frontiers | Frontiers in Food Science and Technology

TYPE Review
PUBLISHED 24 October 2022
DOI 10.3389/frfst.2022.1040396

OPEN ACCESS

EDITED BY
Filiz Icier,
Ege University, Turkey

REVIEWED BY
Stefan Toepfl,
German Institute of Food Technologies, Germany
Hakan Ulukan,
The University of Ankara, Turkey

*CORRESPONDENCE
Maksym Bazhal,
bazhal@yahoo.com

†These authors have contributed equally to this work and share first authorship

SPECIALTY SECTION
This article was submitted to Food Process Design and Engineering, a section of the journal Frontiers in Food Science and Technology

RECEIVED 09 September 2022
ACCEPTED 11 October 2022
PUBLISHED 24 October 2022

CITATION
Bazhal M and Koutchma T (2022), Ukraine as a food and grain hub: Impact of science and technology development on food security in the world.
Front. Food. Sci. Technol. 2:1040396.
doi: 10.3389/frfst.2022.1040396

Ukraine as a food and grain hub: Impact of science and technology development on food security in the world

Maksym Bazhal[1*†] and Tatiana Koutchma[2†]

[1]Department of Food Engineering, National University of Food Technologies, Kyiv, Ukraine, [2]Guelph Food Research and Development Center, Agriculture and Agri-Food Canada, Guelph, ON, Canada

The challenges facing the world today caused by a growing population, reduced resources, global warming, climate shocks, and social and political crises are heavily affecting agri-food systems and supply chains. A global food crisis fueled by conflicts, global warming, climate shocks, and the COVID-19 pandemic is growing because of the bad effects of the war in Ukraine which is one of the world's major breadbaskets. Science and innovation are the key accelerators to achievingthe complex rapid change in food production, distribution, and consumption required to support the global food security. This article reviews the information on grains, crops, and food production in Ukraine and discusses how the development of food education, science, and technology in Ukraine may impact food security in the world. Ukrainian food science as a part of the global scientific community offers solutions to enhance the stability of the grain and food supply while aiding to reduce food and grain loss, improve food safety, develop novel processing technologies such as pulsed electric field technology (PEF), biotechnology, and extraction methods for biomass recovery or separation technologies, increase environmental safety, energy saving, management of food production and distribution, make advancement in the production of sugar and alcohol, and improvements of food attributes. In support of this conclusion, the main research and development achievements of Ukrainian food scientists are represented.

KEYWORDS

food security, PEF, agriculture, grain, science and technology (S&T)

Introduction

According to the United States Department of Agriculture (USDA) definition, food security means ensuring that all people in the world have enough food to live a healthy and active lifestyle. Food sustainability is affected by social, economic, environmental, technological, and geopolitical conditions that may influence the food supply-chain in the long-run including agriculture, food processing, and distribution (Cole et al., 2018; Thomas et al., 2022). In 2020, the Food and Agriculture Organization of the United

Nations (FAO) that about 800 million people faced hunger (https://www.fao.org/state-of-food-security-nutrition/en/). FAO also noted that undernourishment climbed globally from 8.4% in 2019 to 9.9% in 2020. Meanwhile, according to the United Nations (UN), our planet's population is likely to increase up to more than nine billion people by 2050. Increase in food production needs by that time is estimated at 71% (Cole et al., 2018) to 100% (UN evaluation). This presents substantial challenges to achieving global food security goals (Moseley, 2022).

Conflicts and insecurity are the main drivers of food insecurity globally. A global food crisis fueled by conflicts, climate shocks, and the COVID-19 pandemic is growing because of the ripple effects of the war in Ukraine which is one of the world's major breadbaskets (Gross, 2022). Ukraine and Russia together supply about 30% of globally traded wheat (*Triticum aestivum*), 20% of maize (*Zea mays*) and 70% of sunflower (*Helianthus annuus*) supplies. A shortfall in export supplies is driving prices up, leaving import-dependent countries with higher food import bills or less food to eat (Hellegers, 2022).

In 2021, 36 out of 55 countries with food shortages depended on Ukraine and Russian exports for more than 10% of their total wheat imports, while some obtained almost the entire wheat imports from Ukraine and the Russian Federation. Director of the FAO Office of Emergencies and Resilience Mr. Rein Paulsen said: "Ukraine's farmers are feeding themselves, their communities, and millions more people around the world. Ensuring they can continue production, safely store and access alternative markets to sell their produce is vital to secure food availability, protect livelihoods, strengthen food security within Ukraine and ensure other import-dependent countries have a steady and sufficient supply of grain at a manageable cost."

To address the impacts of the war in Ukraine on the global agricultural sector, FAO has launched a new $17 million project to help Ukrainian farmers save the upcoming harvest in July and August of 2022 while ensuring the export of critical agricultural goods to international markets. The project aims to restore grain storage capacity and functionality of supply chains from harvest to export as well as maintain the productive capacity of Ukrainian farmers to enable the continuation of future productions.

Another important factor influencing the global food security is a food loss and waste (Saba and Patil, 2022). The USDA estimates that more than one-third of edible food in the United States is wasted. In developed countries, food waste mainly occurs at the retail and consumer ends of the supply chain (Spellman, 2021). Food loss and waste in agriculture are a pressing problem in developing countries, exacerbated by a lack of distribution infrastructure and problems in food storage such as refrigeration and processing (Cole et al., 2018).

One way to reduce the food waste is the continued development of preservation and stabilization post-harvest technologies (alone or in combination/synergy with other physical and chemical techniques) such as pulsed electric field (PEF) treatment (Bazhal et al., 2006; Barba et al., 2015; Zhang et al., 2020; Raso et al., 2022), high-pressure processing (Abera, 2019; Fam et al., 2021), sonication (Huang et al., 2020), drying (Mousakhani-Ganjeh et al., 2021; Hill et al., 2022), pressing, osmotic dehydration, freezing, cooking, or fermentation (Piergiovanni, 2012; Thatoi et al., 2022) which extend the shelf life of certain foods and can improve the quality of grains (Dar et al., 2022). Moreover, food processors develop new value-added extraction methods for biomass recovery or separation technologies to limit food loss (Feinbaum, 1999; Kumar et al., 2022). With the same purpose, selective recovery and extraction of inulin, starch, sugars, polysaccharides, proteins, polyphenols, flavor compounds, pigments, phytochemicals, and other high-value components present a special interest in the recycling of food wastes, sub-products, and non-food biomasses (Vorobiev and Lebovka, 2020).

Since the food security for people also depends on the nutritional status of livestock, the recycling of food waste into animal feed is also a promising way to rationalize using and reducing food waste (Noori et al., 2022; Sheppard and Rahimifard, 2019).

Actually, the challenges facing the world today are heavily affecting agri-food systems and supply chains, hence the need for complex rapid change in food production, distribution, and consumption (Rao, 2022). The Director-General of FAO, Mr. Qu Dongyu emphasized that the required transformation is critical, and science and innovation are key accelerators to achieve this change. Therefore, FAO initiates the first-ever Science and Innovation Strategy in achieving new levels of productivity, quality, storage, diversity, efficiency, and environmental sustainability.

However, science and innovation alone are not sufficient, enabling policies are also needed that respond to the needs of science results implementation for different level food producers including farmers. Moseley (2022) stated that a major rethink of the conventional food security paradigm has reigned for the past several decades and is needed. Beddington et al. (2012) highlighted that food science plays an integral role in global food security by informing concurrent, strategic investments to establish climate-resilient agricultural and food production systems, minimize greenhouse gas emissions, make efficient use of resources, develop low-waste supply chains, ensure adequate nutrition, encourage healthy eating choices and develop a global knowledge system for sustainability.

It is beyond the scope of this paper to consider all factors affecting food security. The objective of this paper is to review the information on grains, crops, and food production in Ukraine and discuss how the development of food education, science, and technology in Ukraine may impact food security in the world.

Grain and food production in Ukraine

Historically, Ukraine was an agricultural country. According to FAO estimation, Ukraine has about 4,13,000 km^2 of agricultural area of the almost 6,04,000 of total area. Currently Ukraine is one of the five largest world grain exporters, annually supplying more than 45 million tons of grain to the world market. It is also the world's largest producer and exporter of vegetable oil sunflower, rapeseed (*Brassica napus*). Most of all, in 2019 Ukraine exported corn (32 million tons for $5.2 billions, EU—47%, China—13%, Egypt—12%, and others). Sunflower oil ranks second in terms of exports ($3.8 billion). Ukraine exported wheat for $3.65 billion, which makes it the third largest commodity of Ukrainian export (most sold to Turkey, Bangladesh, and Egypt). The eighth place in terms of Ukrainian exports is occupied by rapeseed ($1.26 billion), the ninth place is for soybeans ($1.16 billion), and sunflower seed cake is in the 10th position for exports ($0.975 billion). The Ministry of Agrarian Policy and Food of Ukraine reported that the export of agricultural products and food in 2021 increased by 22% compared to 2020 and reached about $31.3 billion, which accounted for 39.8% of the total exports from Ukraine.

At the same time, imports of agricultural products and food products in 2021 increased by 20% compared to 2020 and amounted to $6.9 billion, or 10.5% of total imports of goods to Ukraine.

The development of the food industry in Ukraine started mainly in the sugar from sugar beet (Beta vulgaris) production and flour milling. Further developments covered all essential branches of the food industry including flour-grinding, alcoholic beverages, brewing, baking, confectionery, meat, poultry and dairy, fishing, fat-and-oil, wine-making, canning, salt, vegetable, tobacco products, etc. (Gulyi, 2000; Mostenska, 2014; Petrushina, 2017). Over 22,000 large, medium and small size enterprises of various forms of ownership produced almost 20% of the total industrial output. Also, in Ukraine there are about 20 food enterprises with foreign capital: Cargill, Bunge (Suntrade), Glencore Agriculture, Nibulon, Delta Wilmar, Pfeifer andLangen, PepsiCo, Coca-Cola, Danone, Nestle, Mondelez (Craft Foods), Carlsberg, SUN InBev, Mareven Food Europe, Imperial Tobacco, JTI, B.A.T., Philip Morris and others.

The largest part of the food is beverages including meat and dairy products, tobacco products, bread and bakery products (such as bread, rolls, crackers, pies, donuts), oils and animal fats. In the total volume of food products sold in 2008, the products of the oil and fat industry accounted for almost 14%, dairy products and ice cream—13.6%, products of the meat processing industry—13.2%, bakery—5.5% (Sabluk, 2008).

In the frame of preparation for Ukraine's accession to the European Union, Ukraine developed and adopted some basic international laws that affected not only businesses, but also ordinary buyers. All food manufacturers have implemented a system of risk analysis, Hazards Analysis and Control of Critical Points (HACCP) aimed at improving food safety in the enterprises.

Brief history of food science education

Food science and research in Ukraine have traditionally contributed to the development of the food industry and vice versa. In the 19th and early 20th centuries, there was no special education in food science, nutrition, processing, and engineering (Mostenska, 2014). Engineers and scientists that graduated from other universities (physicists, chemists) worked in the food industry. However, the growing sugar production determined a need for technical expertise that forced the opening of a program in a school (college) in the city of Smila (Cherkassy region), because it was the center of sugar production in Ukraine (Gulyi, 2000). This was the first specialized educational institution for the training of technologists, chemists, and technicians for the sugar industry. Later, this college became the Smila Institute of Sugar Industry. Also, the course on sugar technology began to be provided at Kyiv University and Kharkiv Technological Institute (Gulyi, 2000). In addition, the internships for some specialists in the laboratories of the Zurich (Switzerland) and Braunschweig Polytechnics, as well as at the Twulpstedf Plant (Germany) were offered (Gulyi, 2000). The number of such specialists was very limited, but this was the first successful experience of international cooperation in Food education.

In 1898, with the financial support of the owners of sugar factories, the Kyiv Polytechnic Institute (KPI, now the National Technical University of KPI) was founded. There was the first department of sugar technology (among mechanical, chemical, engineering, and agriculture) at the KPI, where engineers for the sugar industry have been educated. In 1930, based on the Smila Institute of Sugar Industry and the Department of Sugar Technology of the Kamyanetz-Podil'skyi Chemical Institute, and the Kyiv Polytechnic Institute, the Kyiv Institute of Sugar Industry (now called the National University of Food Technologies, NUFT) was established (Gulyi, 2000). All of the mentioned institutions are the educational and research branches of NUFT situated in different locations in Ukraine.

In total, more than 25,000 students study at the NUFT. Highly qualified specialists are educated in undergraduate, postgraduate, and doctoral programs. The University staff includes more than 750 professors with 21 academicians, 150 doctors of science, and 400 PhD degrees. The University has seven specialized academic councils for the defense of dissertations in 14 scientific specialties (Mostenska, 2014; Gulyi, 2000; https://nuft.edu.ua/).

Food science, research, and technology development

Specialized research laboratories with a focus on fundamental and applied aspects of grain and food research have been functioning in the NUFT for 40 years (Gulyi, 2000; https://nuft.edu.ua/). Research activity is directed to the development of theoretical foundations of food technologies and processing intensification and optimization, development of advanced processing technologies and highly productive equipment, systems and means of mechanization of labor-intensive processes and operations, new power equipment and systems of rational power consumption as well as for the improvement of organizational activity and increase of effectiveness of food and processing enterprises (Mostenska, 2014; Gulyi, 2000; https://nuft.edu.ua/).

NUFT has a few dedicated research centers including (https://nuft.edu.ua/):

- Research institute of food technologies with six subsidiary research laboratories such as laboratory of construction and innovation projects, laboratory for studies on pectin properties, etc.
- Research engineering center of machines and technologies for packing of food production,
- Research engineering center for development and introduction of technologies and equipment for small food production,
- Research production center for quality evaluation of raw materials and finished products,
- Chair groups of research engineers working with economic problems in the food industry of Ukraine
- The institute for energy problems in the food industry

More than 3,000 patents of Ukraine and five license agreements on delivery and development of equipment, abrasive paste, and products have been received over the last 30 years (Gulyi, 2000; Mostenska, 2014). Thirteen (13) scientists of NUFT were awarded with the State Prize of Ukraine for achievements in the field of science and engineering. Four scientific journals are published at the NUFT: Ukrainian Journal of Food Science (in English, http://ukrfoodscience.ho.ua/), Ukrainian Food Journal (in English, http://ufj.nuft.edu.ua/indexen.html), Collection of scientific papers of NUFT (in Ukrainian), Food Industry (in Ukrainian).

In addition to NUFT with its above mentioned branches, there is Odessa Technological Institute of Food Industry (OTIFI) is a part of Odessa National Technological University (ONTU) in Ukriane (https://ontu.edu.ua/). The journal of Food Science and Technology, Economics of the Food Industry, and scientific papers are published by ONTU (in Ukrainian). Also, there is the International Center of Ukrainian-French Cooperation, the International Center of Ukrainian-Bulgarian Cooperation, and the International Center of Ukrainian-Turkish Cooperation at ONTU (https://ontu.edu.ua/#s5).

The main research and development achievements of Ukrainian food scientists are listed in Supplementary Material (Gulyi, 2000; Mostenska, 2014). This includes important contributions in the area of reducing food and grain loss, enhancing of food safety, developing of novel processing technologies such as pulsed electric field technology (PEF), biotechnology, and extraction methods for biomass recovery or separation technologies, improving environmental safety, energy saving, management of food production and distribution, and advancement in the production of sugar and alcohol, bakery and improvements of food attributes (Sabluk, 2008; Mostenska, 2014).

Despite the fact that Ukrainian food science has a huge research potential, it should be noted that industrial implementation of the scientific results and their impact is limited primarily by the lack of project management skills of Ukrainian scientists. Moreover, the challenging political and economic situation in Ukraine contributed to the deterioration of the situation in the food industry, and collaboration with research organizations. Most state-owned food enterprises went bankrupt over the last 30 years. There are only some of them such as bread production companies, for example, are supported through state subsidies. The basic needs of the population in food products are provided by national commercial enterprises and imported products.

In contrast to food production, the state of research in food science has deteriorated to a greater extent (Petrushina, 2017). Enterprises mainly used foreign technological lines, equipment and ready-to-use engineering and technological solutions and supply chains. At the moment, the food industry is experiencing a much greater need for production engineers and other specialists than scientists. However, in some situations of food businesses there is a need for special expertise and need in hiring scientific experts to solve some problems and provide assistance on a consultancy basis. There is also a trend when scientists develop their food technologies and start their business. This mainly takes place in beverage production, the confectionery industry, and meat products (e.g., First Private Brewery LLC, Kombucha LLC (production of beverages based on fermented kombucha), Nutrimed LLC (production of food additives), Ukrpectin LLC (processing of fruit and berry and vegetable products, production of pectin-containing products, and malt and polymalt extracts), MANZANA FOOD LLC (processing of fruit and jam production), etc.). Current government support of science in Ukraine is very limited. In 1991, funding for science was 2.4% of GDP, which gradually decreased to the current level of about 0.2% of GDP (Petrushina, 2017).

In Ukraine, starting in 2019, a new approach to research funding has been introduced on a competitive basis through the National Research Foundation (NRF) of Ukraine (https://nrfu.org.ua/en/). The Foundation determines and provides grant support for scientific research, and scientific and technical

(Experimental) developments of scientific organizations based on priorities. The largest number of grants have been received by scientific institutions of the National Academy of Sciences of Ukraine (108 grants), scientific institutions, and institutions of higher education of the Ministry of Education and Science of Ukraine (98 grants), which accounts for about 95% of the total grant support by the NRF (https://nrfu.org.ua/en/). Besides the fact that competitive funding of scientific activities through the NRF is the right step towards creating a competitive environment in the scientific field, this is not sufficient ($26 million USD in 2021) to effectively use and further develop the scientific potential of Ukraine (https://nrfu.org.ua/en/).

A few directions and next steps can be envisioned for successful Food Science and research development in Ukraine.

- changing the priority of government policy and supporting national science by placing government orders
- involving Ukraine in the FAO Science and Innovation Strategy including the following:

1) do better at monitoring the innovations, promoting adaptation to local needs, and scaling up successful implementations
2) introduction of better knowledge management and sharing as a key factor
3) improve research extension activities, using the best available technological solutions and expertise, including digital technologies, to effectively reach all food producers

- attracting foreign investment in the food industry and food research of Ukraine, to achieve a significant increase in companies with foreign capital
- developing targeted international collaborative programs and creating funds for cooperation with Ukrainian universities and research centers, allocation of grants, etc. that will address food security issues
- implementation of international internship programs for students and young Ukrainian scientists in the world's leading research universities and business centers
- allocation of international food research centers and laboratories in Ukraine

Conclusion

Food science plays an integral role in global food security while we face challenges caused by a growing population, reduced resources, climate shocks, and social and political crisis such as the war. Ukrainian food scientific institutions and organizations as a part of the global scientific community can offer solutions, highly qualified experts, and substantial experience to contribute to and address these complex issues. This may include to enhance the stability of the food supply while aiding to reduce food and grain loss, enhance food safety, develop novel processing technologies such as pulsed electric field technology (PEF) and other preservation and transformation technologies, biotechnology, and extraction methods for biomass recovery or separation technologies, increase environmental safety, energy saving, management of food production and distribution, and make advancement in the production of sugar and alcohol, and improvements in food attributes. Ukraine has an enormous scientific potential, including food science and technology. Exploiting this potential requires extensive international support and wider involvement of Ukrainian researches in global scientific activity.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frfst.2022.1040396/full#supplementary-material

References

Abera, G. (2019). Review on high-pressure processing of foods. *Cogent Food Agric.* 5, 1568725–1568810. doi:10.1080/23311932.2019.1568725

Barba, F. J., Parniakov, O., Pereira, S. A., Wiktor, A., Grimi, N., Boussetta, N., et al. (2015). Current applications and new opportunities for the use of pulsed electric fields in food science and industry. *Food Res. Int.* 77, 773–798. doi:10.1016/j.foodres.2015.09.015

Bazhal, M. I., Ngadi, M. O., Raghavan, V. G. S., and Smith, J. (2006). Kinetics of *Escherichia coli* in the liquid whole egg using combined PEF and thermal treatments. *LWT - Food Sci. Technol.* 39 (4), 420–426. doi:10.1016/j.lwt.2005.02.013

Beddington, J. R., Asaduzzaman, M., Clark, M. E., Bremauntz, A. F., Guillou, M. D., Jahn, M. M., et al. (2012). The role for scientists in tackling food insecurity and climate change. *Agric. Food Secur.* 1, 10. doi:10.1186/2048-7010-1-10

Cole, M. B., Augustin, M. A., Robertson, M. J., and Manners, J. M. (2018). The science of food security. *NPJ Sci. Food* 2, 14. doi:10.1038/s41538-018-0021-9

Dar, B. N., Shah, M. A., and Mir, S. A. (2022). *Shelf life and food safety*. Boca Raton: CRC Press. doi:10.1201/9781003091677

Fam, S. N., Khosravi, K., Massoud, R., and Massoud, A. (2021). High-pressure processing in food *Biointerface Res. Appl. Chem.* 11 (4), 11553–11561. doi:10.33263/BRIAC114.1155311561

Feinbaum, R. (1999). Analyzing the potential of biomass recovery. *BioCycle* 40 (11), 26–28.

Gross, M. (2022). Global food security hit by war. *Curr. Biol.* 32 (8), R341–R343. doi:10.1016/j.cub.2022.04.007

Gulyi, I. S. (2000). "Ukrainian state university of food technologies. 1930-2000," in *Historical essay* (Kyiv: USUFT (Ukrainian State University of Food Technologies), 151.

Hellegers, P. (2022). Food security vulnerability due to trade dependencies on Russia and Ukraine. *Food Secur.* 2022, 1–8. doi:10.1007/s12571-022-01306-8

Hill, K., Ostermeier, R., Töpfl, S., and Heinz, V. (2022). "Pulsed electric fields in the potato industry," in *Pulsed electric fields technology for the food industry*. Editors J. Raso, V. Heinz, I. Alvarez, and S. Toepfl (Cham: Springer). doi:10.1007/978-3-030-70586-2_9

Huang, D., Men, K., Li, D., Wen, T., Gong, Z., Sunden, B., et al. (2020). Application of ultrasound technology in the drying of food products. *Ultrason. Sonochem.* 63, 104950. doi:10.1016/j.ultsonch.2019.104950

Kumar, V., Sharma, N., Umesh, M., Selvaraj, M., Al-Shehri, B. M., Chakraborty, P., et al. (2022). Emerging challenges for the agro-industrial food waste utilization: A review on food waste biorefinery. *Bioresour. Technol.* 362, 127790. doi:10.1016/j.biortech.2022.127790

Moseley, W. G. (2022). The global food system was already unsustainable before the war in Ukraine. AvaliableAt: https://www.researchgate.net/publication/360238988.

Mostenska, T. L. (2014). *Research and development achievements and innovative technologies*. Kyiv: NUFT (National University of Food Technologies, 435.

Mousakhani-Ganjeh, A., Amiri, A., Nasrollahzadeh, F., Wiktor, A., Nilghaz, A., Pratap-Singh, A., et al. (2021). Electro-based technologies in food drying - a comprehensive review. *LWT* 145, 111315. doi:10.1016/j.lwt.2021.111315

Noori, A. W., Royen, M. J., Medved'ova, A., and Hyadary, J. (2022). Drying of food waste for potential use as animal feed. *Sustainability* 14 (10), 5849. doi:10.3390/su141058493390/su14105849

Petrushina, T. O. (2017). The state of science in Ukraine (based on the assessments of Ukrainian and foreign experts). *Visn. Nac. Akad. Nauk. Ukr.* 11, 66–80. doi:10.15407/visn2017.11.066

Piergiovanni, L. (2012). Packaging and shelf life of fermented foods. *Italian J. Food Sci.* 24 (4), 9–15.

Rao, R. K. (2022). *Food security in global challenges*. OECD Publishing.

Raso, J., Heinz, V., Alvarez, I., and Toephl, S. (2022). *Pulsed electric fields technology for the food industry fundamentals and applications: Fundamentals and applications*. Cham: Springer. doi:10.1007/978-3-030-70586-2

Saba, M., and Patil, P. (2022). Food waste management. *Int. J. Res. Appl. Sci. Eng. Technol.* 10, 3487–3491. doi:10.22214/ijraset.2022.45766

Sabluk, P. T. (2008). State and prospects of development of an agro-industrial complex of Ukraine. *Ukr. Econ.* 12, 4–18.

Sheppard, P., and Rahimifard, S. (2019). Embodied energy in preventable food manufacturing waste in the United Kingdom. *Resour. Conserv. Recycl.* 146, 549–559. doi:10.1016/j.resconrec.2019.03.002

Spellman, F. R. (2021). *The science of waste*. Boca Raton: CRC Press.

Thatoi, H., Mohapatra, S., and Das, S. K. (2022). *Innovations in fermentation and phytopharmaceutical technologies*. Elsevier.

Thomas, A., Alpha, A., Barczak, A., and Zakhia-Rozis, N. (2022). Sustainable food systems for food security. *Quae Open Acess*, 222. doi:10.35690/978-2-7592-3576-6

Vorobiev, E., and Lebovka, N. (2020). *Processing of foods and biomass feedstocks by pulsed electric energy*. Cham: Springer.

Zhang, Z., Zhang, B., Yang, R., and Zhao, W. (2020). Recent developments in the preservation of raw fresh food by pulsed electric field. *Food Rev. Int.* 2020, 1–19. doi:10.1080/87559129.2020.1860083