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After the COVID-19 pandemic: changes and continuities in the food supply chain

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Abstract

Objectives: As the global COVID-19 pandemic stabilizes and control measures gradually improve, the food supply chain enters the post-pandemic era. The food supply chain is closely related to people's daily life, and it is becoming increasingly important to grasp its development direction in the post-pandemic era. So the aim of this paper is to summarize the changes and continuity of the food supply chains in the post-pandemic era.

Materials and Methods: We used food reports published by most global authorities as the data source for this study and analyzed the development of production, logistics, and consumption of food supply chains from the two dimensions of post-pandemic and pre-pandemic.

Results: Our paper shows, on one hand, the relaxation of COVID-19 control measures allows food production workers to return to their jobs, facilitates smooth food logistics, and reduces uncertainty in the food supply chain, thereby providing a better environment for its development. On the other hand, Industry 4.0 plays an increasingly prominent role in the food supply chain.

Conclusions: The trends of digitalization and mechanization in food production, cold chain logistics, smart logistics, online shopping and health-conscious consumption that emerged during the pandemic will continue to persist and evolve in the post-pandemic era. We attempt to systematically analyze the development trend of the food supply chain in the post-pandemic era, point out the implications and approaches for future research, and provide theoretical references for researchers, practitioners, and consumers in the food field.

Keywords: COVID-19; the post-pandemic era; food; agriculture; supply chain.

Introduction

The COVID-19 pandemic caused a global health crisis (Pollard *et al.*, 2020; Sparke and Williams, 2022), which has had serious effects on the global food supply chain (Attia *et al.*, 2022; Alabi and Ngwenyama, 2023). First, the lockdown and control measures implemented by governments led to disruptions and bottlenecks in the entire food supply chain (Singh *et al.*, 2021), including production (Burgos and Ivanov, 2021), transportation (Barman *et al.*, 2021), and sales (Abid and Jie, 2021). The shortage of labor and health issues of workers affected the production capacity of agriculture and food processing factories (Hobbs, 2020; Khan *et al.*, 2022a). Governments have strengthened logistics restrictions and import and export controls during the pandemic (Workie *et al.*, 2020), leading to disruptions in cooperation between upstream and downstream companies in the supply chain (Xu *et al.*, 2020; Butt, 2022). As the food supply cannot meet the demand, food prices have also risen (Aday and Aday, 2020). Moreover, the closure or reduced operation of restaurants, hotels, and other venues has changed consumers' offline consumption habits (Hobbs, 2021; Li *et al.*, 2023b). Second, the spread of the novel coronavirus from animals to humans has raised concerns about food safety (Galanakis, 2020; Arnaboldi *et al.*, 2022). Due to the risk of virus transmission and the nutritional need for isolation at home (Pellegrini *et al.*, 2020), consumers are paying more attention to food quality and safety issues (Qi *et al.*, 2020; Filimonau *et al.*, 2022). During the pandemic, people are more concerned about maintaining health and immunity (Orr *et al.*, 2022; Urhan and Okut, 2022), which has led to an increase in the demand for healthy food (Rodrigues *et al.*, 2021; Das *et al.*, 2022). The food supply chain needs to adopt more measures to ensure food quality and safety and more transparency and feedback mechanisms (Joshi and Sharma, 2022; Khan *et al.*, 2022b). Third, the pandemic triggered a global economic recession, which has also affected the development of the food supply chain (Clapp and Moseley, 2020; Ali *et al.*, 2022). Investment in the food sector decreased during the pandemic (Devi *et al.*, 2020), and a large number of food companies went bankrupt or were merged (Dörr *et al.*, 2022). In summary, the COVID-19 pandemic has to some extent reshaped the form and operating mechanism of the food supply chain. However, as the world moves into the post-pandemic era (Boniface and Tapia-Rico, 2022), some countries have relaxed their pandemic control measures (Mena *et al.*, 2022), and the food supply chain will also undergo corresponding changes during this period (Pantano and Willems, 2022). What changes will occur in the global food supply chain in

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the post-pandemic era, and what pandemic-related impacts have been retained?

As the global economy and society gradually recover, the food industry will gradually return to normal operation status prior to the COVID-19 pandemic (Delardas *et al.*, 2022). However, the occurrence of the pandemic will have far-reaching impacts on future development directions and strategies (Kahiya and Delaney, 2022). On the one hand, the travel restrictions and logistics obstacles caused by the pandemic will gradually ease (Kim *et al.*, 2020), and the stability of food trade and supply chains will gradually recover (Grinberga-Zalite *et al.*, 2021; Ivanov, 2021), and offline dining behavior will also gradually resume (Zhang *et al.*, 2021). In the production process, the decline of physical barriers will stabilize the food supply by allowing the labor force to return to work (Dewan *et al.*, 2022). In terms of logistics, the restrictions on cross-border transportation will make the upstream and downstream connections of the food supply chain more closely linked (Zhang *et al.*, 2023), and the division of labor in the food industry can be refined. In terms of consumption (Kim and Liu, 2022), the relaxation of COVID-19 pandemic management will cancel the restriction of social distancing, allowing offline dining consumption to gradually recover (Wu, 2022). On the other hand, the habits developed during the COVID-19 pandemic in food production, supply, and sales will be retained and will affect the subsequent development of the food supply chain to a certain extent (Sgroi and Modica, 2022; Wallnoefer and Riefler, 2022). In the production process, mechanization and digitization tools have been widely used (Liu *et al.*, 2020; Sridhar *et al.*, 2023). In the logistics process, more extensive cold chain logistics and stricter food quality supervision systems have changed food transportation to a certain extent (Abdullah *et al.*, 2021; Qian *et al.*, 2022). In the consumption process, consumers have retained their online food shopping habits during the pandemic and pursue healthier and more convenient food (Janssen *et al.*, 2021; Ramadan *et al.*, 2023). Therefore, in the post-pandemic era, the food supply chain will be influenced both by the easing of the pandemic and by the inertia of industry development due to the pandemic. This article will analyze in detail the changes and continuities of the food supply chain in the post-pandemic era, and compare in depth the development changes of the food supply chain after the pandemic with those during and before the pandemic in two dimensions (Table 1).

This paper reveals that the development of the food supply chain in the post-pandemic era retains certain characteristics observed during the pandemic while also undergoing significant changes. In the food production phase, on the one hand, the lifting of control measures in the post-pandemic era facilitated the return of the labor force to work and improved the smoothness of food logistics, enhancing the stability of the food supply chain. On the other hand, the trends of mechanization and digitalization in the food supply chain observed during the pandemic have been preserved in the post-pandemic era. In the food logistics phase, both domestic and international food logistics have recovered to some extent compared to those in the pandemic period, and the practices of cold chain logistics and smart logistics during the pandemic will continue to develop. In the food consumption phase, consumers in the post-pandemic era can revisit offline settings such as restaurants and farmers' markets for consumption, while still maintaining the habits of online food consumption during the pandemic and the demand for healthy and convenient food.

The main contribution of this paper is a comprehensive analysis of the new changes and trends facing the food industry in the post-pandemic era. Furthermore, these findings can guide the government in formulating policies and enterprises in production and transportation. On the one hand, this paper uses detailed data to systematically outline the development pattern of the food industry in the post-pandemic era, providing abundant empirical evidence for researchers in relevant fields and offering new ideas and directions for the future development of the food industry. For example, in the later period of the pandemic, the food production and processing industry can increase investment in digital and mechanized production. The food transportation industry can pursue more efficient, convenient and safe transportation methods, while increasing the application of digital traceability systems. On the other hand, this paper compares the changes in the development of the food industry in the post-pandemic era with those in the pandemic and pre-pandemic periods, revealing how factors such as the relaxation or retention of pandemic control measures will impact the development of the food industry in the post-pandemic era in two dimensions. This can more intuitively illustrate the different paths of how the food industry has been affected by the pandemic. The conclusions of this study can be applied to different countries to formulate measures that are more consistent with their own economic recovery. For large grain exporting countries, such as the USA, Malaysia, China, and Brazil, this study can determine trends after the end of the pandemic and increase policy support for import and export trade. For large tourism countries, such as France, Spain, and Italy, this study can provide a basis for controlling the intensity of opening-up.

The remainder of this paper is organized as follows. The second section elaborates on the theoretical and policy basis for what has changed and what has remained the same in the post-pandemic era. The third section is the literature review, which highlights the strong theoretical support for this study. The fourth section is the methodology of this paper, describing the research methods and data sources used. The fifth section

Table 1. Changes and continuities in the food supply chain during the post-pandemic era

Comparison dimension	Change after the relaxation of pandemic control measures	Effect retained during the pandemic
Production process	Employment of labor force has resumed	Widely used mechanization and digitization tools in the food production process
Logistics process	More unimpeded food logistics, more closely linked upstream and downstream connections in the food industry	More extensive cold-chain logistics and stricter food quality supervision systems
Consumption process	Lifting of social distancing measures, resumption of offline dining consumption	Development of consumer habits for online food shopping, preference for healthier and more convenient food

expatiates the changes seen at the production end of the food industry in the post-pandemic era, the main changes in the logistics end of the food industry in this era and the realistic changes in the consumption end of the food industry in the post-pandemic era. The sixth section discusses the theoretical significance, practical significance, future research direction and shortcomings of this paper. Finally, the seventh section summarizes the research conclusions of the entire paper.

Background

The significant impacts of the pandemic on the food supply chain

The current context for the development of the food supply chain in the post-pandemic era pertains to a complex set of circumstances. The advent of the COVID-19 pandemic led to significant disruptions within the food industry, particularly in terms of production, transportation and consumption of food products (Kumar *et al.*, 2020; Boyacı-Gündüz *et al.*, 2021). This resulted in food shortages and price hikes (Figure 1), adversely impacting the well-being of millions of people worldwide (Willy *et al.*, 2020; Ling *et al.*, 2022).

On the production side, COVID-19 control policies had various impacts on food production. In some countries and regions, governments imposed lockdown and isolation measures to restrict virus spread, resulting in shortages of human resources and transportation delays. Large-scale social distancing and restrictive measures also presented new challenges for food production companies (Nicola *et al.*, 2020). For instance, to comply with social distancing rules, many factories reduced the number of workers or planned longer working hours, affecting production levels and R&D plans (Ambrogio *et al.*, 2022). Furthermore, to protect employees from infection, many companies introduced various pandemic prevention facilities and hygiene measures, limited production time, and changed their production processes, leading to additional cost increases and decreased production efficiency (Weersink *et al.*, 2021). Finally, changes in consumer habits and demand under COVID-19 controls added uncertainty to food production. Many consumers changed their food-purchasing habits under the impact of the pandemic, which may lower demand for certain products in the food supply chain, trigger price increases and supply shortages causing negative effects on food production companies (Coluccia *et al.*, 2021; Swinnen and Vos, 2021). Therefore, it can be seen that COVID-19 control policies have to some extent altered the production mode of food. Under the impact of the pandemic, there has been a trend of mechanization and digitization transformation in food production (Christiaensen *et al.*, 2021; Xie *et al.*, 2021).

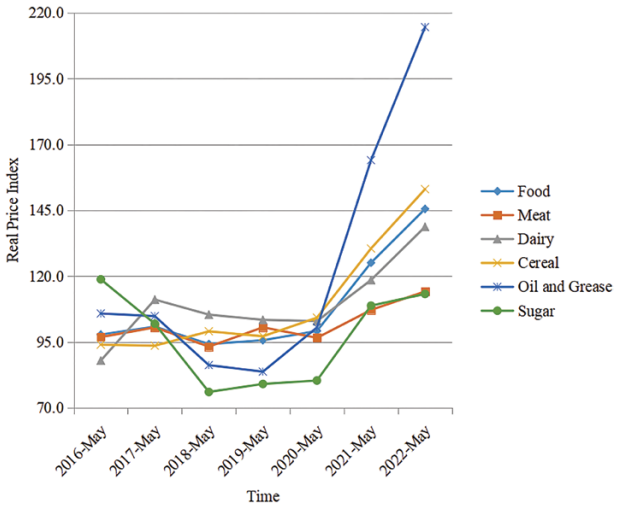

Figure 1. Real price index. Source: Half-annual strategy of the basic chemical industry (Zhongyuan Securities, June 2022).

Mechanization

Mechanization refers to the adoption of automation and robotics technologies by many food production companies to deal with labor shortages and social distancing requirements. For example, in the agricultural sector, some companies have begun to use intelligent agricultural robots that can automate tasks such as planting, irrigation and harvesting.

Digitization

Digitization involves many food production companies adopting digital technologies to better manage and control production processes and inventory. For example, some companies have introduced Internet of Things (IoT) technology to monitor and control production processes through sensors and data analytics, helping improve production efficiency and product quality.

In the realm of logistics, food logistics and trade encounter a myriad of challenges. Transport restrictions and traffic control posed impediments to food logistics and international trade, resulting in a shortage of food supply (Sharma *et al.*, 2020; Laborde *et al.*, 2021). First, logistics costs have escalated. Logistics and transportation enterprises have adopted a series of measures to counteract the pandemic, including augmenting safety equipment and enhancing employee protection measures, which, in turn, lead to an increase in logistics costs (Rejeb *et al.*, 2020). Second, trade and transportation face curtailments and interruptions. The pandemic has induced constraints on travel and freight routes, thereby affecting numerous international trade and transportation activities, such as transporting goods to border ports (Munawar *et al.*, 2021; Alamoush *et al.*, 2022). Third, there are disruptions and shortages in the supply chain. During the pandemic, many enterprises suffered severe impacts on their supply chains, such as a dearth of raw materials and halts in production lines, ultimately incapacitating them to satisfy market demands, hence incurring significant economic losses (Ratnasingam *et al.*, 2020; Moktadir *et al.*, 2023). Cold chain logistics and intelligent logistics have become the development direction of food logistics under pandemic conditions (Abideen *et al.*, 2021; Naz *et al.*, 2021).

Cold chain logistics

Cold chain logistics refers to a logistics method that ensures that product quality, freshness and nutritional value are not lost throughout the entire logistics process by controlling temperature, packaging materials and equipment in the transportation and storage of perishable goods such as food and medicine. During the outbreak of the pandemic, people were more concerned about the safety and hygienic nature of food, and the importance of cold chain logistics to ensure food quality, freshness, and safety was further highlighted.

Intelligent logistics

Intelligent logistics achieves accurate recording and management of information such as food sources, production dates, transport temperatures and sales locations through the IoT technology to track and monitor various links such as production, transportation and storage, ensuring food quality and safety. Meanwhile, promoting automation on production lines and contactless delivery through intelligent technology can effectively reduce contact between people.

On the consumption side, the pandemic's control measures have changed consumers' food consumption habits. Many restaurants and catering enterprises have been forced to close or limit their business due to social distancing and lockdown measures, resulting in a significant decline in industry sales (Brodeur *et al.*, 2021; Orîndaru *et al.*, 2021). This situation is particularly evident in high-end restaurants and cafes (Yang *et al.*, 2020). With people spending more time at home, online food sales channels have rapidly expanded (Leone *et al.*, 2020; Roe *et al.*, 2021). More and more consumers are choosing to shop online, and many physical stores are also maintaining their business through online sales channels (Eger *et al.*, 2021; Nanda *et al.*, 2021). Many people have started cooking at home instead of dining out, and consumers can choose to purchase fresh fruits, vegetables, and meats for cooking at home and pay more attention to hygiene standards in food storage, packaging and transportation processes (Caso *et al.*, 2022; Toiba *et al.*, 2022). Therefore, the development of consumer habits for online shopping and increased demand for healthy and convenient food will be new directions in the food consumption industry (Tien *et al.*, 2021).

Online consumption habits

With people being restricted from shopping at physical stores, more and more online supermarkets and fresh food stores are entering the market. Consumers are shopping more frequently through e-commerce channels during the pandemic, allowing them to order products such as ingredients, fruits, vegetables, and meats. through these online platforms and enjoy home delivery services.

Healthy and convenient food

During the pandemic, people are paying more attention to their health, and consumers are more willing to choose beneficial and healthy foods, such as vegetables and fruits that are rich in nutrients, as well as health supplements with various health benefits, to enhance their immune system. Restrictions on home isolation and social distancing prompted many consumers to spend more time cooking at home. As a result, there has been a significant increase in the market for convenient foods, such as pre-made meals, instant rice, frozen foods and microwave foods.

Pandemic relaxation and food supply chain changes

With the global pandemic gradually stabilizing and the easing of pandemic prevention and control measures, the food supply chain has entered a post-COVID-19 era (Jiao, 2022). The 'post-COVID-19 era' is defined as the period after the global containment of the pandemic and during the gradual recovery phase (Negrete-Cardoso *et al.*, 2022). As the pandemic prevention situation improves, restrictions such as city lockdowns and isolation measures have gradually been lifted, allowing for offline business activities and the gathering of crowds, as well as the relaxation of restrictions on interregional goods flow (Table 2). In this new era, people's lifestyles, work habits and consumption patterns will undergo significant changes, while also giving rise to new trends and opportunities in industries such as the food industry, healthcare, social activities, tourism, and retail (Anggreanti and Suryanata, 2021; Ratten, 2021). As the economy continues to recover and consumer demand increases, the food supply chain must adapt and restructure its operational model to meet market demands while upholding public safety and hygiene standards (Baryshnikova *et al.*, 2021; Nakat and Bou-Mitri, 2021).

The relaxation of pandemic prevention and control measures has alleviated the constraints on the development of the food supply chain. Specifically, in terms of food production, labor employment is no longer restricted by pandemic prevention measures, resulting in a rebound in employment levels in some regions to pre-pandemic standards (Causa *et al.*, 2022; Pizzinelli and Shibata, 2022). Moreover, with the easing of pandemic prevention and control measures in the logistics sector, restrictions on the transportation of food across different regions are gradually being lifted, leading to a decline in food logistics costs (Di Marcantonio *et al.*, 2022). This, in turn, has facilitated the recovery of international trade and supply chains, thereby providing food enterprises with opportunities to expand their international market and deepen the division of labor in the food production process (Panwar *et al.*, 2022; Komarova and Bondarenko, 2023). Furthermore, the lifting of social distancing restrictions has enabled consumers to resume offline dining (Figure 2), resulting in an incremental recovery of consumer demand for offline dining (Zibarzani *et al.*, 2022). Overall, the relaxation of pandemic prevention policies has engendered changes in the development environment faced by the food supply chain.

Despite the gradual relaxation of pandemic prevention and control measures, some of the habits formed during the pandemic are likely to continue to impact the development of the food supply chain. First, in the domain of food safety, heightened scrutiny towards food safety and quality during the pandemic created a zero-tolerance attitude towards substandard food (Chiwona-Karltun, 2021). This trend is expected to persist in the post-pandemic era, necessitating production enterprises to strengthen their quality control and food safety supervision (Thilmany *et al.*, 2021; Ding *et al.*, 2022). Second, consumers have become more health-conscious during the pandemic, which has led to an increased demand for healthy diets (Galanakis *et al.*, 2021). In the post-pandemic era, it is expected that individuals will tend to prioritize the nutritional value of food and opt for healthier, natural and organic alternatives (Birtus and Lăzăroiu, 2021). Third, digital transformation has gained prominence in the food manufacturing industry during the pandemic, with the adoption of online sales channels, intelligent devices and IoT technology becoming vital for industry transformation and upgrading (Bai *et al.*, 2021; Moghrabi *et al.*, 2023). In the post-pandemic era, digital transformation will remain a crucial direction for industry transformation and upgrading, and there is a need to

Table 2. Relaxation schedule of COVID-19 control policies in major countries globally

Country	Relaxation schedule
USA	2 March 2021: Texas lifted its mask mandate and allowed all businesses and places to reopen across the state. 23 April 2021: Florida announced the lifting of most COVID-19 restrictions, including capacity limits on restaurants, entertainment venues, and other locations. 15 June 2021: California lifted most COVID-19 restrictions that had previously restricted commercial activities, sports events, and school resumptions in the state. Starting 8 November 2021, fully vaccinated foreign travelers are allowed to enter the USA by international flights or through land and sea ports. Since 12 June 2022, international travelers do not need to provide negative COVID-19 test results before entry into the USA.
UK	As of 21 June 2021, the UK lifted most social distancing and restriction measures, including the limits on indoor and outdoor gatherings and the closure of entertainment venues, bars, and other restrictions. However, a cautious approach to the variant virus remains crucial. Starting from 1 April 2022, the UK will no longer offer free asymptomatic COVID-19 testing for the general population, with free lateral flow or nucleic acid tests remaining only available to vulnerable groups, such as those with low immunity, the elderly, medical and care industry staff.
Germany	Starting from 15 May 2021, Germany has begun to implement a 'Gradual Resumption of Normal Life' roadmap. Starting 1 February 2023, most federal states in Germany will lift all pandemic control measures, such as no longer requiring masks on public transport and no longer requiring positive patients to isolate at home.
France	Starting 19 May 2021, France began to gradually relax its control measures of the pandemic, including allowing population mobility, free travel, gradually opening commercial activities, cultural and entertainment venues, etc. Starting from 28 February 2022, mask mandates will no longer be enforced in indoor venues that use vaccine passports. Starting from 14 March 2022, mask mandates will also be lifted in other enclosed public places, including school classrooms, companies, stores, places of worship, and more. Starting from 1 February 2023, infected individuals in France will no longer be required to isolate, and their close contacts will not be required to undergo virus screenings.
Republic of Korea	Starting from 19 February 2022, public gathering places such as restaurants, cafes, karaoke rooms, bathhouses, and indoor sports facilities will no longer record personal pandemic information via QR code scanning or manual registration.
Japan	Starting from March 2022, Japan relaxed its entry restrictions for foreign nationals who have non-tourism purposes, including international students, business travelers, and technical interns. Starting from 10 June 2022, foreign tourists from 98 low-risk countries and regions are allowed to enter Japan in group tours with tour guides. Starting from January 2023, entry passengers will no longer be required to provide testing certificates.
China	Starting from 9 December 2022, except for special places such as public security, judicial supervision places, care institutions, welfare institutions, rescue management institutions, mental health institutions, maternal and child service institutions, rehabilitation institutions, medical institutions, childcare institutions, and primary and secondary schools, negative COVID-19 test results are no longer required. Temporary blockades in various forms will not be adopted, and personnel flow is unrestricted in non-high-risk areas.

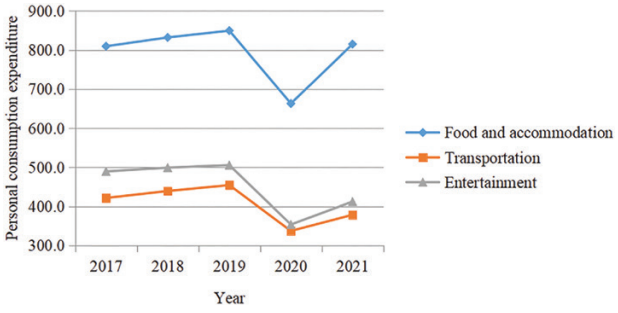

Figure 2. Personal consumption expenditure of American households (unit: USD). Source: iiMedia Think Tank.

accelerate its implementation to accommodate emerging consumer trends and changes.

In conclusion, the emergence of the pandemic has had a profound impact on the developmental trajectory of the food supply chain, and the post-pandemic era will mark a period of new changes in the food supply chain. On the one hand, lifting pandemic prevention and control measures will eliminate some of the constraints that the food supply chain faced during the pandemic, with some food supply chain operating models expected to return to their pre-pandemic state. On the other hand, some novel features that emerged during the pandemic in select parts of the food supply chain will endure and continue to influence the subsequent development of the food supply chain. This paper will analyze the post-pandemic changes and continuity of the food supply chain, focusing on the three key sectors of food production, logistics and consumption. Using a twofold approach, we will examine the similarities and differences in the development and changes of the food supply chain during the post-pandemic era compared to the pre-pandemic and pandemic periods. The objective of this analysis is to explore the factors that influenced the changes and continuities in the food supply chain during the post-pandemic era.

Literature Review

Research has shown a growing interest in understanding the impact of the COVID-19 pandemic on the food supply chain. Measures such as travel restrictions and social distancing disrupted food trade and supply chains (Thukral, 2021; Din *et al.*, 2022), altered consumer behavior (Ben *et al.*, 2020; Donthu and Gustafsson, 2020) and affected the overall operations of the industry (Sarkis, 2020; Shen and Sun, 2023).

Impacts on food trade and supply chains

Bochtis *et al.* (2020) used the employment and salary data from the US Bureau of Labor Statistics (BLS) and analyzed each agricultural occupation. Kumar and Kumar (2022) used the Best–Worst Method (BWM) to determine the importance rating of impacts of COVID-19 on agri-food supply chains. They indicated that the pandemic control measures and labor shortages led to decreased productivity in food production and increased logistics costs and time. Javaid *et al.* (2022) studied the significant benefits of Industry 4.0 for sustainable manufacturing and identified tools and elements of Industry 4.0 for developing environmental sustainability. They reached the same conclusion as Agrawal *et al.* (2020). To address supply chain shortages, there has been widespread adoption and acceleration of digitization and automation technologies, including cloud computing, IoT, big data analytics, and robot automation. Cai and Luo (2020) studied the initial impact caused by worldwide spread of the coronavirus. Zahraee *et al.* (2022) performed a systematic meta-analysis of literature and statistics pertinent to the effects of COVID-19 on various sectors. They indicated that the pandemic posed transportation and logistical challenges, causing disruptions in the food supply chains between countries and regions. Srinivas and Marathe (2021) used a stylized analytical model, and proposed that 'mobile warehouse' can be an effective solution to last-mile logistics issues faced during and beyond COVID-19 under certain conditions. Suguna *et al.* (2021) used total interpretive structural modelling approach to identify, analyze, and categorize the major factors that affect the last mile delivery projects in areas such as e-commerce, food sector, and retail sector. Their results indicated that the type of goods, achieving routing efficiency and meeting fulfilment timelines are the key factors for last-mile delivery projects during the COVID-19 pandemic. Nayal *et al.* (2023) collected a sample of 316 respondents from Indian agricultural supply chain industries and used structural equation modeling (SEM) to investigate the influence of numerous factors on blockchain technology adoption (BLCT). Su *et al.* (2023) collected 350 valid responses from an online response team in Wuhan, China and analyzed the data using exploratory factor analysis and SEM. Then, they combined the theories of perceived value and affect-as-information, taking cold chain logistics services as an example to discuss the influence of the quality of physical distribution services (PDSQ) of online retail cold chain on consumers' psychological emotion (satisfaction and psychological distress), attitude and behavior (loyalty). They found that the pandemic accelerated the adoption of cold-chain logistics and stricter food quality regulations, which played a positive role in ensuring food supply chain safety and stability.

Impacts on consumer behavior

Moon *et al.* (2021) analyzed the characteristics of consumers who used offline shopping channels during the pandemic. Leal *et al.* (2021) employed a quantitative research methodology to report on an international study on the increased consumption and subsequent changes in the amounts of waste produced since the COVID-19 pandemic. They found that pandemic control measures impacted people's consumption behavior, leading to an increase in online food shopping and a decrease in offline dining. Sharma (2020) analyzed how the pandemic affected the purchasing habits and consumption behavior of consumers. Kim *et al.* (2021) reviewed the current status of industrial agriculture along with lessons learned from industrialized agricultural production patterns, industrialized agricultural production processes and the industrialized agri-food supply chain. They reached the same conclusion. Following the lifting of social distancing restrictions, offline dining consumption has gradually recovered, while the consumption habits of online food shopping are expected to continue.

Impacts on the overall operations of the industry

Whitehead and Brad (2022) focused on characterizing the impact of COVID 19 on the meat supply chain in the USA to provide practical insights into the meat/food industry across the globe to develop potential mitigating strategies against COVID-19 and/or any similar pandemic incidences in the future. Sama-Berrocal and Martínez-Azúa (2022) analyzed the data descriptively, and a statistical study was conducted on the existence or absence of independence between effects and actions based on the branches of activity of agri-food industries. They have found that changes in the food supply chain during the pandemic will continue to affect industry development even after the relaxation of pandemic control measures. Pan *et al.* (2020) collected more than 750 000 words on the topic of COVID-19 and agriculture from the largest two media channels in China—WeChat and Sina Weibo—and employed web crawler technology and text mining methods to explore the influence of COVID-19 on agricultural economy and mitigation measures in China. Haqiqi and Horeh (2021) introduced IMLAP, Immediate Impact Model of Local Agricultural Production (IMLAP), and investigated the potential impacts of COVID-19 on farmers in the USA for each county with a special focus on female, Hispanic, black, and African American and small-scale producers. The purpose of these studies was to evaluate the immediate impacts of COVID-19 on agricultural and food systems in the USA. They reached the same conclusion. As labor employment is restored, mechanization and digital tools are widely applied to improve efficiency and productivity in food production processes. Neboh *et al.* (2022) determined the efficacy of supply chain collaboration on resilience in the industry. Ersahin *et al.* (2024) used textual analysis of earnings conference calls and quantified firms' supply chain risk and its sources. They found that since the pandemic gradually stabilized, more extensive cold-chain logistics and closer upstream–downstream linkage have made food logistics more efficient and stable. Saberi *et al.* (2019) critically examined blockchain technology and smart contracts with potential application to supply chain management. Nandi *et al.* (2021) linked localization, agility, and digitization (LAD) to a potential solution using blockchain technology and circular economy principle capabilities. Ibn-Mohammed *et al.* (2021) diagnosed the danger of relying on pandemic-driven benefits to achieve sustainable development goals and emphasized the need for a decisive, fundamental structural change to the dynamics of how we live. Rutitis *et al.* (2022) investigated the industrial consumption of biocomposite materials and the influence of the COVID-19 pandemic on the main stages of the value chain of sustainable industrial consumption of biocomposites. Yu *et al.* (2023a) explored the complex relationship between

supply chain social responsibility and sustainable performance using data collected from 209 Chinese manufacturing companies on the basis of stakeholder theory and SEM and fuzzy set qualitative comparative analysis (fsQCA). They found that the pandemic has allowed people to pay more attention to the transparency and reliability of the food supply chain, and it has promoted the development of new supply chain models that emphasize environmental protection and social responsibility.

While many studies have analyzed the impact of the pandemic on the food supply chain, they have focused mainly on the effects of the pandemic on the food industry during the pandemic period, and there is a lack of systematic analysis of the new changes the food industry faces in the post-pandemic era. Thus, this article aims to comprehensively analyze the new changes that have emerged for food producers, the new demands derived from food consumers, and the new directions for food research work in the post-pandemic era. It attempts to provide theoretical references for researchers, practitioners, and food consumers in the food industry.

Methodology

Hossain (2021) described the research background, data source, and data analysis in his methodology. We refer to his writing framework and discuss the research methods in detail from research method, data collection, data analysis, and validity and reliability.

Research method

The impact of the pandemic on people's daily lives has not disappeared with the recession of the pandemic. In order to determine whether the situation of the food supply chain in the later period of the pandemic recovered to the development trend of the early period of the pandemic and which favorable factors were preserved during the pandemic period, we used various publications, such as food security reports published by various authorities around the world, food science and technology reports, and current situation reports on food market size as our data sources. We used content analysis and data mining to support our findings. Kumar *et al.* (2021) used fuzzy BWM to study how to reduce the risk of perishable food supply chain and established the framework of the article in the methodology section. Yusriza *et al.* (2023) described the research process in the modeling method section. Here, we refer to their approach and present the research framework of this paper. The research framework diagram is shown in the Figure 3.

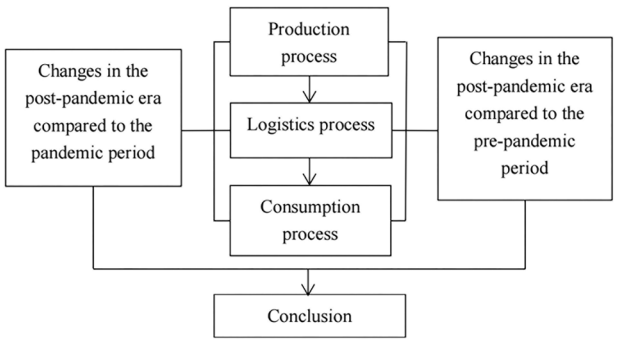

Figure 3. Research framework.

Data collection

The main sources of data include food reports published by the FAO, AgFunder, the ILO, and Dealroom. Through a comprehensive search, we gathered as much information as possible about the ongoing impact of COVID-19 on regions around the world. When searching for reports, we used keywords related to food safety, food security, and the food supply chain. We included only documents that explicitly discuss food and COVID-19, both globally and in individual countries, such as the USA and China. The searches took place between 2019 and the first half of 2023. Whenever we found a suitable report, we downloaded it and categorized it. We do not claim to cover all relevant documents on the Internet, but we feel that our report is comprehensive enough to provide an insightful academic contribution to the impact of COVID-19 on global and regional food supply chains.

Data analysis

All the reports were downloaded in pdf and saved in a folder, and then read one by one to extract ideas and data from three links in the food supply chain: production, transportation and consumption. The data we selected all spanned the three phases before, during, and after the pandemic. For different types of data with the same idea, we combined or reduced them to multiple categories; for the multi-period data of a certain point of view, if some data were classified by month, we intercepted the data of one month and supplemented the corresponding data of other years by searching the database. In addition, for the different manifestations of an indicator, such as when some indicators were expressed by specific values and growth rates, we integrated them into a chart to better reflect the change rule of this indicator. In the end, we divided the results into three categories: production, transportation, and consumption. The results of this study are presented by topic in the following sections.

Validity and reliability

The main data in this paper were extracted and integrated from food reports published by the FAO, AgFunder, the ILO, and Dealroom. The missing data were also mined from authoritative databases to ensure their validity and reliability.

Results

Food production and processing in the post-pandemic era

Changes in the post-pandemic era compared to the pandemic period

First, in the post-pandemic era, there is a significant reduction in logistics restrictions and food costs, which will facilitate the recovery of food production (Figure 4). Since 2020, due to the negative impact of the COVID-19 pandemic on the global economy, global agricultural production has declined significantly. The reasons for this are as follows: first, affected by pandemic control, international logistics, and raw material shortage; second, the increase in raw materials and shipping costs (Bianco *et al.*, 2023; Hu and Yan, 2023; Karunarathna, *et al.*, 2022). For example, in Beihai (Guangxi, China), affected by the pandemic, there were freight transport controls for part of the feed ingredients, prawns and channel fish processing enterprises cannot buy raw fish pond head (as part

of the feed); thus, the processing enterprises were in discontinued or semi discontinued state. However, with the release of pandemic control, the flow of raw materials gradually returned to normal, which promoted the agricultural production of various countries (Fei and Ye, 2023). In January 2023, according to the Brazilian Grain Exporters Association, Brazil shipped more than 1 million tons of corn to China, which helped Brazil's corn exports hit a record high for the same month. A recent USDA Weekly Export Sales report stated that U.S. 22/23 wheat export sales for the week ending on 12 January 2023, increased by 473 100 t net, a significant increase from the previous week and a net 99% increase from the 4-week average, compared with market expectations of 75 000–400 000 t. U.S. 22/23 wheat export sales rose a net of 504 000 t in the week ending on 19 January, up 6% from the previous week and 84% above the 4-week average, compared with market expectations of 150 000–500 000 t.

Second, the lifting of social distancing measures in the post-pandemic era has allowed for the return of the labor force to work, ensuring the labor supply for food production (Table 3). The pandemic prevention and control policy restricts the flow of people and causes the shortage of labor force, thus limiting the progress of agricultural production (Chakraborty, 2023; Li *et al.*, 2023a). According to the CNBC, the biggest concern for U.S. farmers in the face of COVID-19 is a labor shortage before the planting season begins. But in an effort to stem the spread of the virus, the government restricted Mexican immigrants to the USA, an important source of cheap labor for American agriculture. In continental Europe, the pandemic prevented thousands of migrant workers from returning to work, creating labor shortages and causing problems in fruit and vegetable harvesting and logistics, as Bloomberg reported. The Dordogne region in southwestern France is already running out of fresh fruits and vegetables because of a lack of labor. However, with the spread of the pandemic, the release of quarantine and the return of labor force promoted agricultural production (Figure 5) (Inonge Milupi *et al.*, 2023; Kuang *et al.*, 2023). The latest official data from the Ministry of Agriculture of Thailand show that in 2023, the total planting area of durian, mangosteen, rambutan, and Dragon Palace fruit in the eastern fruit producing areas was 1359 km², an increase of approximately 4% compared with that of the previous year, among which the flowering fruit orchard was approximately 1055 km², an increase of 1.21%. If a yield of 1.1 kg/km² is calculated, the total output of fruit in eastern China in that year will reach 1 163 618 t, a year-on-year reduction of 2.18%. In 2022, the fruit yield was 1.14 kg/km² and total output was 1 189 522 t. Taking durian as an example, the total planting area was 888.5 km², a year-on-year increase of 8.26%, among which the flowering fruit orchard was 562.5 square kilometers, a year-on-year increase of 4.85%. The estimated yield per square meter is 1.35 kg, a year-on-year increase of 1.47%, and the total output is expected to be 756 456 t, an increase of 3.3%. In Taiping Town, Yingjiang County, Yunnan Province, China, a demonstration area of the whole process of potato production mechanization has been built, covering an area of 4.7 km². The whole process of potato mechanization operation in the whole town has an area of 10 km² driven by linkage.

Third, in the post-pandemic era, the relaxation of logistics and labor restrictions stabilized food production, significantly reducing the uncertainties faced by the food supply chain and leading to a trend toward stable food prices. With the rapid

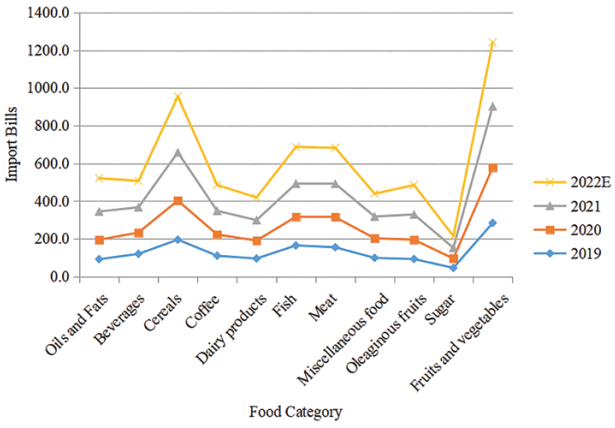

Figure 4. Import bills of total food and food products (unit: 1 billion USD). Adding 'E' after the year indicates that the data for that year is an estimated value. Source: Food Outlook Biannual Report on Global Food Markets (FAO, November 2022).

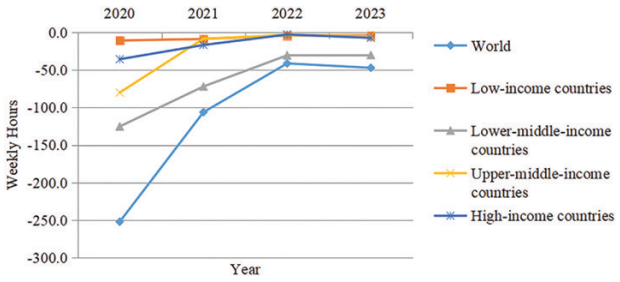

Figure 5. Weekly hours worked relative to the fourth quarter of 2019, full-time equivalent (FTE). Source: World Employment and Social Outlook Trends 2023 (ILO Flagship Report, 2023).

Table 3. Employment and employment-to-population ratio of world and by country income during 2019–2024

Group	2010–2019	2020–2021	2022	2023	2024
World	1.1	0.2	2.3	1.0	1.1
Low-income countries	2.8	2.4	3.7	3.3	3.3
Lower–middle-income countries	1.6	0.4	3.0	1.8	1.8
Upper–middle-income countries	0.5	0.0	1.2	0.1	0.3
Upper–middle-income countries (excluding China)	1.2	–0.6	3.3	0.7	0.8
High-income countries	1.1	–0.6	2.7	0.2	–0.1

Source: World Employment and Social Outlook Trends 2023 (ILO Flagship Report, 2023).

increase in the number of confirmed COVID-19 cases, the shortage of employees is no longer limited to labor-intensive industries in emerging manufacturing countries such as Vietnam and Cambodia. The entire global industrial chain, from manufacturing to service, from production to transportation to sales, is facing operating difficulties caused by a shortage of employees. For example, manufacturing workers refuse to return to work because of the pandemic, transportation lacks truck drivers, aviation lacks airport staff, tourism lacks service workers, and so on. The operation of the global industrial chain has been continuously disrupted by the pandemic, and the COVID-19 pandemic has exacerbated employment difficulties for enterprises, which could further increase the instability of the global industrial chain. For example, many enterprises are unable to pay their employees' salaries. The price of agricultural products fluctuates constantly, and the supply of agricultural products cannot keep up with demand. With the spread of the pandemic, these phenomena gradually improved and the reduction in industrial chain uncertainty stabilized the cash flow (Çetindaş *et al.*, 2023; Guo *et al.*, 2023; Lyu *et al.*, 2023a), the price of agricultural products (Lyu *et al.*, 2023b), and the supply of agricultural products (Ren *et al.*, 2023). The reduction of industrial chain uncertainty is mainly reflected in the fact that enterprises will not temporarily shut down, which can be seen from the resumption of work and production in various countries. For example, the number of people employed in the USA recovered from 87% to 94% six months after the pandemic was relaxed, and exceeded the pre-pandemic level after one year of continuous deregulation. Similar to the pace of employment recovery in the USA, the number of jobs in the UK recovered after the continued relaxation of quarantine policies. The number of jobs in the UK recovered to 99% when the quarantine was fully lifted, and recovered completely after 3 months of coexistence. The extensive resumption of production has brought about stable cash flow. For example, 7-Eleven Japan has 8930 employees and generated a net profit of 11.1 billion yuan in 2022, with a gross margin of 93% and a per-capita net profit of 1.25 million yuan. For the price of agricultural products, according to the monthly price monitoring report of the agricultural products wholesale market in Guizhou, China, in January 2023, the average monthly price of white-tiao chicken was 23.06 yuan/kg, down 0.26% month on month and up 2.67% year on year. The average monthly price of aquatic products was 29.97 yuan/kg, down 2.32% month on month and up 8.51% year on year. The average monthly price of carp was 13.69 yuan/kg, down 1.65% month on month and up 5.07% year on year. The average monthly price of spot fork tail *Ictalurus punctatus* was 23.05 yuan/kg, down 1.12% month to month and up 6.7% year to year . The overall change is small, and the prices are stable. Agricultural supplies also stabilized, with the weekly USDA Export Sales report showing net soybean sales of 1.275 million tons for the week ending on 19 January 2023, above the high end of market forecasts of 600 000 to 1.26 million tons. Of that, 1.069 million tons were sold to China. Year-to-date US soybean export sales totaled 46.54 million tons, up 5.4% from the same period of last year. Total soybean sales to China (shipped and unshipped sales) stood at 28.24 million tonnes, up 11.1% year on year.

Lastly, with the stabilization of food production in the post-pandemic era, there has been a recovery in venture captial (VC) investment from the capital market towards the food supply chain (Figure 6). Starting from the concept of sustainable development, more and more enterprises prefer to make green investment (Table 4). Hanna *et al.* (2020) and Yu *et al.* (2023b)believe that the investment of the government or enterprises must meet the public's immediate needs or not fly. Luckily, there are sweet spots that can deliver and save hundreds of thousands of jobs, such as investing in renewables and energy efficiency, and preserving the existing fleet of zero-emission nuclear power plants. Another result of the stability of the industrial chain after the pandemic is the increase in people's purchasing power (Amalia *et al.*, 2023; Chen *et al.*, 2023; Sutterby *et al.*, 2023), which promotes more capital investment in agricultural production in the post-pandemic era (Hu *et al.*, 2023), and the production and consumption of agricultural products ushered in a recovery. The increase in purchasing power can be reflected in the amount people spend after the pandemic. Data from Pinduoduo show that in China, in the 2023 New Year shopping season, third- and fourth-tier cities became the regions with the fastest growth in purchasing imported fruits such as Chilean cherries, Thai durian and Vietnamese jackfruit, accounting for nearly 50% of the orders. In the consumption of seafood, aquatic products and other categories, domestic seafood sales increased

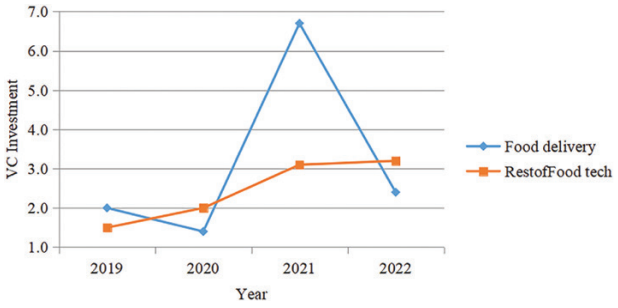

Figure 6. VC investment in European foodtech (food delivery vs. the rest) (unit: 1 billion USD). Source: The State of European Foodtech 2023 (Dealroom.co & Five Seasons Ventures, January 2023).

Table 4. VC investment 2022 vs. 2021

	VC investment 2022 vs. 2021
Functional beverages	375%
Alternative protein	75%
B2B marketplaces	63%
Agritech	37%
Enterprise SAAS	21%
Dark kitchens	–17%
DTC brands	–22%
In-store retail tech	–25%
Food waste	–30%
Food delivery	–64%
Online grocery delivery	–69%
Pet food	–3%
Supply-chain tech	–83%

B2B: Business-to-Business; SAAS: Software as a Service; DTC: Direct to Consumer.
Source: The State of European Foodtech 2023 (Dealroom.co & Five Seasons Ventures, January 2023).

by 140% month on month, and imported seafood such as black tiger prawns, Argentine red prawns, and Arctic sweet prawns increased by 220% month on month. In addition, the USA has announced a number of new investments and resources from executive orders since the pandemic, including: (1) 500 million USD to support U.S. fertilizer production in the summer of 2022; (2) 68 million USD to promote safety innovation in agriculture and alternative products. In March 2022, the USDA announced the need to train the next generation of research and education professionals; (3) 270 million USD to build supply chain resilience through 1 billion tons of bio-based materials, such as fuels and chemicals.

Changes in the post-pandemic era compared to the pre-pandemic period

In terms of production orientation, the post-pandemic era places greater emphasis on the production of healthy, organic and high-quality food compared to the pre-pandemic period (Figure 7). In the post-pandemic era, more and more people have reached an unprecedented new level of healthy eating. Compared to the pre-pandemic period, consumers are more interested in healthy and nutritious foods, which has led to a change in food production orientation. In the post-pandemic era, producers, guided by improving consumer trust (Keogh *et al.*, 2023; Taufik *et al.*, 2023), produce more nutritious, ecological and high-value food (Luković *et al.*, 2023). According to the recent report 'Trends and Innovations in the Food Industry 2022' prepared by the Costa Rican Agency for the Promotion of Foreign Trade and Investment (PROCOMER), food ethics has become a new pillar of the industry for all consumers, especially those in the high-end market. In other words, consumers pay more attention to the nutrition, ecological, and high value of food. Costa Rican companies are targeting strong market segments to continue to meet the needs of the post-pandemic era and increase their international market share by introducing the following products: ginger and turmeric as basic ingredients for energy drinks and snack foods; collagen in the form of drinks, energy bars, and snacks, especially if it comes from plants. In the post-pandemic era, as people pay more and more attention to their daily eating habits, they have a deeper understanding of the hazards of high-sugar foods, and their awareness of sugar control and reduction has gradually strengthened, benefiting the sweetener industry. According to statistics, the global sugar substitute market size is estimated to 16.5 billion USD in 2023 and is expected to reach 20.6 billion USD in 2025.

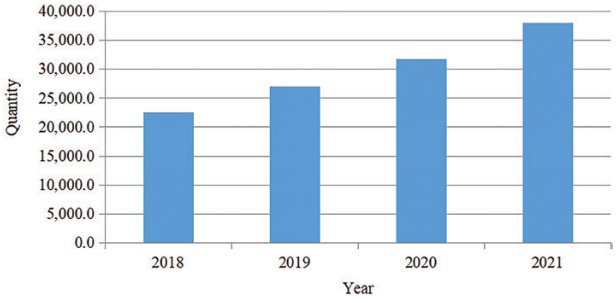

Figure 7. Quantity of cumulative effective standard green agricultural products in China from 2018 to 2021. Source: Analysis of the production and marketing status and market scale of green agricultural products in China in 2022 (Foresight Industry Research Institute, January 2023).

In addition, consumers are placing greater emphasis on plant-derived food ingredients. SPINS reports show that the market for plant-based raw materials is growing at an annual rate of nearly 30%, almost double the rate of the overall food and drink market. Plant-based milk is also taking the lead in the U.S. market, accounting for 16% of the total milk consumption, and a study found that plant-based milk leads growth and innovation across the entire milk category. In the overall plant-based milk market, almond (59%), oats, soybeans, coconut, and mixed milk had the highest market share, in descending order.

In terms of production methods, Industry 4.0 is shining even more brightly; mechanization, digitalization, and precision have become the dominant trends in food production during the post-pandemic era (Figure 8). Cai and Luo (2020) believe that digital supply chains will be a prerequisite for success during the pandemic and later for improving the wisdom and responsiveness of the supply chain. With the maturity of big data and artificial intelligence as tools, coupled with the widespread adoption of cloud technology and rf in 5G environments, COVID-19 can drive digital leaps in supply chains. In the post-pandemic era, consumers' food preferences are more diverse than they were before the pandemic. In the face of such large-scale food demands, manufacturers prefer mechanized, digitized, and refined production (Table 5; Figure 9) (Xu *et al.*, 2023; Zhou *et al.*, 2023). In Quanzhou, Fujian Province, China, Qifeng and Huawei

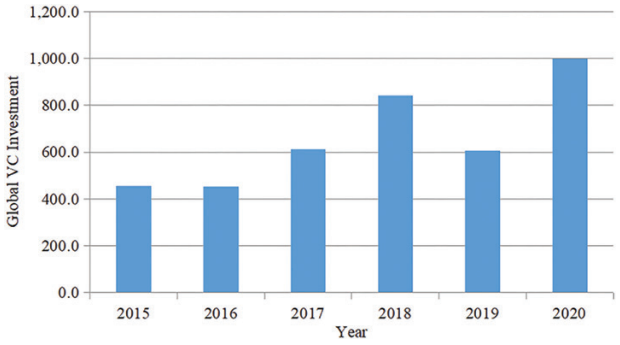

Figure 8. Global VC investment in farm management and robotics (unit: 1 million EUR). Source: The State of European Foodtech 2023 (Dealroom.co & Five Seasons Ventures, January 2023).

Table 5. National development level of agricultural mechanization

Crops	Comprehensive mechanization rate of cultivation and harvest (2021)	Improved compared to 2020
Wheat	97.29%	0.10
Rice	85.59%	1.24
Corn	90.00%	0.23
Soybeen	87.04%	0.34
Rape	61.92%	2.01
Potato	50.76%	2.70
Peanut	65.65%	1.69
Cotton	87.25%	3.27

Source: 2021 National Agricultural Mechanization Development Statistical Bulletin (Great Wall Securities Research Institute, 2022).

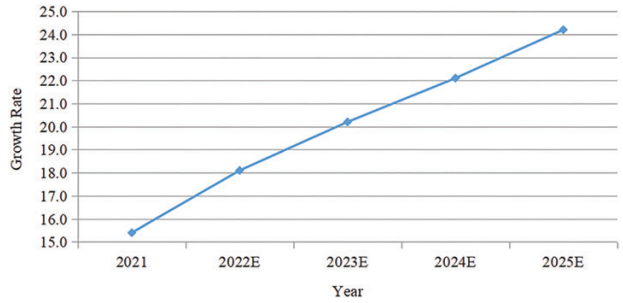

Figure 9. The growth rate of global agricultural digitization. Adding 'E' after the year indicates that the data for that year is an estimated value. Source: 2022 China Agricultural Digitalization Industry Development Trend Report: Digitalization Promotes Rural Revitalization Strategy (Head Leopard Research Institute, Deppon Research Institute, September 2022).

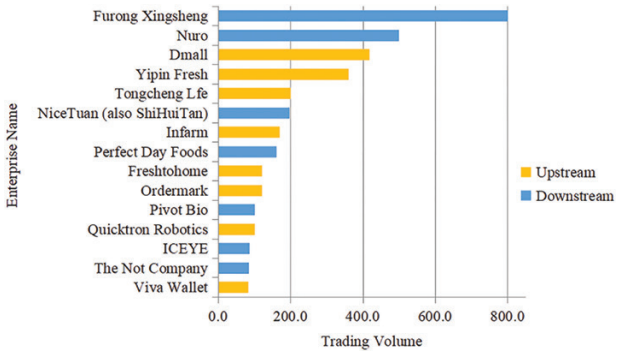

Figure 10. Top 15 Series C deals (unit: 1 million USD). The Series C chart tells a story of demand for hyper-local and fresh foods—both upstream and downstream—from vertical farming in Germany (Infarm), to fresh but discounted grocery delivery in China (Yipin Fresh) and fresh meats in India (Freshtohome). Source: AgFunder AgriFoodTech Investment Report (AgFunder, 2021).

(Jinjiang) Industrial Internet Cloud Incubation Center introduced the production and manufacturing execution system, which can implement digital monitoring of raw material consumption, production quality and equipment running status and realize traceability management of the whole process from raw material entering the factory to product sales. In addition, it can realize visualization of production process, digitalization of quality control, refinement of cost control, greatly improve capacity utilization and real-time control the production work order schedule. Bai *et al.* (2021) suggested that in the post-COVID-19 world, the realization of digitalization helps shape circular, economic, sustainable supply chains, as well as sustainable consumption and production improvements. Digital Star Biotechnology Co., Ltd., located in Suzhou (Anhui Province, China), launched the invoicing and production modules of KIS cloud flagship version, and the process management data of all departments of Digital Star was seamlessly integrated. For example, a production planner can automatically generate a production task order based on the sales order recorded by the sales department through the function of production by sales in the system. When the production of raw materials in a warehouse is insufficient, the system can automatically generate the purchase order of the raw materials. After the raw materials are collected, quality inspection is passed to determine whether the raw materials are qualified, after which the material receiving notice and warehousing order are generated. The qualified food that passes the inspection link is put into the warehouse and sold. According to the'2023–2027 US Land Preparation Machinery Market Investment Environment and Investment Prospects Assessment Report' released by the New Thinking Industry Research Center, in recent years, with increasing crop yield and planting area in the USA, as well as the continuous promotion of agricultural mechanization, the domestic land preparation machinery application market has developed rapidly. Especially in 2022, as the global food crisis intensifies, Feed the Future, a program led by the United States Agency for International Development, is expected to further stimulate agricultural production. In this context, the application demand for land preparation machinery in the USA is increasing, and the scale of imports is also expanding. China, as a global manufacturing power, ranks first in the number of land preparation machinery exported to the USA every year. According to the statistics of the General Administration of Customs of China, in the January–October period of 2022, China exported 631 000 units of land preparation machinery, with an export value of 95 693 000 USD, among which the export value of land preparation machinery to the USA reached 21.677 million USD, accounting for approximately 22.7%. The USA has become the largest export destination for China's land-clearing machinery.

In terms of production organization, the post-pandemic era places greater emphasis on coordinated production between upstream and downstream sectors in the food industry, as well as vigorous promotion of food brands (Figure 10). Handfield *et al.* (2020) believe that supply chain designs are evolving, focusing more on metrics such as sustainability, lower working capital, lean production, resiliency, low emissions, and better risk-recovery strategies. In the post-pandemic era, food enterprises have paid more attention to brand operation and local rough processing modes (Luo, 2023; Mangiapane and Puca, 2023). In China, on 25 February 2023, Anhui Xinlian Poultry Industry Co., Ltd. launched the Xinlian Black Chicken Brand Egg Industry Alliance in Hangzhou (Zhejiang Province, China), aiming to create delicious and high premium egg products. In order to promote the sustainable and healthy development of the Xinlian black chicken industry and create an industrial ecological system of black eggs, old black chickens and young black chickens, Xinlian poultry industry has adjusted its development direction, focused on black chickens and the promotion of black chicken seedlings and brand operation of black eggs nationwide, and ultimately formed an industrial chain operation mode with the Xinlian black chicken as the core. The company proposes to set up the brand egg industry alliance for the Xinlian black chicken to guide new changes in the laying chicken industry for terminal consumption, not only to produce high-quality eggs but also to sell high-quality eggs at a good price. In early December 2022, Grimsby, UK-based whitefish processor Subzero, the largest processor of whitefish primary products in the UK, opened a new 15 000 square foot facility in the coastal town of Grimsby, doubling the company's whitefish processing capacity. In the UK, Subzero is one of the few companies specializing in primary whitefish processing. It mainly produces rough products such as pressed fish blocks, bricks and frozen blocks, which are sold to secondary processing plants for further processing. Subzero is also equipped with a 'SubShape' power press for pressing and molding some ready-to-eat products. Subzero says its new production line

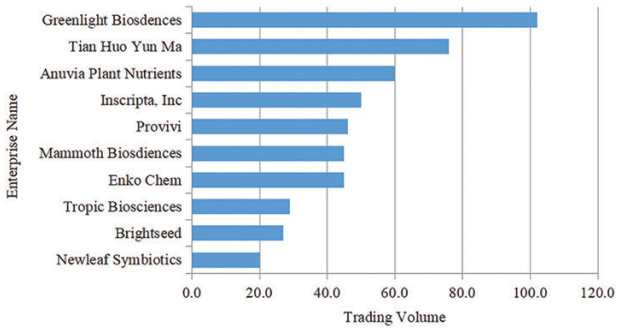

Figure 11. Top Ag Biotech deals (unit: million USD). Source: AgFunder AgriFoodTech Investment Report (AgFunder, 2021).

Table 6. Import bills of total inputs and input type (billion USD)

Type	2019	2020	2021	2022
EnergyAg	109.4	77.4	125.2	197.5
Fertilizer	76.7	70.6	107.5	168.0
Pesticides	37.9	44.2	45.7	50.4
Seeds	7.7	7.5	8.5	8.3
Total	231.6	199.7	286.9	424.3

Forecasts are based on data from January 2022 to July 2022.
Source: Food Outlook Biannual Report on Global Food Markets (FAO, November 2022).

can process up to 300 t of raw fish a week, and the company has an internal cold storage capacity of 100 t.

In the field of food research, nutrition and health have become the guiding principles, leading to an increased emphasis on the integration of industry, academia, and research in food research. This approach has accelerated the implementation of numerous novel food technologies. Food producers are paying more attention to the application of technology in food research and development. In the post-pandemic era, nutrition and health become the direction of breeding (Figure 11) (Nair *et al.*, 2023; Titirică *et al.*, 2023). The producers combine industry, university, and research and are paying attention to the implementation of technology (Cobo *et al.*, 2023; De Vries *et al.*, 2023), and the development of gene editing breeding is accelerating (English, 2023; Roca *et al.*, 2023). In the post-pandemic era, functional foods generated from probiotics have received unprecedented attention and pursuit. The research and development of probiotic strains is regarded as the technology 'chip' in the field of food science. Only the development of strains with independent intellectual property rights can truly promote the future development of the probiotic industry. On 6 March 2023, Yili officially released the 'China Patented Space Strain' in cooperation with the China Aerospace Science and Technology International Exchange Center. The patented probiotic strain independently developed by Yili is deeply participating in the space flight experiment, laying a key foundation for enabling human health in the future with space science and technology. On 4 October 2022, in Cambridge, Massachusetts, startup Inari announced that it had successfully closed its latest Series E funding round and raised 124 million USD. The company is currently raising 475 million USD. This investment will further enhance Inari's leading position in multi-gene-editing seed technology, support the expansion of the company's product development, and ultimately create new value in the commercial seed market. In addition, the U.S. precision breeding company Acceligen announced that it had created gene-edited pigs resistant to PRRS. The company has created pigs with natural resistance to Porcine Reproductive and Respiratory Syndrome (PRRS) through gene editing using protein modification technology developed at Kansas State University. This technology will improve the overall well-being of animals, resulting in healthier animals and safer food supplies; breeding pigs with natural resistance to PRRS could reduce the environmental impact of pork production by improving efficiency. The findings from the Max Planck Institute for Molecular Plant Physiology were published online in *Nature Biotechnology* on 3 January 2023. The study identified a series of tRNA-like sequence (TLS) that travel long distances within plants as RNA signals and fused this mobile TLS element to the CRISPR/Cas9 sequence, enabling the plant to produce a 'mobile' version of CRISPR/Cas9RNA. In this study, the tool was further applied to the cross-species grafting of *Arabidopsis* and cabbage rapeseed to achieve remote gene editing across species. This novel mobile gene-editing system provides a fast and efficient channel for precise molecular design and breeding in the future, and provides strong technical support for the study of important agronomic traits and genetic improvement of crops.

Food circulation and trade in the post-pandemic era

Changes in the post-pandemic era compared to the pandemic period

In the post-pandemic era, the smooth flow of food logistics has broken down the segmentation of the food market during the pandemic, leading to a reshaping of the agricultural product trade division system. After the release of physical pandemic control, goods can circulate (Zhao, 2023b). Consequently, the market segmentation of agricultural products has been disrupted, and the division of labor in the agricultural product trade is gradually recovering (Table 6; Table 7) (Shi, 2023). According to the data released on the official website of the National Bureau of Statistics of China and related analysis, from the perspective of non-manufacturing services, retail, accommodation, and catering business activity indexes were all over 24 percentage points higher than those in January 2023, returning to the expansion range, indicating that people's willingness to consume is significantly stronger and market activity is recovering.

In the post-pandemic era, the international food trade has gradually recovered, leading to a stabilization in prices of bulk agricultural commodities and alleviating food security concerns in certain regions (Figure 12). With the liberalization of import and export trade restrictions in various countries, the international trade barriers caused by the pandemic have been weakened (Minh, 2023; Wang and Ma, 2023), and the import and export volume of agricultural products have rebounded (Mao and Chen, 2023); thus, the food security problems caused by logistics and trade control have been solved in many places, such as through quantity shortage (Alabi and Ngwenyama, 2023), and the price of bulk agricultural products has stabilized (Figure 13; Figure 14) (Ulussever *et al.*, 2023). According to data released by the General Administration of Customs, China's total imports and exports of agricultural products in 2022 reached 2230.568 billion yuan, up 9.9% year on year, according to data released

Table 7. Summary of dry bulk freight markets

Index	24 Oct 2022	Change	
		6 months	Year on year
Baltic Dry Index (BDI)*	1797	–22%	–59%
Sub-indices			
Capesize	2036	+10%	–67%
Panamax	2113	–30%	–51%
Supramax	1670	–38%	–53%
Baltic Handysize Index (BHSI)**	959	–36%	–53%
IGC Grains and Oilseeds Freight Index(GOFI)***	175	–24%	–35%

*4 January 1985=1000; **23 May2006=1000; and ***1 January 2013=100.
Source: Food Outlook Biannual Report on Global Food Markets (FAO, November 2022).

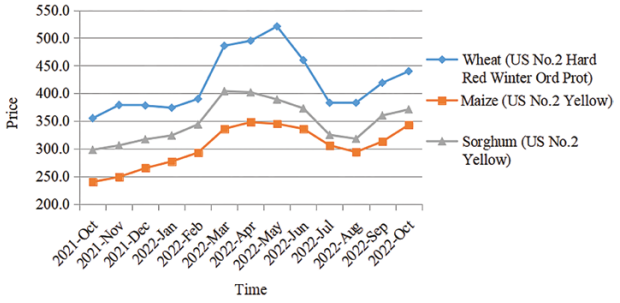

Figure 12. Selected international prices for wheat and coarse grains (unit: USD/t). Source: Food Outlook Biannual Report on Global Food Markets (FAO, November 2022).

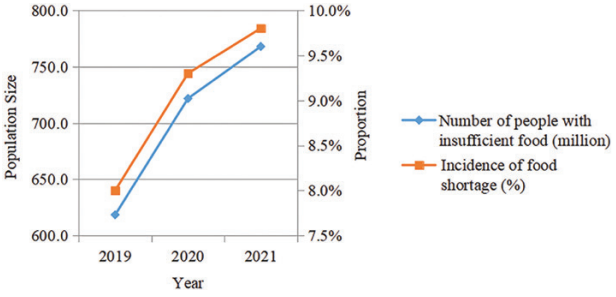

Figure 14. Global food shortage situation from 2019 to 2021. 2021 predicted values are indicated by the dashed line. The shaded regions show the upper and lower bounds of the estimated range. Source: World food security and nutritional status in 2022 (FAO, 2022).

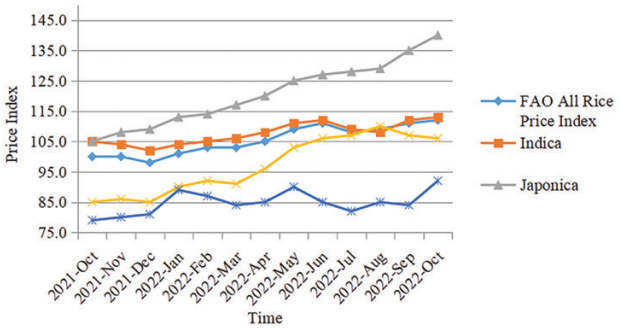

Figure 13. Selected international prices for rice and price indices. The FAO Rice Price Index is based on 21 rice export quotations. 'Quality' is defined by the percentage of broken kernels, with higher (lower) quality referring to rice with less (equal to or more) than 15% broken. The sub-index for Aromatic Rice follows movements in prices of Basmati and Fragrant rice. Sources: FAO for indices; Rice prices: Creed Rice Market Report, Livericeindex.com, Thai Department of Foreign Trade (DFT), Viettraders, and other public sources.

by the General Administration of Customs. Among them, the export value was 65.96 billion yuan, up 16.5% year on year; the value of imports was 1574.608 billion yuan, up 7.4% year on year; the trade deficit was 918.647 billion yuan, up 1.7% year on year. According to data released by the Japan Ministry of Agriculture, Forestry and Fisheries, Japan's exports of agricultural, forestry, water and food products increased 14.3% from the previous year to 1.4148 trillion yen in 2022. Australian wheat exports in December 2022 reached 2.7 million tons, up more than 20% from a year earlier. Of that, 860 000 t went to China, and that month's wheat trade between the two countries increased by 150 000 t from a year earlier. Meanwhile, purchases from Indonesia rose by 65% in December from a year earlier, while exports to South Korea and the Philippines more than tripled. Russian grain exports continue to be strong, according to data from the Russian Grains Union (RGU). In the first 10 d of February 2023, wheat exports were 1.01 million tons, up 76% year on year. Russian wheat prices are more competitive than those of other producers, and RGU expects exports of approximately 1.5 million tons in the first half of February, before export quotas took effect, up from 863 000 t in the same period last year. In the second week of 2023, the fluctuation range of international agricultural commodity prices was small and tended to be stable. Among them: (1) rice, soybean, cotton, and corn prices rose slightly. The weekly average prices of Thailand 100% B grade and 5% broken rice in Bangkok were 512 USD and 497 USD per ton, respectively, up 4% month on month and 17% and 18% higher than the previous year. The average closing weekly prices of the latest Chicago Mercantile Exchange futures contract for soybeans and corn were 558 USD and 243 USD a ton, up by 2% and 1% from the previous month and 11% and 4% higher than the previous year, respectively. The International Cotton Index (SM grade) was 101.45 cents per pound (2237 USD per ton), up 2% month on month and down 24% year on year. (2) Soybean oil prices were basically flat on a month-on-month basis. The latest soy oil futures contract on the Chicago Mercantile Exchange ended the week at an average of 1393 USD per ton, virtually

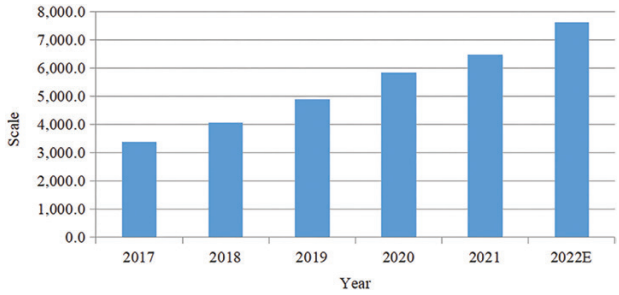

Figure 15. Scale of China's intelligent logistics industry (unit: 100 million yuan). Adding 'E' after the year indicates that the data for that year is an estimated value. Source: Forecast and analysis of the market size and development trend of China's intelligent logistics industry in 2022 (China Commercial Industry Research Institute, June 2022).

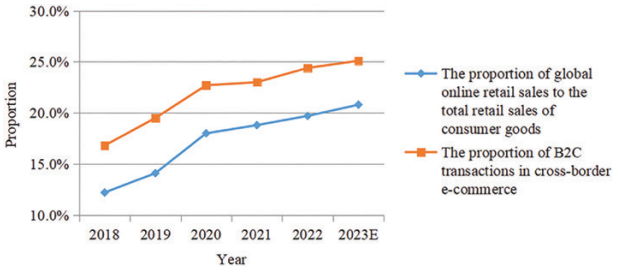

Figure 16. The proportion of global online retail sales to total retail sales of consumer goods and the proportion of B2C transactions from 2018 to 2023. Adding 'E' after the year indicates that the data for that year is an estimated value. Source: 2022 Cross-border Data Report (Guangdong Trade Research Institute, June 2023).

unchanged from the previous month and 8% higher than the previous year.

Changes in the post-pandemic era compared to the pre-pandemic period

In the post-pandemic era, more attention has been given to tracing the origin of food to ensure food quality and safety. With the development of Industry 4.0, more and more digital technologies have been applied to the food supply chain (Figure 15). The combination of digital technology and traceability systems has attracted more and more attention due to its advantages of high efficiency and accuracy (Hui and Zhang, 2023; Kafetzopoulos *et al.*, 2023; Shi *et al.*, 2023b). Chia Tai Foods Co. Ltd., a multinational food producer based in Thailand with export markets worldwide, has successfully applied blockchain technology to its digital food traceability system for fresh pork and chicken products. Blockchain technology makes it easier for consumers to quickly access product information by scanning QR codes on packaging. In addition to the origin of products, consumers can learn about certification of quality and food safety standards, as well as information related to sustainable production, including greenhouse gas emissions. In China, CCN Zhongshang digital quality traceability system can provide whole-chain effective traceability for the prepared vegetable enterprises through the key links of food material traceability, intelligent production line, warehousing logistics, market circulation, quality control, and inspection from the source, and realize the construction of a whole chain visual management platform. Consumers can check the whole process information of prepared vegetables from raw material production, processing, storage, logistics, and terminal dealers through one-click scanning of the source code, realizing efficient supervision of the production information of prepared vegetables can be traced, circulation information can be queried, and sales information can be fed back.

In the post-COVID-19 era, digital technology has also played a prominent role in monitoring supply and demand systems and allocating commodities (Figure 16) (Mantravadi and Srai, 2023; Wasswa *et al.*, 2023). Moreover, international trade has developed rapidly with the help of digital means (Figure 17) (Enderwick, 2023; Zhao, 2023). In China, FoodTalks aims to open up the information chain of the food industry, and establish an information channel that can quickly match the resources of both sides to achieve efficient cooperation between food enterprises. Based on the

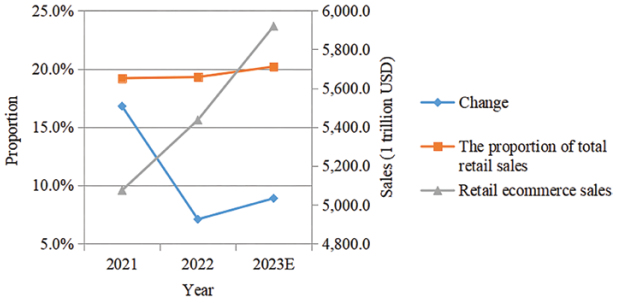

Figure 17. Retail e-commerce sales worldwide during 2021–2023. Adding 'E' after the year indicates that the data for that year is an estimated value. Source: 2022 Cross-border Data Report (Guangdong Trade Research Institute, June 2023).

user content of the FoodTalks supply and demand platform (foodtalks.cn/wefood), the FoodTalks supply and demand release column selects the demand, supply, recruitment, and other information of enterprises every week, and posts some details to the FoodTalks official account. According to the classification of OEM, ingredients, equipment, design, marketing, and other information, the precise promotion of FBIF and FoodTalks community corresponded to the theme and function (total coverage of 150 000+). TradeTech, as a new track combining digital technology and international trade, is grabbing the attention of investors and market participants as well as governments all over the world. As a blockchain-distributed platform focusing on the international trade of bulk commodities, TradeGo allows customers to keep their data in their own hands to ensure data security. No market participant discloses any transaction connotations or details on TradeGo, and at the same time, the great convenience brought by the digitalization of core documents is enjoyed. On 12 October 2022, the cdn.ymaws website published an article entitled 'ICC and its Centre for Digital Trade and Innovation (C4DTI) Launch Trade Digitisation Preparations'. To prepare the market for digital trading systems, C4DTI has launched a number of initiatives highlighting the use of Legal Entity Identitfier (LEI): one is to work with Ubisecure and the Global Corporate Identity Coding Foundation (GLEIF) on a nationwide campaign to promote the use of LEI. This will enable companies to speed up due diligence, reduce fraud and effectively track secure goods and financial transactions. The second is to organize

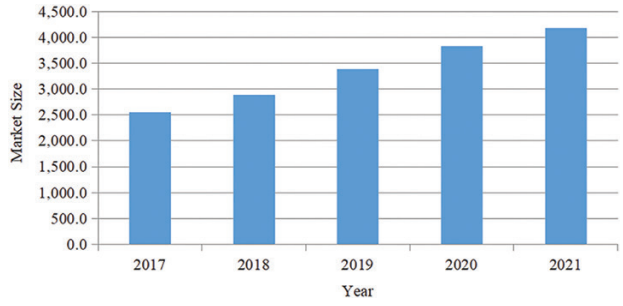

Figure 18. China's cold-chain logistics market size (unit: 100 million yuan). Source: 2023 China fresh e-commerce industry market panorama survey, investment strategy research report (Zhiyan consultation and sorting, 2023).

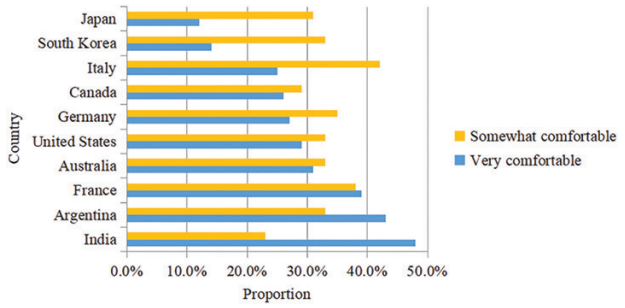

Figure 19. Share of adults who said they feel comfortable going out to eat at a restaurant. The poll was conducted on January 20–24, 2022 among a representative sample of roughly 9,000 global consumers, with an unweighted margin of error of +/-3 percentage points. Source: The State of Food & Beverage (Morning Consult, Q1 2022).

two training courses in cooperation with the Institute of Export and International Trade to help enterprises deal with digital files and use LEI effectively.

In the post-pandemic era, compared to the pre-pandemic period, there is a significant increase in the demand for cold-chain logistics in the food industry (Figure 18). During the pandemic, people tasted the sweetness brought by the convenience of cold-chain logistics. After the pandemic, the cold-chain logistics system was maintained and the flow of fresh food was more convenient (Huo *et al.*, 2023; Lam and Tang, 2023; Wang *et al.*, 2023a). The development of intelligent cold-chain logistics also highlights the development momentum of Industry 4.0 in the post-pandemic situation. According to the cold-chain logistics market data collected by Beziers Consulting, the global cold-chain logistics market scale reached 2 147 232 billion yuan in 2022. According to the Chinese enterprise database Qiaomao, as of January 2023, the registered capital of Guangdong cold-chain logistics enterprises was mainly distributed between 10 million and 50 million, and the number of related enterprises was 394; it was followed by 1–2 million enterprises, and the number of related enterprises was 338. On the whole, more than 48% of China's cold-chain logistics enterprises have registered capital of more than 5 million yuan, and more than 25% have registered capital of more than 10 million yuan. On 6 February 2023, CIMC Lianda Logistics Technology (Group) Co., Ltd.'s strategic investment in Qingdao Hechuan International Freight Co., Ltd. signing ceremony was held in Shenzhen. Through this strategic investment, the CIMC World Alliance will, on the basis of the original CIMC Small Flying Fish cross-border cold-chain logistics, integrate the business layout of Hechuan Group in the export industry for more than 20 years, form a cross-border 'in and out of circulation' business flow of fruit and vegetable cold chain, improve the location ability and team strength of 'North–South complementary' in China, and create a global network layout of 'internal and external double access'. After the deep integration of the two sides, it will become the only enterprise in the industry that provides import and export two-way sea transportation, road, rail, and air transportation with complete capacity and large-scale services.

Food consumption in the post-pandemic era

Changes in the post-pandemic era compared to the pandemic period

On one hand, with the release of the pandemic in various countries, people's travel is no longer subject to the control

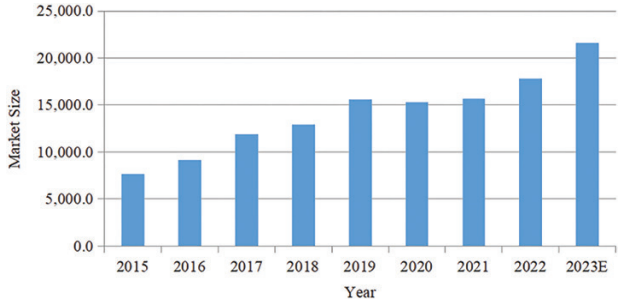

Figure 20. China's group meal market size (unit: 100 million yuan). Adding 'E' after the year indicates that the data for that year is an estimated value. Source: The White Paper on China's Catering Industry Ecology in 2023 (Red Food Industry Research Institute, March 2023).

and restriction. In this context, the catering industry gradually recovers, catering consumption picks up, people start offline dining again, and agglomeration catering reappears (Figures 19 and 20) (Ahmed *et al.*, 2023; Gu *et al.*, 2023; He and Huang, 2023; Hooshmand *et al.*, 2023; Mohanty and Samal, 2023; Ndhlovu and Dube, 2023). In China, during the 2023 Spring Festival, Meituan data showed that the number of orders for multiple sit-in set meals in the first six days of the holiday increased by 53% year on year. In terms of offline shopping malls, the passenger flow and sales volume also experienced significant growth during the Spring Festival, with 160 million people visiting 480 Wanda plazas nationwide and sales revenue reaching 12.68 billion yuan, up 15% and 29%, respectively, over the 2019 Spring Festival. Compared with the pandemic period, food and beverage consumption in China reached a peak in 2023. According to the Spring Festival Consumption Outlook Report, the catering and cultural travel markets are bustling ahead of the holiday, with more than 27 million orders related to the Spring Festival from 9 to 15 January. According to data from the Beijing Restaurant Association, reservations for private rooms in many brand catering enterprises are booming, and the turnover rate of private rooms in their stores has reached 200%. Moreover, the increase in tourism has led to substantial growth of catering consumption in other places. In Sichuan Province (China), consumers from other places accounted for approximately one-third of the total, and the average daily consumption increased by 43% year on year, contributing 47.6% to

food and beverage consumption. In general, offline catering consumption increases and the future momentum is good. According to the statistics of the quarterly income of listed catering companies in the USA by Ansin Securities, the income of catering enterprises in Q2 and Q3 of 2022 generally increased compared with that in the same period in 2019, among which the income of catering enterprises with strong social and leisure attributes such as barbecue and bar grew strongly. Yelp shows that North American restaurant sales surpassed pre-coronavirus levels in 2022. Therefore consumers have not changed their spending habits even though they are affected by the pandemic and inflation. According to a Forbes report, in 2022, the U.S. foodservice industry sales of 898 billion USD exceeded pre-pandemic sales (up from 864 billion USD in 2019). That's an increase of 99 billion USD from 2021 and 220 billion USD from 2020. Cinda Securities statistics of Japan's catering business shows income has exceeded the pre-pandemic level. After the pandemic control was lifted, passenger flow recovered to more than 80%, and in October, it recovered to more than 90%. Due to the increase in the unit price of customers, the operating income of catering in October exceeded the pre-pandemic level.

On the other hand, food markets also resumed operation after the release of the pandemic (Luković *et al.*, 2023; Philavong and Onphanhdala, 2023), and after the control during the pandemic period, there was an overall upgrade, more diversified functions, and higher quality of agricultural products (Fei *et al.*, 2023). In China, there is still a long way to go to upgrade farmers' markets. The transformation and upgrading of China's farmers' markets before and after the pandemic also achieved good results. In February 2023, the farmers' market in Caili Community (Lieshan Town, Huaibei, Anhui Province, China) was upgraded and renovated. By transforming the interior of the farmers' market, unified planning of snack stalls and strengthening sanitary supervision, Caili Community has realized the transformation from 'dirty and bad' to 'clean and beautiful'.

Changes in the post-pandemic era compared to the pre-pandemic period

In the Industry 4.0 era, the rapid development of technology and the Internet has also affected people's consumption habits in the post-pandemic era. In the post-pandemic era, the online consumption habits of food have been retained (Figure 21). During the pandemic, due to the high risk of consumers going out to purchase food, online shopping is characterized by convenience and no contact, which can reduce the risk of cross-infection, and e-commerce orders of fresh food doubled. In China, in 2020, the number of online orders during the Hema Fresh outbreak increased by 220% compared with that in the pre-pandemic period. The transaction volume of Daily Food during the Spring Festival increased by 350% compared with that before the pandemic; Jd.com's overall sales during the pandemic increased by 450% compared with those in the pre-pandemic period. The demand for fresh food in supermarkets also increased significantly. On 1 February 2020, the national order volume of Yonghui Life APP exceeded 200 000, and on 8 February 2020, the order volume exceeded 300 000. According to statistics from eMarketer and other sources, the total fresh e-commerce sales in the USA in 2020 surged by 54% compared to the pre-pandemic level. The '2020 China

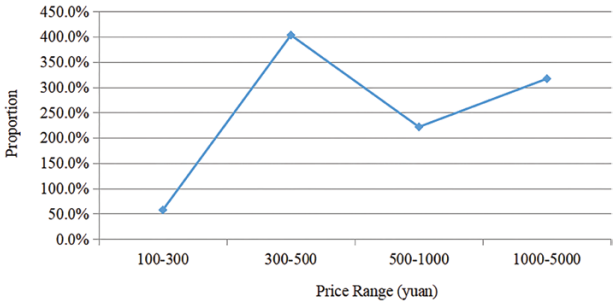

Figure 21. Average sales volume growth rate of the fruit industry in 2022. Source: Tiktok E-commerce Fresh Vegetable Industry Report (Chan Mama Data Report, January 2023).

fresh e-commerce data report' shows that the market size of fresh e-commerce in 2020 was 364.13 billion yuan, compared with 255.45 billion yuan in 2019, up 42.54% year on year. According to data released by the National Statistical Office and the food industry, online food sales in Republic of Korea reached 43.4 trillion won (251.886 billion yuan) in 2020, up 62.4% from a year earlier. Among them, the trade volume of agricultural and sideline products was 6.1 trillion won, up 71.4% year on year. After the gradual liberalization of pandemic prevention and control in various countries, such online fresh food purchasing behavior has been retained, and more convenient door-to-door fresh food service has become the habit of most consumers (El Khoury *et al.*, 2023; Liu, 2023; Lu *et al.*, 2023). Instacart, a U.S. fresh food delivery unicorn, reported revenue of 2.5 billion USD in 2022 (17.35 billion yuan as of March 2023), up 39% from the previous year. In addition, the State of Fresh Food Report from the Food Industry Association of America shows that American consumers are embracing fresh food and finding it more reassuring to buy it online. Currently, approximately 40% of fresh food consumption comes from online shopping. Meat accounted for 10% of online fresh food, and seafood accounted for 2%. In China, JD hour shopping data show that fruit gift boxes have increased more than 3 times year on year since 2023, during which cherry gift box sales increased 102%. In addition, JD.com sales show that during the Spring Festival, consumers in the high-line market prefer to buy fresh, flowers, and other lifestyle products.

After the control during the pandemic, compared with that before the pandemic, the demand for convenience food and prepared food gradually rose in the post-pandemic era, and the consumption habits of such food were preserved during the pandemic (Figure 22) (Atin and Lintangah, 2023; Mudzakkir *et al.*, 2023). According to data released by the Korea Customs Service on 25 January 2023, the amount of kimchi imported by Republic of Korea in 2022 reached a record high of 169.4 million USD, up 20.4% from the same period the previous year. Convenience food has been popular in Thailand since the country gradually lifted coronavirus control measures in February 2022. According to LINEMAN, the most popular food delivery service ordered by Thais in 2022 was Songdang green papaya Salad, with more than 6.8 million Songdang servings sold on the platform from January to November. From April to July, the platform sold 320 000 servings of mango sticky rice, equivalent to using 150 t of mango and 60 t of sticky rice. During the

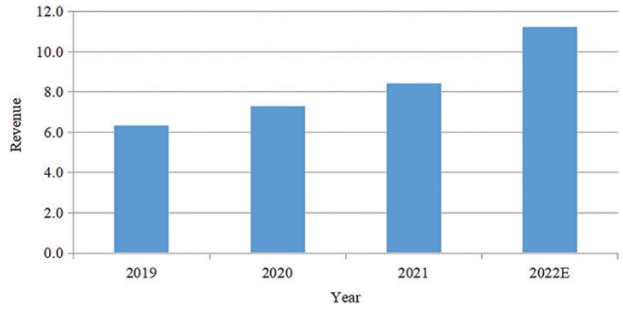

Figure 22. 2019–2022 prefabricated vegetable revenue (100 million yuan). Adding 'E' after the year indicates that the data for that year is an estimated value. Source: By prefabricated vegetables Dongfeng, aquatic food giant set sail again (Hua'an Securities Research Institute, March 2023).

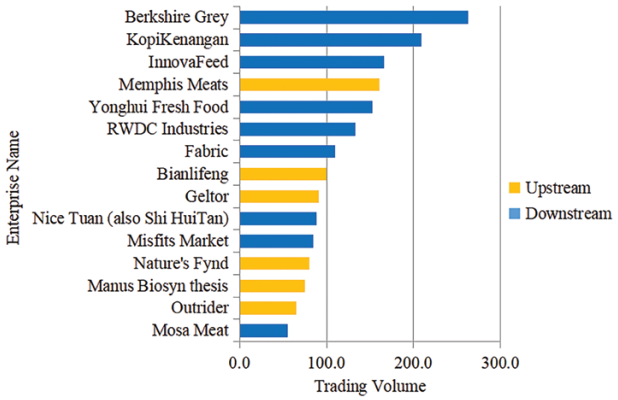

Figure 23. Top 15 Series B deals (unit: million USD). The robotics and automation venture, Berkshire Grey, raised its first round in 2013. Kopi Kenangan is boosting Indonesia's domestic coffee consumption in a market known for exports. The cultured meat companies, Memphis Meats and Mosa Meat, signal that they are edging towards commercialization. Source: AgFunder AgriFoodTech Investment Report (AgFunder, 2021).

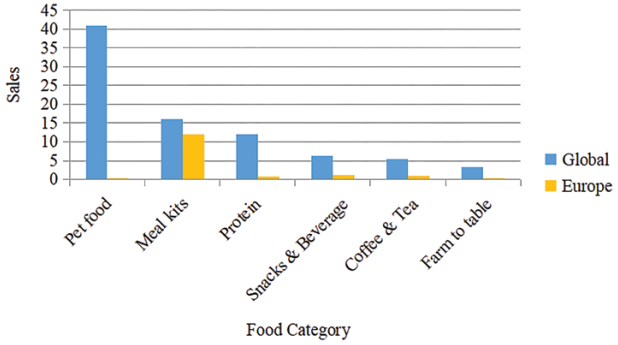

Figure 24. Top categories by combined value (unit: 1 billion EUR). COVID-19 paved the way for a D2C revival, unleashing 84 billion EUR in value. Source: The State of European Foodtech 2023 (Dealroom.co & Five Seasons Ventures, January 2023).

2023 Spring Festival in China, sales in prepared wet markets continue to soar. According to the '2023 Douyin Good Food Festival' data report released by the e-commerce company Douyin, pre-prepared dishes for New Year's Eve dinner have reached the peak of booking early, with sales increasing by 248% over the same period the previous year. According to the '2023 Spring Festival Holiday Consumption Trend' released by JD.com, the transaction volume of prepared dishes has increased more than 6 times year on year since the off-year. The monitoring data from iiMedia Research showed that as of 26 January, the sales volume of prepared dishes in the 2023 Spring Festival sales season in China was approximately 130.753 billion yuan, an increase of approximately 43.6% compared with the same period the previous year. The main sales areas were concentrated in East, South, and North China as well as large and medium-sized cities in China. Among them, the overall consumption of Guangdong accounted for one-tenth of the national market, approximately 12.875 billion yuan. The global demand for prepared food is also high. In 2022, Guangdong exported 834 000 t of prepared food, with an export value of 31.04 billion yuan, which made it a dining table for many countries, including the USA, Vietnam, Canada, and Singapore. According to the relevant data from Guangzhou Customs in 2022, during January–November 2022, Guangzhou Customs inspected and quarantined the export of cooked meat products, pickled cabbage fish, fish rotten fish eggs, and other prepared dishes worth approximately 1.82 billion yuan.

Compared to the pre-pandemic period, the post-pandemic era in the restaurant industry is characterized by a concerted effort to establish a more robust and interconnected supply chain system, bolster brand strength, and pursue a strategy of diversification in business development (Figure 23). The industry, which has withstood the test of COVID-19, has welcomed a spring in the post-COVID-19 era. The catering industry is gradually industrializing food (Wang *et al.*, 2023b), constantly pursuing stronger brand appeal (Wang and Yu, 2023), and greater capacity for stores and supply chain (Zechun *et al.*, 2023). In addition, a sales system has been established (Dinesh and Muniraju, 2023), which can sell both finished and semi-finished products, as well as pure vegetables and premade products (Figure 24). U.S. food and beverage tech startup Zitti has raised 3.5 million USD in seed funding, TechCrunch reports. Zitti charges restaurants 150 USD per month. Dicicco says that Zitti saves restaurants much money, and as a result, it gets a lot of conversion and good response from customers. Zitti currently focuses on southern California and Chicago, but the next plan is to expand to Austin. According to Dicicco, Zitti's expansion is based on a city-by-city approach, with a high-density layout providing it with more market intelligence. In China, cross-brand co-branding is a common way to strengthen brand appeal. The joint activity of the new Guofeng tea brand Throbbing Shao Xiancao and one of the most influential top animation IPs, 'Fox Demon Little Matchgirl', was officially launched on 6 January 2023. In just one week, the sales volume of the new products launched by Throbbing for the activity reached 500 000 cups in the country, and the exposure of the activity on the whole platform exceeded 100 million. According to the PR Newswire, on 2 August 2022, Grub Market, a U.S. food supply chain company, announced that it has completed the acquisition of IOTPay, a Vancouver-based company. IOTPay is a leading fintech company offering omnichannel payment services. With the acquisition of IOTPay, Grub Market will leverage IOTPay's payment infrastructure to meet the growing demand for faster, more flexible, and more powerful digital payments and financial services in the traditional food supply chain.

Discussion

Rejeb *et al.* (2022) analyzed the relationship between artificial intelligence (AI) and the agri-food industry and AI's role in accelerating the shift to precision and cognitive agriculture. In the discussion section, they discussed the development of artificial intelligence and the agri-food industry from three aspects: theoretical significance, practical significance, and research limitations. Qaz and Appolloni (2022) added management and policy implications in their discussion section. Sahoo *et al.* (2023) added the importance of management to their article and expanded the application scope of the research. We refer to the practice of the above authors to extend the research significance and contribution of this paper in three parts: theoretical implications (mainly management and policy implications), practical implications, limitations, and future research avenues.

Theoretical implications

The purpose of this study was to study the development trend of the food supply chain before, during and after the pandemic, and to strengthen the management of food supply chain safety and stability. This can help managers develop different timely strategies to address the barriers that hinder the implementation of food supply chain safety management. According to this study, industry professionals can develop different plans to address different types of barriers and take advantage of these barriers. The findings can be used by businesses, governments and other stakeholders. Managers can use less time and resources to more accurately maintain the safety and stability of the food supply chain.

This has major implications for sustainable production, trade and consumption policymakers. In the wake of the pandemic, policymakers can invest more in efficient production, whether expertise or infrastructure. Similarly, policymakers can gradually relax import and export control policies and stimulate enthusiasm for consumption. In addition, for the control of food safety, more accurate and efficient methods can be adopted to increase the policy tilt in this area.

Practical implications

For governments, ensuring the revival of economic activities to stimulate consumption is of paramount importance. This can be achieved through measures such as job creation, technical training programs for workers, and direct distribution of consumer vouchers. Additionally, policy support should be extended to enterprises employing digital technology and gene technology in food production and processing, including tax reduction. Moreover, it is imperative to prioritize food safety and environmental protection. Specific regulatory systems and provisions should be established to address issues related to food raw material sourcing, food waste management, takeaway packaging waste, and health and safety in the food production process. Standardizing production processes within the food industry, implementing robust supervision systems, and employing stringent digital traceability systems are essential for enhancing transparency and ensuring food quality and safety. These measures not only safeguard consumer rights and interests but also contribute to environmental conservation, thereby promoting a virtuous cycle between the environment and society. Finally, reducing trade barriers and facilitating import–export activities should be prioritized.

For farmers, embracing digitalization and mechanized production is crucial for enhanced convenience. Thus, emphasis should be placed on integrating digital and mechanical technologies into agricultural practices while striking a balance between human labor and technological advancements. Furthermore, the pandemic has revealed vulnerabilities and shortcomings, underscoring the need for farmers to not only restore pre-pandemic production levels but also ensure the cultivation of essential crops as contingency measures. Additionally, incorporating healthy gene breeding practices into crop production should be considered in line with consumer preferences.

Enterprises must recognize the diverse and significant demands emerging in the post-pandemic era and prioritize digitalization and mechanization in production processes. Collaboration with other industrial brands can enhance brand appeal and achieve economies of scope. Enterprises should also seize the opportunities presented by the post-pandemic period and actively engage in digital transformation. For example, the logistics industry can expand cold-chain logistics operations while enhancing safety supervision, and the catering industry can capitalize on the characteristics of pre-packaged food and fast food to expedite transformation efforts.

For consumers, health, speed, and safety have become imperative considerations. In addition, consumers should be mindful of balancing nutrition, minimizing food packaging waste, and addressing environmental concerns. Consequently, green food options should be prioritized as a crucial factor in consumption decisions.

Limitations and potential directions for future research

This study provides many research directions for future research on the food supply chain. For example, how can we improve digital traceability so that every food chain is traceable? How can emerging industries gain a foothold in financing after the pandemic? Will 100% mechanization and digitization of agricultural production be required? Where should those engaged in agricultural activities go, if needed?

Each study has its limitations. Nothing is perfect and lasting, like this study. The first limitation is common in systematic literature reviews because it relates to methods. To examine the methodology in its current form, we need to draw from a limited and predefined literature. Therefore, multiple keywords and multiple databases were used in this study to ensure that a large number of studies were related to the research question. However, we cannot rule out the possibility that any relevant research may be lost. The second limitation relates to people, which may affect the interpretation and analysis process. Although all the reports and data analysis were rigorously screened, it is not possible to exclude the selection of data by management factors.

Conclusions

The global COVID-19 pandemic had a profound impact on the global economy and people's lives. In the post-pandemic era, various production and consumption habits that developed during the pandemic have persisted, leading to transformation and challenges in traditional industries but creating opportunities for emerging industries (Table 8).

In the realm of food production and processing, the easing of restrictions and the resumption of raw material flows has stimulated agricultural production. The supply chain has

Table 8. Conclusion points

Process	Main point
Production	Agricultural production has resumed. Investment in agriculture has been increased. More attention to nutrition, ecology, high-value products, more attention to mechanization, digital production mode.
Circulation and Trade	The agricultural and trade sector has been reshaped. Imports and exports of agricultural products resumed. Pay more attention to the application of intelligent logistics and digital traceability system.
Consumption	The habit of buying food online was preserved. More nutritious, convenient food. The restaurant industry is becoming more industrialized.

stabilized, and increased purchasing power has attracted more capital investment in agriculture. The production focus has shifted towards nutrition, ecology, and high-value products, adopting mechanization, digitalization, and refinement as production modes. Enterprises emphasize brand management and local processing, while scientific research emphasizes nutrition and health breeding models, industry–academia collaboration, and technology implementation. In terms of food circulation and trade, the relaxation of physical control measures enables the flow of goods, overcoming market segmentation and reshaping the agricultural trade division. The pandemic-induced international trade barriers have weakened, leading to the recovery of import and export volumes for agricultural products, stabilization of bulk agricultural commodity prices, and resolution of food security concerns related to logistics and trade control. Digital technology plays a significant role in reshaping traceability systems, enabling real-time monitoring of supply and demand information, and facilitating rapid international trade through digital means. The cold-chain logistics system has been preserved, enhancing the convenience of fresh food transportation, and fostering the growth of specialized food logistics companies. In terms of food consumption, the relaxation of social distancing measures has revitalized the restaurant industry and encouraged its recovery. Farmers' markets have reopened with upgraded features, offering a wider range of functions and higher-quality agricultural products. Online fresh food purchases have become an enduring behavior, with convenient door-to-door delivery services becoming a new consumer habit. Convenient and pre-packaged foods have also gained popularity. The catering industry is gradually becoming more industrialized, making efforts to establish stronger brand appeal, expand store networks, enhance supply chain capacities, and establish comprehensive systems for selling finished and semi-finished products, as well as clean vegetables and pre-processed goods.

Author Contributions

Chenyang Yu: Data collection, data analysis, methodology, and writing. Jinbo Song: Data collection, data analysis, writing and editing.

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Conflict of Interest

The authors declare no conflict of interest.

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