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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

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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

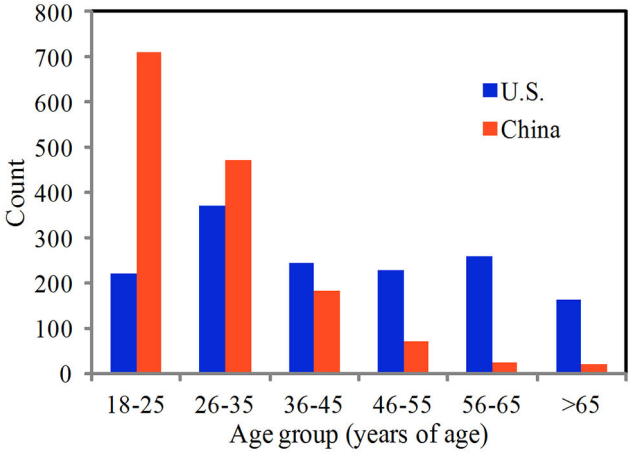

FIGURE 1 | Age group distribution of survey participants. The U.S. cohort (N = 1,547) was more or less evenly distributed whereas the Chinese cohort (N = 1,732) consisted of proportionally more people in the younger range of age.

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.

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

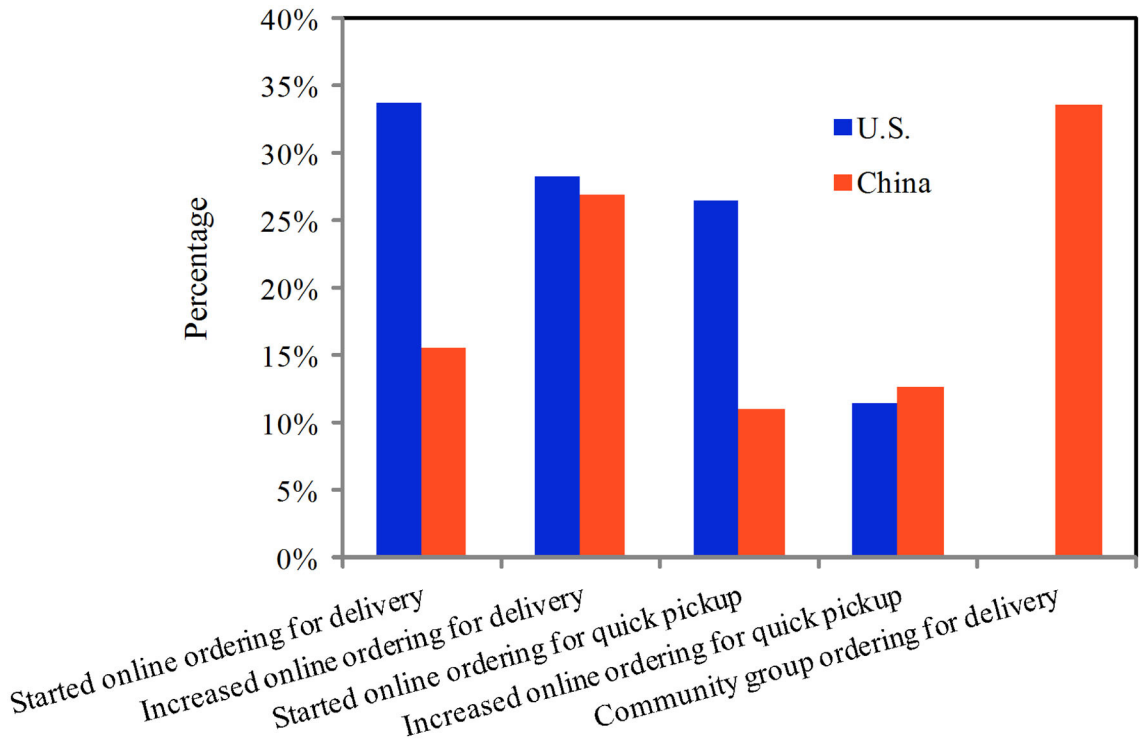

FIGURE 2 | Online grocery-shopping increased dramatically during the COVID-19 pandemic. Many reported ordering groceries online for delivery or curbside pickup for the first time. About 1/3 of the Chinese cohort reported community-based group ordering for delivery.

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	China	*p*-value for U.S. vs. China
	No. (%)	No. (%)	
"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

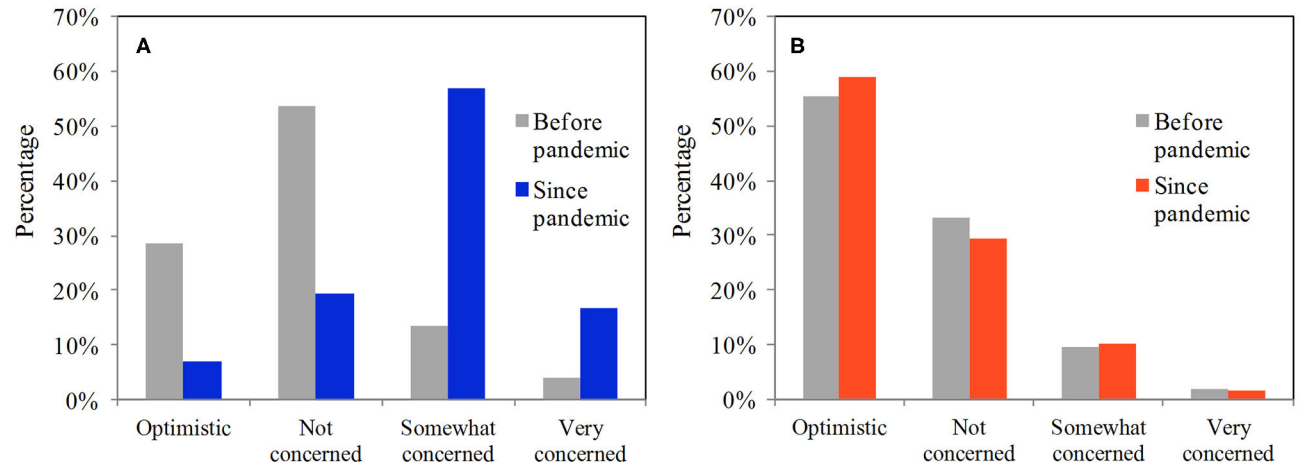

FIGURE 3 | Perception of food security during as compared to before the COVID-19 pandemic. The U.S. cohort exhibited a sharp decrease in confidence in food supply and availability in their area or the nation in general **(A)**, whereas the Chinese cohort retained their confidence **(B)**.

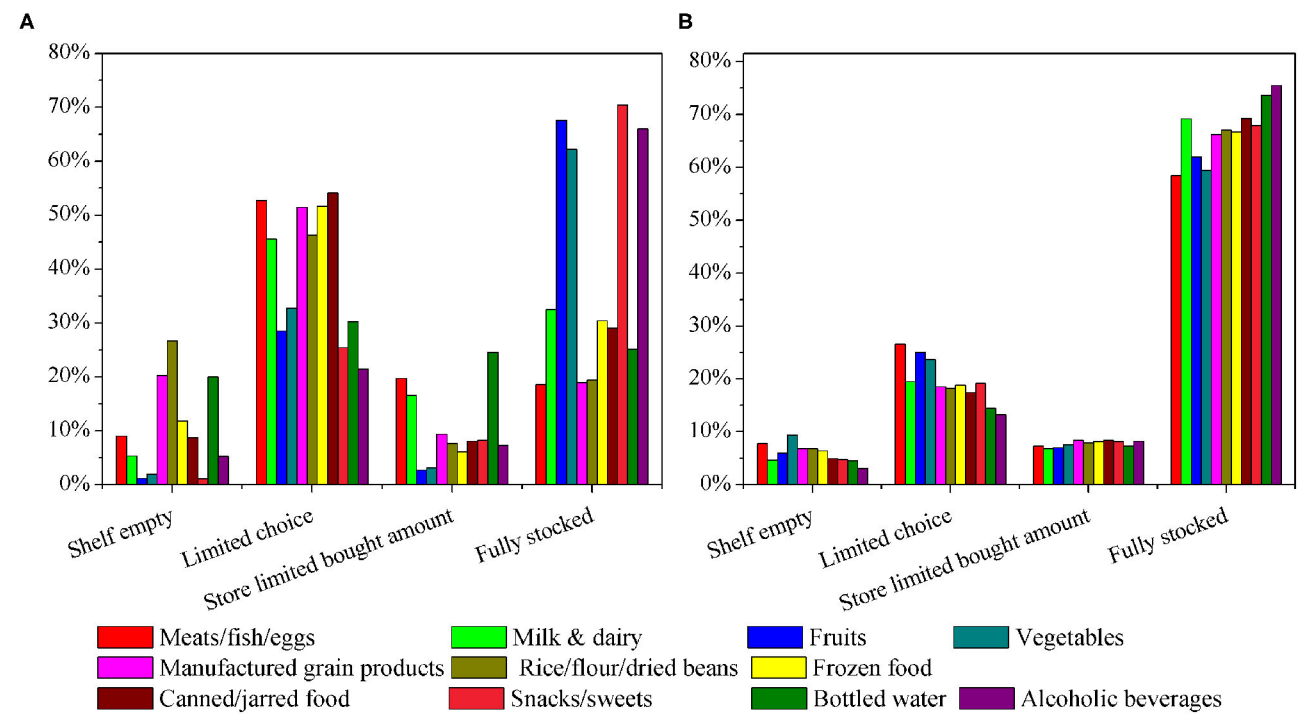

FIGURE 4 | Food availability as experienced when grocery-shopping by survey respondents from the U.S. **(A)** vs. China **(B)**. Foods were categorized into 9 groups. Two types of beverages were also included in survey questionnaire. Food availability was more variable for the U.S. than the Chinese datasets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

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,

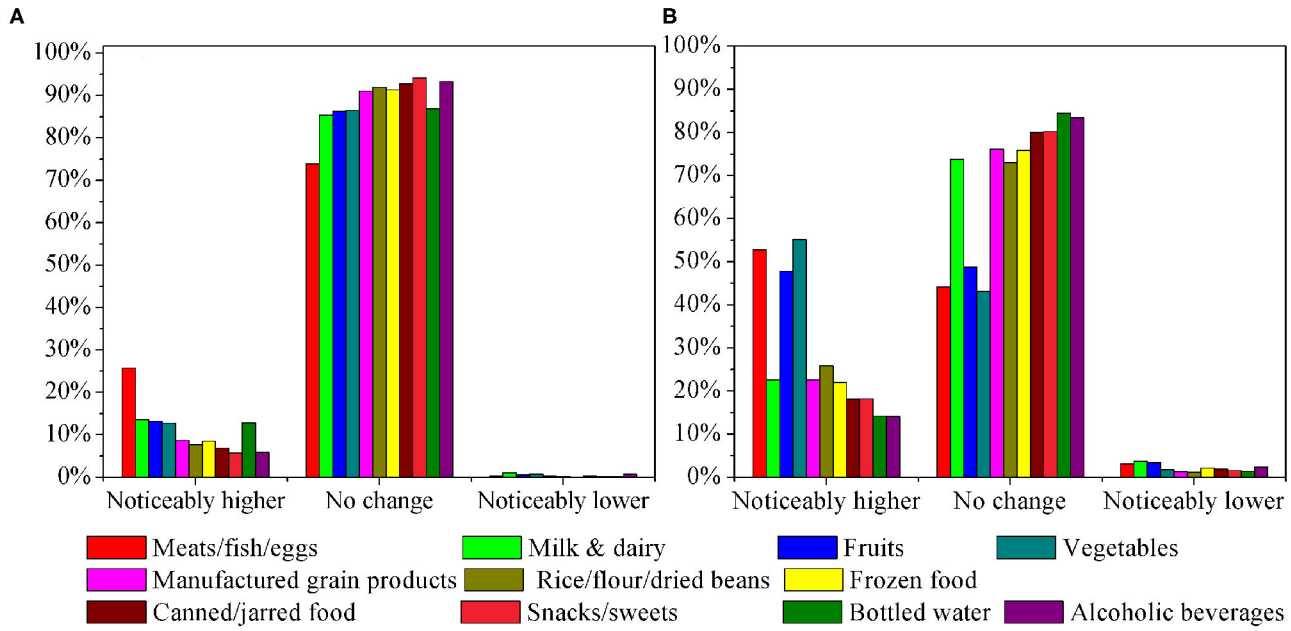

FIGURE 5 | Food price change during as compared to before the COVID-19 pandemic, according to U.S. **(A)** and Chinese **(B)** survey participants when grocery-shopping. Proportionally, noticeably higher prices were reported by more Chinese than U.S. participants ($P < 0.001$) for all food types, particularly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

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