., 2009; Insfran-Rivarola et al., 2015; Lindahl et al., 2015). Although echinococcosis—a FBZ caused by *Echinococcus granulosus*—is endemic in some areas of Morocco, butchers and meat vendors, unaware that dogs play a role in the transmission, continue to dispose of offal where these animals have access to it (Thys et al., 2019). They strongly believe that their actions do not, in any way, contribute to the disease problem in the community. Similarly, in Pakistan, butchers are identified as being at high risk for echinococcosis, yet few knew the transmission pathway for the disease, an important predisposing factor for the infection (Khan et al., 2017). In many African countries, it is not uncommon to see meat retailers turning carcasses destined for human consumption into sitting chairs or resting platforms with little or no concern over the potential effects of their actions (contamination of the meat or themselves indirectly contracting infections from the carcasses) (Okoli et al., 2005). There is evidence that interventions that have addressed low knowledge levels have reduced foodborne disease transmission risks, training of meat vendors in Nigeria and milk vendors in India saw a significant reduction in coliform bacterium, indicators of fecal contamination (and in turn of the potential presence of pathogenic organisms), in meat and milk post-intervention (Grace et al., 2012a; Lindahl et al., 2018a) and a hygiene educational intervention showed increased hand washing among food handlers in Malaysia, in a 6 weeks post-intervention follow-up study (Nh et al., 2018).

The premise that the provision of information will lead directly to a change in attitude and, consequently, a change in behavior or practice can be successful in the short term, however, it's long-term sustainability is questionable (Insfran-Rivarola et al., 2015). In Nigeria, a follow-up study 9 years after the training intervention saw coliform bacterial load (an indicator of potential food safety risk) in meat creep back up to previously high levels again (Grace et al., 2019). In India, milk sold by producers and vendors 3 years post the training intervention was highly contaminated with *E. coli* (Lindahl et al., 2018a). It appears, therefore, that knowledge-focused interventions can create temporary improvements in food safety, but time-limited educational efforts may only partly improve long-term food safety practices of food vendors (Singh et al., 2016). This suggests the need for both repeated educational efforts over the long-term and that other aspects of vendor beliefs and behaviors within the market context must be considered when designing interventions.

Several studies illustrate how interventions to mitigate FBZ among ASF vendors must consider local beliefs and values regarding zoonotic disease transmission pathways and that knowledge alone does not translate in to practices (Zanin et al., 2017). One Kenyan study highlights how cultural and religious practices influence informal market vendors' perceptions to food safety risks, disease transmission, and ultimately their willingness to adopt biosecurity measures: some vendors, when asked, believed that disease outbreaks were a divine punishment (Nyokabi et al., 2018), a perception that can greatly impact adoption of health interventions. A study among pastoralists in Mali found they believed milk was naturally a pure and wholesome substance and so could not, by definition, contain harmful substances. This belief, alongside a fear that soap would taint the milk, led to a reluctance to wash milk containers with anything but water (Roesel and Grace, 2014). Naturally, any food safety intervention in these contexts would first have to develop a strategy to overcome such beliefs.

As well as addressing vendors' current knowledge of food safety and their underlying beliefs and values, we should also consider the context within which they work and their ability to comply adequately with food safety protocols. In Kenya, when milk vendors were asked why they failed to wear the mandatory personal protective equipment (PPE), which the Kenya government requires them to wear, they said the PPE was cumbersome, reduced their productivity, and did not generate any tangible benefits (Nyokabi et al., 2018), illustrating the need for interventions to be feasible for the actors, within the context in which they work.

Limitations to sustained adoption of hygiene practices in infrastructure-constrained settings reflect a still-developing understanding of the factors that influence these practices (Dreibelbis et al., 2013). We know that interventions used to reduce FBZ transmission risks are likely to fail if engagement with local, key actors is lacking (Grace, 2015). It is therefore imperative that we address knowledge gaps, local values, and beliefs shared by ASF vendors in specific communities, whilst also addressing vendors' capacity to undertake a desired behavior without undue burden, if interventions are to succeed.

4. Interventions targeting consumers of animal source foods in traditional markets

Consumers across traditional markets in LMIC comprise heterogenous groups with varying demographic characteristics (Ajayi and Salaudeen, 2014; Abebe et al., 2020). Despite this heterogeneity, most consumers of products from traditional markets state that they care about food safety (Grace, 2015), although specific knowledge on hazards and protective measures are often lacking as demonstrated through a 2017 review on consumer demand for food safety in LMIC (Ortega and Tschirley, 2017). A dichotomy between consumer knowledge of a risk and their capacity to mitigate that risk has been demonstrate, for example, pork consumers in South Africa, were aware that *T. solium* cysticercosis could be harmful but lacked the knowledge on how to identify *T. solium* cysts in pork, they also lacked sufficient knowledge regarding butchery certification processes including disease control, slaughter, and food preparation (Sithole et al., 2020), In Nigeria, consumers at an informal market claimed to be knowledgeable and aware of hazards and food pathogens which caused health risks, yet still engaged in risky eating habits; they did not wash their hands prior to eating consumed products made from raw milk, drank untreated water from boreholes and consumed *suya*, a beef product prepared under unhygienic conditions and linked to many foodborne disease outbreaks in Nigeria (Ajayi and Salaudeen, 2014) and a scoping review of studies conducted in Ethiopia also highlighted the lack of translation from consumer knowledge and attitudes to food-safety and their food-safety practices (Parikh et al., 2022). Attitudes and behaviors, therefore, are highly influenced by customs and beliefs, and knowledge of disease risks does not always curb local customs or eating traditions. From the examples given, it is possible to foresee how consumers may wrongly provide the impression that they know and observe basic food safety practices, masking the need for interventions. Therefore, similar to the case of vendors, interventions aimed at consumers of products from traditional markets will require a prior consideration of local beliefs and awareness about FBZ, but how these can be translated to practices to better mitigate FBZ remains a challenge (Ajayi and Salaudeen, 2014; Umar et al., 2019).

Despite sub-optimal practices, the increasing awareness of consumers of food-safety issues does present a valuable entry-point for interventions to reduce FBZ, through heightened consumer demand for safe food and through improving the food-safety practices of consumers (Riaz et al., 2016). Shifts in consumer purchasing behavior because of food safety concerns have been observed. As much as 40% of consumers reported switching to alternative meats in the wake of animal disease epidemics (Roesel and Grace, 2014), for example moving to poultry meat away from pork after a swine flu outbreak in Asia (Shao et al., 2011). Willingness to Pay (WTP) studies seek to determine the value to consumers of a particular attribute of a commodity demonstrated through their revealed or stated willingness to pay for a particular product. They have been used as a tool to gain insights into the value consumers place on safe food (Alimi and Workneh, 2016). The WTP literature in LMIC, particularly in sub-Saharan Africa is still scarce (Ortega and Tschirley, 2017) yet a growing body of work demonstrates an increasing consumer demand for safer food products, particularly in urban settings (Jabbar et al., 2010; Ifft et al., 2012; Tran et al., 2022).

Several studies demonstrating consumer demand for safe food indicate the potential benefits of a certification scheme as a signal of safety to the consumer (Owusu-Sekyere et al., 2014; Tran et al., 2022). Such an example was seen in India, where growing concern among consumers about the purity and quality of milk marketed by informal milk vendors and the possible health risks it posed, paved the way for the introduction of a successful milk certification programme (Lindahl et al., 2018b). Currently, official certification in traditional markets is scarce, and often not trusted by consumers (Roesel and Grace, 2014): the generation of trust, and an awareness of consumers' food control risk perception, are two key attributes that must be considered in successful implementation (Akinwehinmi et al., 2021; Tran et al., 2022). There is also a need for certification schemes to be based on appropriate standards, however, in many LMICs such standards for food quality and safety are either non-existent or exist defined by public health norms in developed countries, with no real relevance for traditional markets in resource-poor settings (Jabbar et al., 2010).

The ability of consumers to pay the premium which they state to place on food safety is another key barrier to the successful leverage of consumer demand to improve food safety. What a consumer may want but what they actually can access may differ. Therefore, despite their stated willingness to pay more for safer products, consumers can find themselves in a vulnerable situation where they rely heavily on the hygiene practices of vendors (Akinbode et al., 2011) and other market forces, prohibiting their access to safe products (Thi Nguyen et al., 2019), and for certain demographics, food safety is not an attribute which influences their purchasing decisions (Asiegbu et al., 2016). There is certainly a research gap on food-safety interventions focussing on leveraging consumer demand, through certification schemes or other mechanisms. These interventions must, however, be designed in line with contextually relevant standards, with concomitant trust-building so that the certification is accepted by consumers and in line with consumers' ability, as well as willingness, to pay.

Importantly such schemes will only flourish if consumers are equipped with relevant and accurate knowledge about food-safety risks.

Although low food-safety knowledge and practices have been demonstrated in LMIC consumers, targeted food-safety education interventions directed at these consumers are few. A 2016 systematic literature review identified 246 studies on consumer-focused interventions, of which just 22 were from Asia, six from Central/South America, and the Caribbean and no studies identified from the African continent (Sivaramalingam et al., 2015).

However, it is interesting to note that inadequate knowledge of food safety is not only restricted to consumers of traditional markets in LMIC. For example, a survey of 1,008 German consumers demonstrated that only 11.5% knew how to protect themselves from infection with *Campylobacter* spp., an organism that is the most reported causative agent of foodborne bacterial infection in Germany (Henke et al., 2020).

In a similar way to educational interventions directed toward vendors as discussed above, short-term efficacy of consumer-focused interventions to improve food-safety knowledge has been demonstrated, predominately through un-controlled, before-after trials (Young et al., 2015), with changes in the incidence of foodborne illness and microbial contamination being infrequently monitored. Randomized controlled trials (RCTs) of educational interventions for food safety are still relatively scarce and short follow-up periods reduce our ability to judge long-term efficacy. Even within HIC, RCTs are relatively rare with only 79 studies identified in a 2015 systematic review and meta-analysis, with heterogeneous outcomes leading to a weak evidence base (Young et al., 2015). A 6-week follow up of an RCT for mothers of young children in Nepal which used a behavioral-centered approach to its' intervention demonstrated an increase in target behaviors (Gautam et al., 2017). Longer-term studies of educational interventions are rare, though a computer-based educational tool for *T. solium* "The Vicious Worm" has been evaluated after a period of 1-year and students were found to have retained higher than baseline knowledge through this period (Hobbs et al., 2019) and a 2-year follow up of community-based training for food-safety in Vietnam also demonstrated an improvement in the majority of target behaviors through the period (Takanashi et al., 2013).

It is important that educational interventions focussed on consumers consider the relevant contextual factors including beliefs and values and the capacity of consumers to enact change, as we discussed in relation to vendors. The gap between knowledge and practice as identified in several studies (Parikh et al., 2022), should be explicitly considered and educational interventions which aim to increase knowledge without creating an enabling environment for change may find success elusive. If consumers are to be agents of change, both through their own practices and through their demand for safe products, there is a need to establish their trust in the food systems that serve them. This brings into play the question of governance and if interventions to improve governance of these markets can improve consumers' access to safer food.

5. Interventions focused on governance

5.1. Local governance

ASFs flow through informal market chains with much diversity among the many actors involved and poor official regulation and governance throughout the market chain (Roesel and Grace, 2014). While opportunities to improve food safety in traditional markets through restructuring of governance exist, their feasibility and effectiveness are not well-understood (Grace, 2015). For vendors in traditional markets, attempts to regulate through a "command and control" method does not appear to improve food safety (Johnson et al., 2015). In Ghana, one-third of meat vendors obtained meat from unlicensed sources ignoring the government certification requirements and in spite of being harassed by authorities (King et al., 2000). In high-income countries, risk-based approaches are becoming popular and are now a recognized standard for food-safety governance in many areas, where sufficient data is available to inform the probable risks to exposed populations (Grace et al., 2012a; Barlow et al., 2015). In LMIC settings, where traditional markets dominate, risk analysis is not widely used mainly because of human and financial resource constraints and the paucity of reliable data (Fahrion et al., 2014). To make risk-based approaches more commonplace in traditional markets, several challenges firstly need to be addressed; lack of pre-existing information on diverse structures and practices, difficulties of working with informal sector participants due to poor relations with local government officials, and lack of local laboratory capacity (Grace et al., 2008).

Food safety interventions in traditional markets which try to enforce specific practices rather than principles can impact negatively on food safety (Johnson et al., 2015). For example, washing hands could pose a health risk if the water is not clean and if soap is not used (Roesel and Grace, 2014). Therefore, attempts to set mandatory safety standards at traditional markets alone can be unsuccessful in mitigating foodborne zoonoses, and the banning or criminalizing of vendors of ASF, on the basis of poor food safety, can have far-reaching negative implications for health and nutrition overall (Johnson et al., 2015). A "light touch" governance approach has shown to yield better results, an example being the voluntary training schemes for milk suppliers and traders in Kenya which saw a marked improvement in milk safety (Blackmore et al., 2015). When hard-line approaches are taken, with violent crackdowns on informal market vendors, there may not only be serious consequences for food security

(Resnick, 2017), but also loss of life (Grace et al., 2019). A draconian food safety policy can make things worse (Grace, 2015). Interventions to regulate traditional markets will require public policies that are inclusive and consider everybody along the food chain if the health of vendors and consumers is to be protected (Alimi and Workneh, 2016) and in a similar way to the implementation of infrastructural investments, legislative change should consider society at large and may require careful monitoring and evaluation to identify and mitigate unintended consequences.

Across many of Africa's urban food markets, a vibrant set of market vendor associations have emerged in recent years (Resnick, 2017). Understanding the social structures between and among these vendor groups or associations can identify opportunities for interventions to mitigate FBZ. Informal food safety standards "rules in use" can differ among groups and subgroups of traders, as seen among butchers' associations in Nigeria, with better hygiene standards among female butchers compared to their male counterparts (Grace et al., 2012a). Such subgroups within the marketplace could act as champions of good food safety standards, future research should endeavor to understand the social dynamics within the marketplace and how this could leverage improved food safety standards.

5.2. National governance

Decision-makers at the policy level need to be convinced of the benefits of improving food safety in traditional markets (Fahrion et al., 2014), this will require more empirical evidence on the cost-effectiveness of food safety interventions (Hall et al., 2004). The use of standardized metrics and formal assessment of the health and economic burden of foodborne zoonoses can advocate for their relative importance and improve resource allocation (Grace, 2015). In LMIC, however, accessing data for these parameters is challenging (Thomas et al., 2020). Data forming a business case for interventions that improve food safety at the informal market level should be made available for policy decision-makers. These may take the form of cost-effectiveness data (the cost per unit of "health," often a Disability Adjusted Life Year or Quality Adjusted Life Year) or cost-benefit analysis (Thomas et al., 2020), where the cost of interventions to improve food safety, such as training meat retailers in traditional markets may be far cheaper than the health care costs linked to the diarrhea suffered by those who eat unsafe meat, as seen in a Nigerian study (Grace et al., 2012b). A surveillance system would need to be developed to capture the required data, and monitor these to assess the interventions.

While mitigating foodborne zoonoses and improving food safety should be a long-term goal of improved governance of traditional markets, a consequence of improving governance is that as standards ratchet upward, there is a risk that poor producers and value chain actors will be displaced from rapidly growing domestic markets (Resnick, 2017). This has already occurred in export markets where smaller farmers are forced to drop out, as they lack the human and financial capital needed to participate in highly demanding markets (Grace, 2015). Costly farm-to-table tracking systems effective in HIC, may not be an option within traditional markets in LMIC settings. Instead, locally orchestrated, vertically integrated systems may have merit in reducing food safety risks and in providing small-scale farmers with increased access to markets, locally, and internationally (Hall et al., 2004).

Training on developing businesses and facilitating the establishment of contracts between farmers and markets to improve food safety and gain certification may counteract growing pressure on small-scale producers, retailers, and distributors (Grwambi, 2020). Governments need to promote accreditation programs for food safety including offering training to promote traceability, record-keeping, and sharing of information along the value chain (Jaffee et al., 2018). Long-term investments in food safety can have significant positive development impacts. Countries with agri-food sectors that have a limited capacity to manage food safety might find themselves excluded from lucrative export markets or face periodic yet costly rejections of products; improving agri-food exports contributes to sustainable economic development and poverty reduction (Jaffee et al., 2018).

5.3. One health governance

Addressing challenges at the human, animal, environment interface through multi-disciplinary, collaborative approaches, requires institutions and policies which enable an integrated form of governance not traditionally observed in our highly specialized, siloed institutions. In animal, human and environment health at the national and international levels there is a predominance of vertical, programmatic-based approaches to individual challenges without acknowledgment of the complex systems in which they occur. A radical restructuring of global health governance mechanisms has been suggested to optimize the policy-development-setting-evaluation cycle through enhanced multi-sectoral learning, systems thinking, use of multi-criteria analysis frameworks, data sharing frameworks, and appropriate institutional structures for co-ordinated action (Hitziger et al., 2018). For food-safety governance, collaboration and coordination mechanisms are required between the health, veterinary, and environmental sectors including formal data-sharing agreements, mechanisms for inter-sectoral communication which escape the highly hierarchical protocols often existing within government institutions, and for intervention implementation inter-sectoral budgetary sharing agreements may be required. Such factors were recognized by health and veterinary surveillance officers in Western Kenya as being key enablers for integrated surveillance and response to zoonoses; including foodborne zoonoses (Thomas et al., 2021). Recent declarations, including from the G7 and the G20, regarding the need for a One Health approach specifically targeting pandemic prevention & preparedness, should provide a platform under which global One Health governance will be strengthened (G20 High Level Independent Panel, 2021; G7, 2021). The inter-sectoral policies and institutional structures developed within the realm of pandemic prevention and preparedness will also provide collaborative platforms relevant to all One Health challenges including food safety.

6. Improving food safety intervention design through an understanding of context and use of participatory methods

Contextual consideration is potentially missing in some interventional design, through the increased acknowledgment of the need to develop multi-disciplinary teams with a strong representation from the social sciences, will continue to enhance intervention design, implementation, and evaluation (Ngwili et al., 2021; Di Prima et al., 2022). Qualitative studies drawing on ethnographic methodologies are an important yet underutilized method when it comes to fully understand the behavioral context within which interventions are designed (Bardosh et al., 2014; Crandall et al., 2016; Nordhagen et al., 2022), and such studies can be supplemented by contextual analysis through systematic literature reviews (Nordhagen et al., 2022), structured surveys, or direct observations (Lee et al., 2022). Ethnographic methods can also be applied to understand why interventions fail to yield improvements, such as in the case of understanding community norms and beliefs on latrine use in light of a disappointing uptake of a community led total sanitation program in Zambia aiming to reduce exposure to *T. solium* (Bulaya et al., 2015; Thys et al., 2015).

To successfully draw upon the knowledge of the target community for interventional design, implementation, and evaluation various methodological frameworks are available that explicitly require stakeholder participation. One method which has proved effective in understanding social structures and in the development of a shared sense of ownership of interventions among vendors and improving the safety of ASF is Participatory Learning and Action. Participatory Learning provides a tool to navigate the complex dynamics among vendors and their supply chains in traditional markets (Nyokabi et al., 2018). In Nigeria, interactive training workshops were held for Butchers Associations' representatives, who were then responsible to pass on information and training to their groups, in addition, a gender analysis identifying tasks differentiation by gender was carried out. The findings present gender and group membership as important food safety determinants and both as promising entry points for interventions to improve food safety (Grace et al., 2012a). The Nigerian Participatory Learning intervention underpins how food safety has both gender equity and empowerment implications which warrant consideration in future interventions.

Another participatory model utilized with success for the control of FBZ has been the PRECEDE-PROCEED model (Porter, 2016), a nine-phase planning model facilitating the design of health promotion interventions in a contextually relevant way. The model requires that communities participate both in the definition of the problem and in the development and implementation of solutions. The PRECEDE-PROCEED model has been used to develop control strategies for *T. solium* in Tanzania, Nepal, and Burkina Faso which include the education of pork consumers who access their pork through traditional markets (Carabin et al., 2018). In Tanzania and Burkina Faso, the approach was implemented within the context of a Randomized Controlled Trial, and the resulting educational intervention was demonstrated to significantly reduce the consumption of infected pork by 20% in Tanzania, whilst the cumulative incidence of active human cysticercosis was demonstrated to be reducing in Burkina Faso. Utilizing participatory frameworks such as these in an attempt to create interventions that acknowledge context and provide empowerment to the stakeholders involved is an important step to achieving tangible and sustainable improvements in food safety.

7. Traditional markets and the emergence of diseases of zoonotic origin

Traditional food markets, in addition to contributing to the potential transmission of FBZ and other pathogens, may also play an important role in the emergence—as well as prevention—of FBZ emergence. The multi-factorial drivers of zoonotic spill-over is a particularly striking example of wicked problems at the human, animal, environment interface for which One Health concepts are needed. The emergence of the SARS-CoV2 virus, suspected to be from an unknown animal source in or around the vicinity of the Wuhan Seafood Market in late 2019 is just the latest, and most dramatic, example of a disease emergence event of zoonotic origin. It follows the relatively recent emergence of Severe Acute Respiratory Syndrome (SARS), Middle East Respiratory Syndrome (MERS), Nipah virus, "Swine Flu," and the Highly Pathogenic Avian Influenza (H5N1) (Thomas et al., 2020). Although not a foodborne zoonosis, COVID-19 demonstrated the challenges in preventing and controlling such pathogen spill-over and spread worldwide and the lack of preparedness to tackle the pandemic. The One Health approach has been highlighted by many as a much-needed paradigm shift to prevent such occurrences in the future (Amuasi et al., 2020), understanding the causes, as well as consequences, of such events can avoid the "ripple effect" and disruption of local food systems in LMIC, brought about when movement restrictions are implemented (Béné, 2020; Mutua et al., 2021).

Several factors can drive the emergence of new zoonotic pathogens and the re-emergence of endemic zoonoses. Epidemics like Ebola and HIV were driven by poverty and food insecurity, where an increase in demand for wild animals for consumption and related trade led to increased contact between wild animals and humans (Roe et al., 2020). Climate change can increase foodborne disease risks by causing novel vectors and pathogens to move into temperate regions, or by temperature-associated changes in contamination levels (Grace, 2015; Aiyar and Pingali, 2020). Ecosystem degradation due to rapid urbanization, intensification of animal production, modernization of food marketing systems as well as changes in food consumption habits have increased human exposure to animal pathogens (Carrique-Mas and Bryant, 2013). Intensification of bovine and dairy production in Vietnam, for instance, has increased the prevalence of bovine tuberculosis and brucellosis (Carrique-Mas and Bryant, 2013). As urban populations grow, livestock enterprises tend to expand, and whilst intensive units may be found in peri-urban locations and those rural locations relatively close to urban and conurbation areas to facilitate supply to markets, urban livestock keeping is also present in many LMIC cities increasing mixing of people, livestock, other domestic animals and wildlife, and creating a fertile ground for zoonotic disease transmission (Gilbert et al., 2020). Furthermore, the lack of food-safety standards enforcement in traditional markets, where improper management of animals, overcrowding, inadequate hygiene, and improper disposal of feces and carcasses routinely occur, can cause markets to become infectious disease hot spots (Aiyar and Pingali, 2020).Human behavior; consumer purchasing practices and preferences, as well as low perception of disease risk on behalf of vendors, has impacted on avian influence transmission rates (Kuo et al., 2011), showing how traditional markets are hotspots for zoonoses transmission in general, not just FBZ.

This consumer demand for bush meat and other "exotic" foods has also increased the risk of human exposure to animal pathogens (Roesel and Grace, 2014). In countries like China, Myanmar, Vietnam, and Thailand, the social status, prestige, and gastronomic exclusivity deriving from ye wei (literally "wild taste") is the main driver of the demand for wild meat, particularly among the wealthiest and those aspiring to be, with the consequence of increasing sale of wildlife meats in markets (Volpato et al., 2020). Interventions that address the problem by banning wet markets, wildlife trade, and wildlife farming, without driving down the demand for wild meat, may not succeed as they risk driving the illegal trade underground (Roe et al., 2020). Also, research shows that bans on wildlife markets often, and wrongly include calls for bans on "wet" markets, but the two are not the same thing, and wet markets (synonymous with "fresh" markets) can be a critical underpinning of traditional food systems (Volpato et al., 2020). Therefore, the complex interplay of social, economic, and cultural reasons behind the increasing pressure on the sale of wildlife must be taken into consideration, in efforts to address the challenge. If not, interventions that try to control or regulate these markets or practices could potentially lead to undue pressure on fragile food systems and indeed undermine human rights and harm sustainable development (Roe et al., 2020).

Another area of intervention key in mitigating foodborne disease emergence is the development of integrated surveillance systems based on a One Health approach, integrating data from the human, animal, and environment sectors (Bordier et al., 2018; Thomas et al., 2020). Research on the self-regulating systems that local communities put in place to avoid overexploitation of specific resources, as well as political ecological research on how governance systems at different levels impact ASF supply chains (Volpato et al., 2020), are other areas where interventions to mitigate FBZ emergence could be developed. Overall, taking proactive steps to incorporate One Health expertise along with food safety interventions may reduce the risks of the emergence of new diseases (Aiyar and Pingali, 2020) as it brings in perspectives that single disciplines or single sectors may ignore.

The race to investigate the pathogenesis and epidemiology of COVID-19 has seen governments and funding agencies allocate substantial resources to fund COVID-19-related research proposals with unusual swiftness (Prudêncio and Costa, 2020). Such international collaborations and funding were not always apparent; previously the emergence in China of two emerging zoonoses, severe acute respiratory syndrome (SARS) and H5N1 avian influenza virus, failed to get the attention of the international community to address the lack of surveillance systems associated with handling and consuming ASF (Shao et al., 2011). While further scientific inquiry to ascertain the zoonotic origin of COVID-19 is required, integrated wildlife, livestock, and human surveillance and response may contribute to preventing future zoonoses outbreaks (Zinsstag et al., 2020). Major challenges still exist concerning the reorientation of market incentives and food safety standards, yet in the light of COVID-19 consumers are increasingly aware of the broader effects of current food systems (Thomas et al., 2020). A possible silver lining to this pandemic may be that policymakers will work harder to reshape global food systems to support better health for all.

8. Conclusion

The sale and consumption of ASFs within traditional markets represents a potentially risky activity, yet traditional markets provide a vital source of nutrition for much of the world's population and most foods available are safe. The potential link between the emergence of COVID-19 and the Wuhan Seafood market has put traditional markets in the spotlight and interventions, both at the traditional market nexus and within the wider food system are certainly required to mitigate potential risks to communities that markets serve. This review highlights several areas in which market-based interventions may be of value, but also some key challenges in implementing these interventions.

Improving the knowledge of vendors and consumers on food safety is important, yet an understanding of the motivations and incentives behind stakeholder behavior and the physical and social determinants of food safety must be considered to drive long-term improvements. A one-size-fits-all approach for consumers and vendors will not work. Site-specific cultural, social, and economic factors make tailored intervention design a necessity. Governance of traditional markets is complex and draconian measures to regulate them have been demonstrated not to work. Interventions that focus on marketplace regulation need to take a grassroots approach that considers the actions and values of all traditional market stakeholders; such values must be considered when introducing mandatory changes.

It is unlikely that interventions that concentrate on a single subset of actors or one single stage in the value chain will have a lasting and sustainable impact. Rather, utilizing the ethos of One Health, implementing multi-disciplinary collaborations for the enhancement of human, animal, and environment health, the interventions discussed in this review under the auspices of 'vendors, consumers, and governance' should be considered as a toolkit from which to select multiple approaches that can work synergistically, to enhance food safety in traditional markets. The market-based approaches identified here should also be supported by veterinary input in the pre-market value-chain to improve the health of livestock "at source" as well as by post-market interventions focused on consumer practices within the home.

Fostering teams of clinicians, veterinarians, environmental health specialists, microbiologists, nutritionists, ethnographers, anthropologists, policy analysts, behavior change, and communication specialists to work together to solve "wicked problems" is an exemplar of One Health in action. This approach has gained increasing traction considering the recent COVID-19 pandemic. While there are logistical and economic challenges to implementing a One Health approach, it should remain an optimistic goal for those working in food systems development.

Author contributions

ELe, FM, DG, ELa, and LT made substantial contributions to conception and writing of the review. All authors read and approved the final draft of the manuscript.

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Conflict of interest

ELa was employed by Global Alliance for Improved Nutrition (GAIN).

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Abebe, E., Gugsa, G., and Ahmed, M. (2020). Review on major food-borne zoonotic bacterial pathogens. *J. Trop. Med.* 2020, 4674235. doi: 10.1155/2020/4674235

Adesogan, A. T., Havelaar, A. H., McKune, S. L., Eilittä, M., and Dahl, G. E. (2020). Animal source foods: sustainability problem or malnutrition and sustainability solution? Perspective matters. *Glob. Food Security* 25, 100325. doi: 10.1016/j.gfs.2019.100325

Aiyar, A., and Pingali, P. (2020). Pandemics and food systems-towards a proactive food safety approach to disease prevention and management. *Food Secur.* 12, 749–756. doi: 10.1007/s12571-020-01074-3

Ajayi, O. A., and Salaudeen, T. (2014). Consumer food safety awareness and knowledge in Nigeria. *Internet J. Food Saf.* 16, 17–24.

Akinbode, S., Dipeolu, A., and Okuneye, P. (2011). Willingness to pay for street food safety in Ogun State, Nigeria. *J. Agric. Food Inf.* 12, 154–166. doi: 10.1080/10496505.2011.563226

Akinwehinmi, O., Ogundari, K., and Amos, T. T. (2021). Consumers' food control risk perception and preference for food safety certification in emerging food markets. *J. Agric. Econ.* 73, 690–708. doi: 10.1111/1477-9552.12474

Alders, R. G., Campbell, A., Costa, R., Guèye, E. F., Ahasanul Hoque, M., Perezgrovas-Garza, R., et al. (2021). Livestock across the world: diverse animal species with complex roles in human societies and ecosystem services. *Anim. Front.* 11, 20–29. doi: 10.1093/af/vfab047

Alimi, B. A. (2016). Risk factors in street food practices in developing countries: a review. *Food Sci. Human Wellness* 5, 141–148. doi: 10.1016/j.fshw.2016.05.001

Alimi, B. A., and Workneh, T. S. (2016). Consumer awareness and willingness to pay for safety of street foods in developing countries: a review. *Int. J. Consum. Stud.* 40, 242–248. doi: 10.1111/ijcs.12248

Amuasi, J. H., Walzer, C., Heymann, D., Carabin, H., Haines, A., and Winkler, A. S. (2020). Calling for a COVID-19 one health research coalition. *Lancet* 395, 1543–1544. doi: 10.1016/S0140-6736(20)31028-X

Asiegbu, C. V., Lebelo, S. L., and Tabit, F. T. (2016). The food safety knowledge and microbial hazards awareness of consumers of ready-to-eat street-vended food. *Food Control* 60, 422–429. doi: 10.1016/j.foodcont.2015.08.021

Bardosh, K., Inthavong, P., Xayaheuang, S., and Okello, A. L. (2014). Controlling parasites, understanding practices: the biosocial complexity of a One Health intervention for neglected zoonotic helminths in northern Lao PDR. *Soc. Sci. Med.* 120, 215–223. doi: 10.1016/j.socscimed.2014.09.030

Barlow, S. M., Boobis, A. R., Bridges, J., Cockburn, A., Dekant, W., Hepburn, P, et al. (2015). The role of hazard-and risk-based approaches in ensuring food safety. *Trends Food Sci. Technol.* 46, 176–188. doi: 10.1016/j.tifs.2015.10.007

Béné, C. (2020). Resilience of local food systems and links to food security–a review of some important concepts in the context of COVID-19 and other shocks. *Food Secur.* 12, 805–822. doi: 10.1007/s12571-020-01076-1

Blackmore, E., Alonso, S., and Grace, D. (2015). *Legitimising Informal Markets: A Case Study of the Dairy Sector in Kenya.* (London: IIED Briefing Paper).

Bordier, M., Uea-Anuwong, T., Binot, A., Hendrikx, P., and Goutard, F. L. (2018). Characteristics of One Health surveillance systems: a systematic literature review. *Prev. Vet. Med.* 181, 104560. doi: 10.1016/j.prevetmed.2018.10.005

Bulaya, C., Mwape, K. E., Michelo, C., Sikasunge, C. S., Makungu, C., Gabriel, S., et al. (2015). Preliminary evaluation of community-led total sanitation for the control of *Taenia solium* cysticercosis in Katete District of Zambia. *Vet. Parasitol.* 207, 241–248. doi: 10.1016/j.vetpar.2014.12.030

Carabin, H., Millogo, A., Ngowi, H. A., Bauer, C., Dermauw, V., Koné, A. C., et al. (2018). Effectiveness of a community-based educational programme in reducing the cumulative incidence and prevalence of human *Taenia solium* cysticercosis in burkina faso in 2011–2014 (EFECAB): a cluster-randomised controlled trial. *Lancet Glob. Health* 6, e411–e425. doi: 10.1016/S2214-109X(18)30027-5

Carrique-Mas, J. J., and Bryant, J. (2013). A review of foodborne bacterial and parasitic zoonoses in Vietnam. *Ecohealth* 10, 465–489. doi: 10.1007/s10393-013-0884-9

Chukwuocha, U., Dozie, I., Amadi, A., Nwankwo, B., Ukaga, C., Aguwa, O., et al. (2009). The knowledge, attitude and practices of food handlers in food sanitation in a metropolis in south eastern Nigeria. *East Afr. J. Public Health* 6, 240–243.

Crandall, P. G., O'Bryan, C. A., Grinstead, D. A., Das, K., Rose, C., and Shabatura, J. J. (2016). Role of ethnographic research for assessing behavior of employees during cleaning and sanitation in food preparation areas. *Food Control* 59, 849–853. doi: 10.1016/j.foodcont.2015.07.008

De Balogh, K., Halliday, J., and Lubroth, J. (2013). Integrating the surveillance of animal health, foodborne pathogens and foodborne diseases in developing and in-transition countries. *Rev. Int. Epizoot.* 32, 539–548. doi: 10.20506/rst.32.2.2241

Desiree, K. (2019). *Characterizing Food Safety Aspects of the Cambodian Vegetable Value-Chain: A Quantitative and Qualitative Investigation of Biological Hazards and Food Safety Practices in Cambodia.* Available online at: https://krex.k-state.edu/dspace/bitstream/handle/2097/40063/KarinaDesiree2019.pdf?sequence=1&isAllowed=y

Di Prima, S., Wright, E. P., Sharma, I. K., Syurina, E., and Broerse, J. E. (2022). Implementation and scale-up of nutrition-sensitive agriculture in low-and middle-income countries: a systematic review of what works, what doesn't work and why. *Glob. Food Secur.* 32, 100595. doi: 10.1016/j.gfs.2021.100595

Dreibelbis, R., Winch, P. J., Leontsini, E., Hulland, K. R., Ram, P. K., Unicomb, L., et al. (2013). The integrated behavioural model for water, sanitation, and hygiene: a systematic review of behavioural models and a framework for designing and evaluating behaviour change interventions in infrastructure-restricted settings. *BMC Public Health* 13, 1015. doi: 10.1186/1471-2458-13-1015

Fahrion, A. S., Jamir, L., Richa, K., Begum, S., Rutsa, V., Ao, S., et al. (2014). Food-safety hazards in the pork chain in Nagaland, North East India: implications for human health. *Int. J. Environ. Res. Public Health* 11, 403–417. doi: 10.3390/ijerph110100403

G20 High Level Independent Panel (2021). *Global Deal for Our Pandemic Age*. G20 High Level Independent Panel. Available online at: https://pandemic-financing.org/report/foreword/

G7 (2021). *Carbis Bay G7 Communiqué. Our Shared Agenda for Global Action to Build Back Better 2021.* Available online at: https://www.g7uk.org/wp-content/uploads/2021/06/Carbis-Bay-G7-Summit-Communique-PDF-430KB-25-pages-1-1.pdf (accessed October 28, 2021).

Gautam, O. P., Schmidt, W.-P., Cairncross, S., Cavill, S., and Curtis, V. (2017). Trial of a novel intervention to improve multiple food hygiene behaviors in Nepal. *Am. J. Trop. Med. Hyg.* 96, 1415–1426. doi: 10.4269/ajtmh.16-0526

Gilbert, W., Thomas, L., Coyne, L., and Rushton, J. (2020). Mitigating the risks posed by intensification in livestock production: the examples of antimicrobial resistance and zoonoses. *Animal* 15, 100123. doi: 10.1016/j.animal.2020.100123

Global Alliance for Improved Nutrition (2021). *Report on Learnings from Phase I Research: From Formative Research to Intervention Design. A USAID EatSafe Project Report*. Global Alliance for Improved Nutrition.

Grace, D. (2015). Food safety in low and middle income countries. *Int. J. Environ. Res. Public Health* 12, 10490–10507. doi: 10.3390/ijerph120910490

Grace, D., Alonso, S., Mutua, F., Roesel, K., Lindahl, J. F., and Amenu, K. (2018). Food safety investment expert advice: Burkina Faso, Ethiopia, Nigeria. Available online at: https://cgspace.cgiar.org/bitstream/handle/10568/91963/Food%20safety%20investment%20Mar%202%20General.pdf?sequence=1&isAllowed=y

Grace, D., Dipeolu, M., and Alonso, S. (2019). Improving food safety in the informal sector: nine years later. *Infect. Ecol. Epidemiol.* 9, 1579613. doi: 10.1080/20008686.2019.1579613

Grace, D., Dipeolu, M., Olawoye, J., Ojo, E., Odebode, S., Agbaje, M., et al. (2012a). Evaluating a group-based intervention to improve the safety of meat in Bodija market, Ibadan, Nigeria. *Trop. Anim. Health Prod.* 44, 61–66. doi: 10.1007/s11250-012-0208-z

Grace, D., Olowoye, J., Dipeolu, M., Odebode, S., and Randolph, T. (2012b). The influence of gender and group membership on food safety: the case of meat sellers in Bodija market, Ibadan, Nigeria. *Trop. Anim. Health Prod.* 44, 53–59. doi: 10.1007/s11250-012-0207-0

Grace, D., Omore, A. O., Kang'ethe, E., Nasinyama, G. and Randolph, T. F. (2008). Risk analysis: an emerging ecohealth perspective? *A International Center for Tropical Agriculture Report*. Available online at: https://agris.fao.org/agris-search/search.do?recordID=QT2016101597

Grwambi, B. (2020). "Food safety and food security in the informal sector," in *Food Security in Africa* (London: IntechOpen).

Hall, D. C., Ehui, S., and Delgado, C. (2004). The livestock revolution, food safety, and small-scale farmers: why they matter to us all. *J. Agric. Environ. Ethics* 17, 425–444. doi: 10.1007/s10806-004-5183-6

Henke, K., Alter, T., Doherr, M., and Merle, R. (2020). Comparison of consumer knowledge about *Campylobacter*, *Salmonella* and *Toxoplasma* and their transmissibility *via* meat: results of a consumer study in Germany. *BMC Public Health* 20, 336. doi: 10.1186/s12889-020-08476-0

Hitziger, M., Esposito, R., Canali, M., Aragrande, M., Häsler, B., and Rüegg, S. R. (2018). Knowledge integration in One Health policy formulation, implementation and evaluation. *Bull. World Health Organ.* 96, 211. doi: 10.2471/BLT.17.202705

Hobbs, E. C., Mwape, K. E., Devleesschauwer, B., Van Damme, I., Krit, M., Berkvens, D., et al. (2019). Effects of "the vicious worm" educational tool on *Taenia solium* knowledge retention in Zambian primary school students after one year. *PLoS Negl. Trop. Dis.* 13, e0007336. doi: 10.1371/journal.pntd.0007336

Ifft, J., Roland-Holst, D., and Zilberman, D. (2012). Consumer valuation of safety-labeled free-range chicken: results of a field experiment in Hanoi. *Agric. Econ.* 43, 607–620. doi: 10.1111/j.1574-0862.2012.00607.x

Insfran-Rivarola, A., Waddell, L., Harding, S., Greig, J., Mascarenhas, M., Sivaramalingam, B., et al. (2015). A systematic review and meta-analysis of the effects of food safety and hygiene training on food handlers. *Foods* 9, 1169. doi: 10.3390/foods9091169

Jabbar, M. A., Baker, D., and Fadiga, M. L. (2010). *Demand for Livestock Products in Developing Countries With a Focus on Quality and Safety Attributes: Evidence From Asia and Africa, Vol. 24*. Nairobi: ILRI (aka ILCA and ILRAD).

Jaffee, S., Henson, S., Unnevehr, L., Grace, D., and Cassou, E. (2018). *The Safe Food Imperative: Accelerating Progress in Low- and Middle-Income Countries*. Washington, DC: World Bank Publications.

Johnson, N., Mayne, J. R., Grace, D., and Wyatt, A. J. (2015). *How Will Training Traders Contribute to Improved Food Safety in Informal Markets for Meat and Milk? A Theory of Change Analysis.* Available online at: https://ssrn.com/abstract=2685229

Kang'ethe, E. K., Grace, D., Alonso, S., Lindahl, J. F., Mutua, F., and Haggblade, S. (2020). *Food Safety and Public Health Implications of Growing Urban FOOD Markets*. Nairobi: AGRA.

Khan, A., da Cunha, D. T., de Rosso, V. V., Capriles, V. D., and Stedefeldt, E. (2017). Knowledge, attitudes and practices related to cystic echinococcosis endemicity in Pakistan. *Infect. Dis. Poverty* 7, 1–15. doi: 10.1186/s40249-017-0383-2

Kilango, K. (2011). *Food Safety in Milk Markets of Smallholder Farmers in Tanzania: A Case of Peri-Urban Wards in Temeke Municipality.* Morogoro: Sokoine University of Agriculture. Available online at: https://cgspace.cgiar.org/bitstream/handle/10568/12432/Kaiza-Thesis.pdf?sequence=2&isAllowed=y

King, L., Awumbila, B., Canacoo, E., and Ofosu-Amaah, S. (2000). An assessment of the safety of street foods in the Ga district, of Ghana; implications for the spread of zoonoses. *Acta Trop.* 76, 39–43. doi: 10.1016/S0001-706X(00)00087-5

Kuo, P.-C., Huang, J-, H., and Liu, M.-., D. (2011). Avian influenza risk perception and preventive behavior among traditional market workers and shoppers in Taiwan: practical implications for prevention. *PLoS ONE* 6, e24157. doi: 10.1371/journal.pone.0024157

Lee, J., Pelto, G. H., and Nordhagen, S. (2022). Beliefs, values, and sociocultural patterns related to food safety in low- and middle-income countries: a synthesis of the descriptive ethnographic literature. *Appetite* 178, 106265. doi: 10.1016/j.appet.2022.106265

Li, M., Havelaar, A. H., Hoffmann, S., Hald, T., Kirk, M. D., Torgerson, P. R., et al. (2019). Global disease burden of pathogens in animal source foods, 2010. *PLoS ONE* 14, e0216545. doi: 10.1371/journal.pone.0216545

Lindahl, E., Sattorov, N., Boqvist, S., and Magnusson, U. (2015). A study of knowledge, attitudes and practices relating to brucellosis among small-scale dairy farmers in an urban and peri-urban area of Tajikistan. *PLoS ONE* 10, e0117318. doi: 10.1371/journal.pone.0117318

Lindahl, J. F., Deka, R. P., Asse, R., Lapar, L., and Grace, D. (2018a). Hygiene knowledge, attitudes and practices among dairy value chain actors in Assam, north-east India and the impact of a training intervention. *Infect. Ecol. Epidemiol.* 8, 1555444. doi: 10.1080/20008686.2018.1555444

Lindahl, J. F., Deka, R. P., Melin, D., Berg, A., Lundén, H., Lapar, M. L., et al. (2018b). An inclusive and participatory approach to changing policies and practices for improved milk safety in Assam, northeast India. *Glob. Food Secur.* 17, 9–13. doi: 10.1016/j.gfs.2018.03.002

Mutua, F., Kang'ethe, E., and Grace, D. (2021). *The COVID-19 Pandemic and Its Implications for Food Safety in East Africa.* Nairobi: ILRI Discussion Paper.

Muyanja, C., Nayiga, L., Brenda, N., and Nasinyama, G. (2011). Practices, knowledge and risk factors of street food vendors in Uganda. *Food Control* 22, 1551–1558. doi: 10.1016/j.foodcont.2011.01.016

Ndhlovu, P. K. (2011). *Street vending in Zambia: a case of Lusaka District* (Unpublished masters dissertation). Institute of Social Studies (ISS), The Hague (The Netherlands).

Ngwili, N., Johnson, N., Wahome, R., Githigia, S., Roesel, K., and Thomas, L. (2021). A qualitative assessment of the context and enabling environment for the control of *Taenia solium* infections in endemic settings. *PLoS Negl. Trop. Dis.* 15, e0009470. doi: 10.1371/journal.pntd.0009470

Nh, N. R., Wm, W. M., Nj, N. I., Nh, N. N., and Ar, R. (2018). The effect of food safety education on handwashing practices in school canteens' food handlers. *Sains Malays.* 47, 2119–2128. doi: 10.17576/jsm-2018-4709-21

Nordhagen, S., Lee, J., Onuigbo-Chatta, N., Okoruwa, A., Monterrosa, E., Lambertini, E., et al. (2022). What is safe and how much does it matter? Food vendors' and consumers' views on food safety in Urban Nigeria. *Foods* 11, 225. doi: 10.3390/foods11020225

Nyokabi, S., Birner, R., Bett, B., Isuyi, L., Grace, D., Güttler, D., et al. (2018). Informal value chain actors' knowledge and perceptions about zoonotic diseases and biosecurity in Kenya and the importance for food safety and public health. *Trop. Anim. Health Prod.* 50, 509–518. doi: 10.1007/s11250-017-1460-z

Okoli, I., Aladi, N., Etuk, E., Opara, M., Anyanwu, G., and Okeudo, N. (2005). Current facts about the animal food products safety situation in Nigeria. *Ecol. Food Nutr.* 44, 359–373. doi: 10.1080/03670240500253385

Ortega, D. L., and Tschirley, D. L. (2017). Demand for food safety in emerging and developing countries: a research agenda for Asia and Sub-Saharan Africa. *J. Agribusiness Dev. Emerg. Econ.* 7, 21–34. doi: 10.1108/JADEE-12-2014-0045

Owusu-Sekyere, E., Owusu, V., and Jordaan, H. (2014). Consumer preferences and willingness to pay for beef food safety assurance labels in the Kumasi Metropolis and Sunyani Municipality of Ghana. *Food Control* 46, 152–159. doi: 10.1016/j.foodcont.2014.05.019

Parikh, P., Aparo, N. O., Nordhagen, S., and De Steur, H. (2022). Food safety-related perspectives and practices of consumers and vendors in Ethiopia: a scoping review. *Food Res. Int.* 2022, 111376. doi: 10.1016/j.foodres.2022.111376

Porter, C. M. (2016). Revisiting precede–proceed: a leading model for ecological and ethical health promotion. *Health Educ. J.* 75, 753–764. doi: 10.1177/0017896915619645

Prudêncio, M., and Costa, J. C. (2020). Research funding after COVID-19. *Nat. Microbiol.* 5, 986–986. doi: 10.1038/s41564-020-0768-z

Randolph, T. F., Schelling, E., Grace, D., Nicholson, C. F., Leroy, J., Cole, D., et al. (2007). Invited review: role of livestock in human nutrition and health for poverty reduction in developing countries. *J. Anim. Sci.* 85, 2788–2800. doi: 10.2527/jas.2007-0467

Resnick, D. (2017). "Governance: informal food markets in Africa's cities," in *IFPRI Book Chapters* [International Food Policy Research Institute (IFPRI)], 50–57.

Riaz, B. K., Alim, M. A., Islam, A. S., Amin, K. B., Sarker, M. A. B., Hasan, K., et al. (2016). Role of courtyard counselling meeting in improving household food safety knowledge and practices in Munshiganj district of Bangladesh. *Nagoya J. Med. Sci.* 78, 387–398. doi: 10.18999/nagjms.78.4.387

Rock, K. T., Mugizi, D. R., Ståhl, K., Magnusson, U., and Boqvist, S. (2016). The milk delivery chain and presence of *Brucella* spp. antibodies in bulk milk in Uganda. *Trop. Anim. Health Product.* 48, 985–994. doi: 10.1007/s11250-016-1052-3

Roe, D., Dickman, A., Kock, R., Milner-Gulland, E., and Rihoy, E. (2020). Beyond banning wildlife trade: COVID-19, conservation and development. *World Dev.* 136, 105121. doi: 10.1016/j.worlddev.2020.105121

Roesel, K., and Grace, D. (2014). *Food Safety and Informal Markets: Animal Products in Sub-Saharan Africa*. London: Routledge.

Schwan, C. L., Desiree, K., Bello, N. M., Bastos, L., Hok, L., Phebus, R. K., et al. (2021). Prevalence of salmonella enterica isolated from food contact and nonfood contact surfaces in cambodian informal markets. *J. Food Prot.* 84, 73–79. doi: 10.4315/JFP-20-112

Shao, D., Shi, Z., Wei, J., and Ma, Z. (2011). A brief review of foodborne zoonoses in China. *Epidemiol. Infect.* 139, 1497–1504. doi: 10.1017/S0950268811000872

Singh, A. K., Dudeja, P., Kaushal, N., and Mukherji, S. (2016). Impact of health education intervention on food safety and hygiene of street vendors: a pilot study. *Med. J. Armed Forces India* 72, 265–269. doi: 10.1016/j.mjafi.2016.02.008

Sithole, M. I., Bekker, J. L., and Mukaratirwa, S. (2020). Consumer knowledge and practices to pork safety in two *Taenia solium* cysticercosis endemic districts in Eastern Cape Province of South Africa. *BMC Infect. Dis.* 20, 107. doi: 10.1186/s12879-020-4839-9

Sivaramalingam, B., Young, I., Pham, M. T., Waddell, L., Greig, J., Mascarenhas, M., et al. (2015). Scoping review of research on the effectiveness of food-safety education interventions directed at consumers. *Foodborne Pathog. Dis.* 12, 561–570. doi: 10.1089/fpd.2014.1927

Smit, W. (2016). Urban governance and urban food systems in Africa: examining the linkages. *Cities* 58, 80–86. doi: 10.1016/j.cities.2016.05.001

Takanashi, K., Quyen, D. T., Le Hoa, N. T., Khan, N. C., Yasuoka, J., and Jimba, M. (2013). Long-term impact of community-based information, education and communication activities on food hygiene and food safety behaviors in Vietnam: a longitudinal study. *PLoS ONE* 8, e70654. doi: 10.1371/journal.pone.0070654

Thaler, R., and Sunstein, C. (2008). "Nudge: improving decisions about health, wealth and happiness," in *Amsterdam Law Forum* (London: HeinOnline).

Thi Nguyen, H., Nguyen, Q. C., Kabango, A. N., and Pham, T. D. (2019). Vietnamese consumers' willingness to pay for safe pork in Hanoi. *J. Int. Food Agribusiness Mark.* 31, 378–399. doi: 10.1080/08974438.2018.1533506

Thomas, L. F., Patterson, G., Coyne, L., and Rushton, J. (2020). Countering the double-whammy of zoonotic diseases. *Rural* 21:8–11. Available online at: https://hdl.handle.net/10568/110405

Thomas, L. F., Rushton, J., Bukachi, S. A., Falzon, L. C., Howland, O., and Fèvre, E. M. (2021). Cross-sectoral zoonotic disease surveillance in western kenya: identifying drivers and barriers within a resource constrained setting. *Front. Vet. Sci.* 8, 658454. doi: 10.3389/fvets.2021.658454

Thys, S., Mwape, K. E., Lefevre, P., Dorny, P., Marcotty, T., Phiri, A. M., et al. (2015). Why latrines are not used: communities' perceptions and practices regarding latrines in a *Taenia solium* endemic rural area in Eastern Zambia. *PLoS Negl. Trop. Dis.* 9, e0003570. doi: 10.1371/journal.pntd.0003570

Thys, S., Sahibi, H., Gabriël, S., Rahali, T., Lefèvre, P., Rhalem, A., et al. (2019). Community perception and knowledge of cystic echinococcosis in the high atlas mountains, Morocco. *BMC Public Health* 19, 118. doi: 10.1186/s12889-018-6372-y

Tran, N., Shikuku, K. M., Hoffmann, V., Lagerkvist, C. J., Pincus, L., Akintola, S. L., et al. (2022). Are consumers in developing countries willing to pay for aquaculture food safety certification? Evidence from a field experiment in Nigeria. *Aquaculture* 550, 737829. doi: 10.1016/j.aquaculture.2021.737829

Umar, A. A., Sambo, M. N., Sabitu, K., Mande, A. T., and Umar, J. (2019). Personal hygiene of street-food vendors in Sabon-Gari local government area of Kaduna State, Nigeria. *Nigerian J. Basic Clin. Sci.* 16, 114. doi: 10.4103/archms.archms_44_17

Volpato, G., Fontefrancesco, M. F., Gruppuso, P., Zocchi, D. M., and Pieroni, A. (2020). Baby pangolins on my plate: possible lessons to learn from the COVID-19 pandemic. *J. Ethnobiol. Ethnomed.* 16, 19. doi: 10.1186/s13002-020-00366-4

Watanabe, F. (2007). Vitamin B12 sources and bioavailability. *Exp. Biol. Med.* 232, 1266–1274. doi: 10.3181/0703-MR-67

Young, I., Waddell, L., Harding, S., Greig, J., Mascarenhas, M., Sivaramalingam, B., et al. (2015). A systematic review and meta-analysis of the effectiveness of food safety education interventions for consumers in developed countries. *BMC Public Health* 15, 822. doi: 10.1186/s12889-015-2171-x

Zanin, L. M., da Cunha, D. T., de Rosso, V. V., Capriles, V. D., and Stedefeldt, E. (2017). Knowledge, attitudes and practices of food handlers in food safety: an integrative review. *Food Res. Int.* 100, 53–62. doi: 10.1016/j.foodres.2017.07.042

Zinsstag, J., Utzinger, J., Probst-Hensch, N., Shan, L., and Zhou, X.-N. (2020). Towards integrated surveillance-response systems for the prevention of future pandemics. *Infect. Dis. Poverty* 9, 140. doi: 10.1186/s40249-020-00757-5