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The Compounded Effects of COVID-19 Pandemic and Desert Locust Outbreak on Food Security and Food Supply Chain

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Abstract: The COVID-19 pandemic and locust swarm outbreaks pose a significant threat to global food systems, causing severe disruptions in both local and international food supplies from farm to fork. The main objective of this study is to understand and identify the disruptions during the crises and create a map of how resilience can be established to recover and sustain the food supply chain (FSC) functions as well as food security. The detrimental impacts of the compound crises on the FSC are explored and the effects of the affected areas are estimated under optimistic and pessimistic scenarios. As a response to the disruption caused by the crisis in FSCs, reactive and proactive solutions are proposed to develop resilience at the food sector level. In the short term, the reactive solutions, consisting of smoothing the food demand, supply and delivery, and food production and processing, can be borrowed. In the long term, the proactive solutions can be conducted by developing multi-level short intertwined FSCs. Our comprehensive investigation of the resilience elements in diverse operations and potential strategies should contribute to the improvement of FSC resilience in the face of ongoing and growing threats.

Keywords: food security; food supply chains; COVID-19 pandemic; locust swarm; resilience of agri-food supply chains

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1. Introduction

The worldwide spread of COVID-19 has caused the worst recession since the Second World War [1]. Among these, the food industry is one of the most vulnerable sectors, and the populations living in food crisis contexts are particularly exposed to the effects of the pandemic. Food systems incorporate all the stages of food production, from agriculture to household consumption [2,3]. Since the food supply chain (FSC) is becoming increasingly complex and multi-tiered, the accessibility of market factors, such as labor force and logistic resources, is vital for FSC functioning in the global environment. However, the COVID-19 outbreak, accompanied by mitigations, has exerted a synchronous negative impact on the FSCs. COVID-19 is not the only threat to FSCs. Since October 2019, the biggest locust invasion in almost three decades has broken out across Africa, the Middle East, South Asia, and South America and threatened more than three billion people's food insecurity [4].

COVID-19 and locust outbreaks, coupled with mitigation strategies adopted by countries, have posed multiple and synchronous effects on food production and logistics as well as food demands due to panic buying. As the crisis continues, the full impact on food security is difficult to predict and assess. To avoid exacerbating the food crisis, it is therefore essential to analyze the specific set of risks posed by COVID-19 and the locust crisis and provide insights and response strategies with a supply chain perspective. However, the overlapping effects of crises of FSCs have remained scantily explored in the literature. In response to the pressing food security problems, we address the following issues in this study: (1) how the food system will be affected, and (2) how to mitigate food security with a supply chain perspective.

The long duration of compound crises requires the government and organizations to examine FSCs from a broad viewpoint. The purpose of the current research is to understand and identify the negative effects of COVID-19 and the locust invasion and create a map of how resilience can be established to recover and sustain FSC function as well as food security. To this end, the content analysis method is adopted to analyze the current investigations and build on this information to assess the effects of the crises and develop resilience in FSCs.

The rest of the paper is structured as follows: We provide a brief literature review on resilience FSCs in Section 2. In Section 3, the research methodology of this study is introduced. The main disruptions of COVID-19 are analyzed in Section 4. In Section 5, the negative effects of the disruptions are assessed. The development of resilience in FSCs is presented in Section 6. Finally, Section 7 summarizes the main conclusions of this paper.

2. Literature Review

2.1. COVID-19 and Locust Crisis in Food Supply Chain

The strict lockdown has affected the demand and supply of various products as a result of restrictions imposed on shopkeepers and retailers in FSCs [3]. A few literature works have been dedicated to analyzing, assessing, and generating recommendations to function the FSC during the crises. Hossain [5] investigated the impacts of COVID-19 on the agri-food sector of Asia Productivity Organization Members. This analysis shows that the government plays a vital role in sustaining the critical agricultural inputs, such as fertilizers and safe, quality seeds, to meet seasonal crop calendars. The cross-sectional survey research design was employed by Inegbedion [6] through Facebook. The results show that food security can be threatened by insufficient labor, transportation, farmers' morale, and farm coordination. A simulation model of the public distribution system network was developed by Singh, Kumar, Panchal, and Tiwari [3] to help in developing resilient and responsive FSCs to assist in providing decision-making support for rerouting the vehicles as per travel restrictions in the concerned areas. Erokhin and Gao [7] explored the impacts of macroeconomic fluctuations on food insecurity in the cases of 45 developing countries. In this study, the autoregressive distributed lag method, Yamamoto's causality test, and variance decomposition were used and results show that food security risks in the lower-income and high-income developing countries are affected by COVID-19 differently. The former are mainly related to access to an adequate food supply, while the latter are subject to the food trade and currency exchange. O'Hara and Toussaint [8] investigated food justice during the COVID-19 pandemic in Washington, D.C. Three legal strategies, namely, landbanks and conservation easements, community land trusts, and cooperative business models, were proposed to help steer food justice. Rowan and Galanakis [9] reviewed the recent articles and discussed the challenges and opportunities presented by the COVID-19 pandemic for cross-cutting disruption in agri-food and Green Deal innovations. A set of recommendations was provided to facilitate community transitioning, training, enterprise, and employment in a low-carbon economy. The study conducted by Béné [10] reveals that the reason for the food security is not the virus itself but rather the consequence of the loss of income and purchasing power.

Several additional studies addressed the food security caused by the locust crisis. Chatterjee [11] adopted the district-level panel dataset from India covering more than 200 districts over 45 years to estimate the impact of an upsurge on crop yields. This study shows that wheat productivity would reduce no less than by 5–6%, whereas the wheat yield would decline by 12%. A review of the locust outbreak and its causes and prevention was conducted by Peng et al. [12]. This review shows that a shift in the crops towards soybean, rape, and watermelon would help to prevent locust outbreaks and obtain food security. Furthermore, the short commentary articles such as those by Rahaman et al. [13] and Editors [14] have also highlighted that the overlapping of locust swarms with the COVID-19 pandemic has resulted in a food crisis in many places all over the world.

2.2. Resilient Food Supply Chain

Uncertainties due to natural disasters, epidemics, policy, technological accidents, and terrorism-related risks have put the FSC in a precarious and vulnerable position [10,15]. Outbreaks of infectious diseases, such as the 2009 swine flu, mad cow disease, and Ebola, not only endanger health but also disrupt the FSC [16]. The risks may emerge at different FSC stages and could disrupt the flow of goods and services [15].

A resilience FSC can develop an adaptive capability to prepare for unexpected events and recover from or adapt to disruptions of various lengths, impacts, and probabilities [17] or optimize performance [18]. Various strategies have been developed to enhance the resilience of FSCs, including improving flexibility, creating redundancy, alternative sourcing, improving supply chain agility, enhancing visibility, restructuring of the supply chain, leveraging collaboration and relationships with supply chain partners, and information sharing [16,19]. Resilience is classified into operational and strategic resilience in the FSC. The former is reactive management and recovery-focused, while the latter is proactive management and renewal-focused [20]. Thus, the strategies available for building resilience have been classified as proactive and reactive depending on whether they are employed to avoid or recover from threats [21]. Queiroz and Ivanov [16] developed a framework including adaptation, digitalization, preparedness, recovery, ripple effect, and sustainability, in order to mitigate the impact of COVID-19 on the supply chain. Hecht and Biehl [22] identified ten factors contributing to organization-level resilience, specifically, formal emergency planning, staff training, staff attendance, redundancy of food supply, food suppliers, infrastructure, location, service providers, insurance, and post-event learning. In a study focused on business continuity, Caiazza and Volpe [23] developed a 3R (ready, respond, and recovery) business resilience risk assessment framework and an associated resilience indicator framework to ensure the readiness of the FSC.

Resilience requires creating a network of relatively independent self-reliant nodes so that the failure of one node does not risk the entire system [24]. An intertwined supply network (ISN) was introduced by Ivanov and Dolgui [25] to enhance supply chain resilience. Distinct from linearly directed supply chains with static structures, firms in ISNs exhibit multiple behaviors in buyer–supplier relations in interconnected or even competing supply chains [26]. Queiroz and Ivanov [16] developed a framework including adaptation, digitalization, preparedness, recovery, ripple effect, and sustainability, in order to mitigate the impact of COVID-19 on the supply chain.

2.3. Research Gaps

Several previous studies have documented risks and disruptions of the FSC, and most of these have focused on external catastrophic events, such as devastating earthquakes and political turmoil [21]. Frameworks, conceptual models, and quantitative models have been developed to address the resilience of FSCs to date. However, research on the impacts of epidemic outbreaks on the FSC is still a novel field. The current COVID-19 outbreak combined with the locust invasion has created a novel harmful situation for FSCs. Very limited articles addressed food security in terms of COVID-19 [8,27]; however, limited works have been reported on the resilience of the FSC from both the COVID-19 and the locust invasion perspectives. Further in-depth analysis on enhancing the resilience of FSCs in food industries is essential to address the complex risks. Moreover, few studies have explored sector-level resilience, which requires the FSC to contribute to resilience at the industrial, national, or supranational level [28]. This study covers a huge gap in the literature of the FSCs problem at hand through reviewing and analyzing the up-to-dated studies to assess the disruptions and build a resilient FSC to achieve food security at the sector level.

3. Research Methodology

To address the research questions, an analysis framework of the effects of COVID-19 and the locust invasion on the FSC was developed, as shown in Figure 1. The content analysis method was adopted in this study for disruptions identification, effects assessment, and resilience enhancement (See Figure 1). Content analysis is a research technique for making replicable and valid inferences from texts to the contexts of their use [29]. This research approach allows for the consideration of materials from various data sources and provides a systematic, rule-governed, and theory-driven analysis of the fixed communication [30,31]. The information is collected from both electronic databases, such as Taylor and Francis, ScienceDirect, Inderscience, EmeraldInsight, and websites by adopting the well-proved keyword-based and phrase-based searches [31]. In this study, keywords including COVID-19 and locust crisis combined with food demand, food security, FSC, food delivery, food production, agriculture, and farming were used. Since this study aims to develop resilient FSCs on the basis of the damage facts of the ongoing crises, the information collection not only included the facts and the statistical data in reports, web news, and articles for identifying the disruptions and assessing the damages in the FSC but also included articles relevant to the theoretical bases of the resilient FSC. The former offers firsthand and updated information of the damages to the FSC, and the latter provides well-proved principles and theory-based guidance which can be borrowed and extended to assist resilience development in the FSC to promise food security.

In the effects assessment of the crises, the scenarios analysis approach was used. Scenarios are best suited for long-range, macro, uncertain environments which are typified by a scarcity of data and a large number of non-quantifiable factors [32]. Scenario analysis is the process of understanding, analyzing, and describing system behavior in the context of uncertainties [33]. It requires only minimal mathematical or computer support, does not require extensive historical data, can readily reflect internal changes, and adapts well to shifts [32,34].

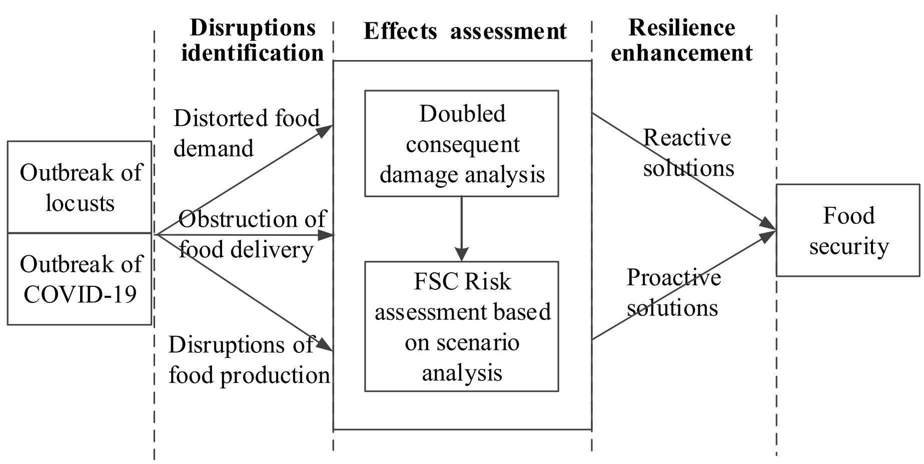

Figure 1. Analysis framework of the effects of COVID-19 and the locust crisis on the food supply chain (FSC).

4. Food Supply Chain and Disruptions Caused by COVID-19 and Locust Invasion

An FSC typically comprises a large variety of different supply chain partners such as retailers, wholesalers/distributors, various traders, processors, marketers/storage, farmers, and farm suppliers [2,7]. FSCs beginning with the domestic farmer A and the oversea farmer B represent a local FSC and a global FSC, respectively. As shown in Figure 2, both depend on a complex flow of semi-finished materials, finalized food products, food production, and processing resources, such as machines and fertilizers, as well as workers. The global FSC differs from local FSCs based on three key trends: globalization, consolidation, and commoditization [35]. Consolidation indicates that a few large businesses have concentrated control of the markets by integrating vertically up the chain and horizontally across markets [35]. The food products are commoditized and traded as undifferentiated goods, generally in large quantities to seek higher margins in FSCs.

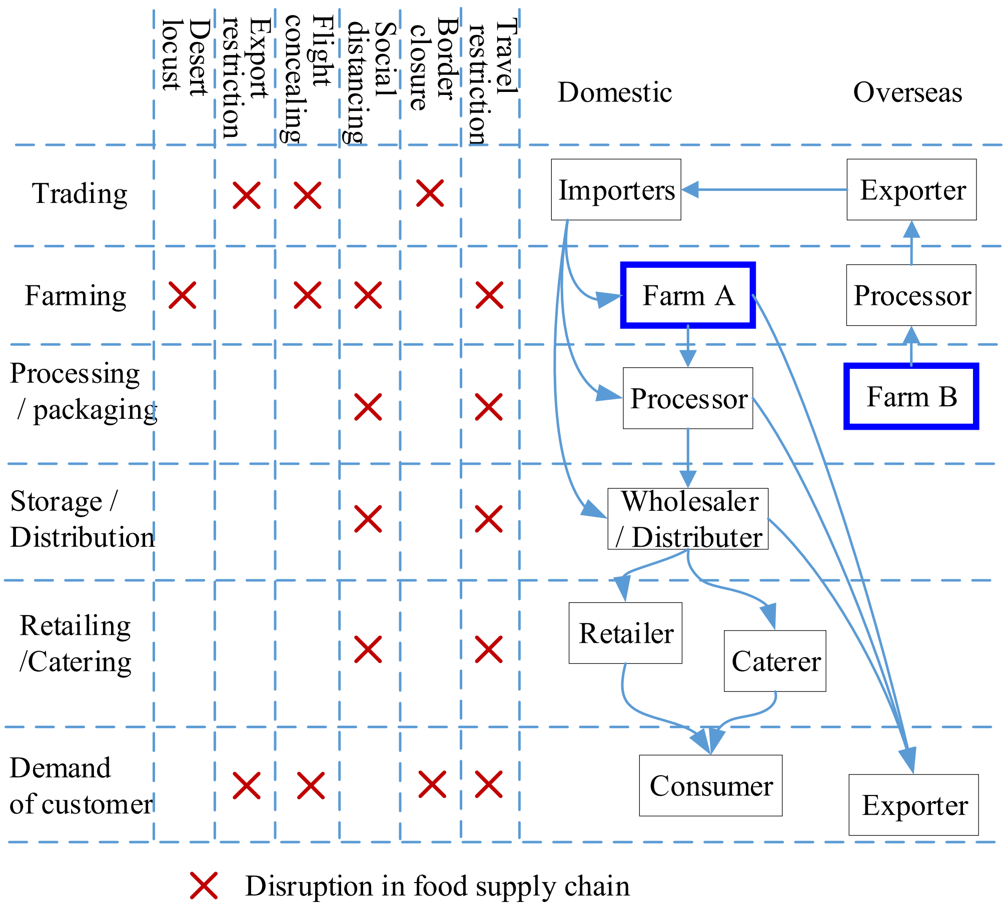

Figure 2. Structure and disruption of the food supply chain.

Movement constraints have been imposed on human resources, goods, and machines and have led to interference with food demand, production, and delivery in both global and local FSCs (left-hand side, Figure 2. The locust invasion affects the FSC directly by destroying the crops in the farmland.

4.1. Distorted Food Demand

Based on the motivation of the customers' buying behavior, food demands during the crisis can be grouped into three categories: normal, panic, and humanitarian demands. Normal demand is relatively stable unless the crisis is estimated to have a very long duration, such as the demand for rice and flour. Panic demand is a result of non-rational behavior and motivated by the fear of shortage. Panic demand, which is developed by panic buying behavior, is not caused by the actual food shortage but rather the fear when people face uncertainties during a crisis [36]. As a response to restrictions on free movement and stringent confinement rules, many countries have witnessed short-term spikes in demand for various basic products, such as the U.S. [37]. Humanitarian demand is driven by meeting the necessary nutrition requirement to keep healthy. Some underprivileged groups are experiencing undermining of nutritional security due to a significant reduction in income and purchasing capacity. Some 20 million people are facing a food crisis due to the locust invasion [14]. The U.N. World Food Programme has warned that an additional 130 million people could face acute food insecurity by the end of 2020 [38].

4.2. Obstruction of Food Delivery

Food products are delivered by logistics using various transportation modes. The restrictions on the movement of people and goods across many countries have led to a major strain in food delivery systems both at the local and global levels. The flow of staple foods and fresh products has been heavily disrupted worldwide. For instance, Malaysia faces a shortage of rice as Vietnam has suspended its rice exports [39]. The closure of borders by Malaysia has, in turn, sparked fears that fresh food that is normally exported may not reach Singapore [40]. In retail, restaurants, supermarkets, and stores play crucial roles in last-mile food delivery. Social distancing and quarantine measures are preventing or limiting access to the public to food outlets. Moreover, the popular just-in-time inventory mode in food retailing reduces their flexibility to adapt to the sudden surge in demand [24,41].

4.3. Disruptions of Food Production

The restrictions on mobility have not only restricted farmers' access to markets for buying and selling products but also to plantations for farming. Over 80% of countries, accounting for 92% of the global GDP, are facing a shortage of labor availability for agricultural supply chains [36]. For instance, in Liberia, 47% of farmers reported that they were unable to cultivate farmland due to the virus outbreak [42]. In some parts of the world, due to the unavailability of seasonal laborers, unharvested crops have been left to rot in fields [43]. High-value foods, including fruits, vegetables, and dairy products, require considerable labor for picking, sorting, and packing. Supply chains for these foods are usually dominated by a few big concentrated processors that are particularly vulnerable. Disruptions have been observed in the harvest of fruits and vegetables in Western Europe due to quarantined or sick employees and a lack of migrant laborers [44].

Comparably, the locust invasion is a severe and direct threat to food security, devouring crops and destroying the livelihoods of entire communities of farmers and herders. The locust breeds extensively in semi-arid zones extending from West Africa through the Middle East to Southwest Asia, threatening the livelihoods of populations in over 65 countries [45]. A very small part of an average swarm eats the same amount of food in one day as about 10 elephants or 25 camels or 2500 people [46]. Several communities across Kenya and Ethiopia have reported up to 100% destruction of their crops by the swarms [4]. Production of cassava crops in East Africa is anticipated to decline considerably. Pakistan has registered inflation in the price of tomatoes and wheat [47]. A great loss in food production has been observed and the locust crisis situation is still serious in some areas.

5. Effects Assessment of COVID-19 and Locust Invasion on FSC

5.1. The People and Agriculture Affected by the Doubled Consequent Damages

The population, COVID-19 cases per million of the population, the arable land, and the cereal production in 2019 of the main affected areas are presented in Table 1. This information consists of 35 countries whose detailed data are provided in Appendix A. Here, data from Sri Lanka were removed from South Asia, since there is no locust threat in this region. The average number of COVID-19 tests per million of the population in these countries is 51,647, while the number is 5303 in West Africa, which is significantly lower than the average global level of 284,980. Moreover, in South America, the cases per million of the population are more than two times the average global infections. Those countries covers less than 37.3% of the global arable land, however, it has to help more than 43.3% of the world population to survive. Since around 32% of the world cereal production has been produced in normal time in the affected area, the coupled damages would result in several food shortages in the context of the disrupted international logistics.

Table 1. People and agriculture affected by both COVID-19 and the locust invasion.

Affected Areas (by Locust Invasion)	Population (million)	COVID-19 Cases per Million Population	Arable Land (Million Hectares)	Cereal Production in 2019 (million tons)
North Africa	195.6	5864	21.2	38.1
West Africa	320.7	454	72.8	58.2
East Africa	335.7	681	62.2	53.4
Southern Africa	191.9	3587	31.7	22.2
South America	258.2	32,809	120.2	203.2
Near East Asia	274.1	11,949	54.5	64.3
South Asia (not including Sri Lanka)	1799.0	5150	197.4	438.8

The population and the COVID-19 cases are given based on Worldometers [48]; arable land is given based on the World Bank [49]; cereal production is given base on the FAO [42] and the Office for the Coordination of Humanitarian Affairs (OCHA) [50].

5.2. Assessment of FSC Risk Based on Scenario Analysis

5.2.1. Scenario Generation

In this section, the scenario analysis method is adopted to assess the negative impacts of COVID-19 and the locust invasion on cereal production. In this analysis, the damage to FSCs caused by the crises is assessed in terms of availability of mass vaccination and controllability of the locust invasion in the affected countries in the coming twelve months. Based on the analysis of the impact of COVID-19 and the locust crisis on the FSCs, two scenarios have been generated to estimate the damage. The assumptions of the scenario generation are presented in Table 2.

Concerning COVID-19, Worldometers [48] shows it is too early to claim that the second wave of COVID-19 has happened in most of these double affected countries. Here, the second wave of COVID-19 refers to the peak of infections per day no less than the maximum cases in the past twelve months. Though some countries have amounted vaccination plans in the coming months, due to the constrained supply, it is unclear whether developing countries, including most of the doubled affected countries, can access the mass vaccinations. To provide vaccines to low-income people in developing countries will always be full of challenges in 2021 [51].

In general, a total of 878 million tons of global cereal production has been heavily affected by the locust invasion. Among these products, 85.2% of cereals are harvested in the summer and 14.8% are harvested in the winter. Thus, the damage caused by the locust crisis to the production of different cereals, including rice, wheat, and coarse grains, depends on the crop harvest time. The harvest periods in most of those countries are around May and October; thus, the controllability of the locust invasion would affect the yields of the cereals in summer and autumn. Two parameters determine the controllability of the locust invasion: the available funds received by the Food and Agriculture Organization of the United Nations (FAO) and the precipitation in the breeding areas. The assumption relevant to the former is based on the funding information provided by [52], while the basis of the weather prediction was performed by [53,54].

Table 2. Assumptions of the scenario analysis.

	Second Wave of COVID-19 and the Vaccine Availability	Controllability of the Locust Invasion
Optimistic scenario 1	No second wave of COVID-19 in the winter of 2020–2021 occurs; Mass vaccinations are available within six months for the most vulnerable populations.	The spread of the locust crisis is conditionally controlled in most of the affected countries in six months.
Pessimistic scenario 2	The second wave of COVID-19 in the winter of 2020–2021 occurs; The mass vaccination is unavailable within six months but available for most of the vulnerable population in twelve months.	The locust crisis continues in the affected countries in six months but is conditionally controlled in twelve months.

5.2.2. Cereal Production Estimated Based on Optimistic and Pessimistic Scenario Analysis

The estimated cereal production change rates in 2020 and 2021 are compared with those of 2019, as shown in Table 3. It can be observed that cereal production in North Africa, West Africa, and East Africa will cut down sharply in 2020 and 2021. The rapid increase in the yields recently will also be halted in Southern Africa due to the crises [55].

Table 3. Changes in cereal production in the areas affected by the locust invasion.

Affected Areas (by Locust Invasion)	Cereal Production in 2019 (million tons)	Optimistic Scenario 1		Pessimistic Scenario 2	
		Change in 2020	Change in 2021	Change in 2020	Change in 2021
North Africa	38.2	−50.00%	−41.23%	−57.02%	−90.00%
West Africa	73.9	−10.00%	−7.10%	−33.17%	−90.00%
East Africa	55.4	−20.00%	−17.69%	−25.78%	−70.00%
Southern Africa	22.2	39.89%	72.35%	15.57%	4.14%
South America	235.3	0.50%	0.45%	0.49%	0.35%
Near East Asia	74.6	2.90%	2.69%	2.84%	2.03%
South Asia (excluding Sri Lanka)	394.6	1.25%	1.05%	1.19%	0.88%

Data are estimated based on the reports of the United States Department of Agriculture [56], Asian Development Bank [57], FAO [58–63], Irfan and Kirby [64], and Office for the Coordination of Humanitarian Affairs (OCHA) [50].

In optimistic scenario 1, since the countries will not experience the second wave of COVID-19 and vaccines should protect the people gradually in the coming months, current restrictions on domestic and intercontinental travel would start to ease in this case. Local and migrant workers would go back to the farms, food plants, and logistics and retailing sectors would return to normal. FSCs would be expected to recover rapidly in terms of both supply and demand. Moreover, given that locust outbreaks in these countries are conditionally controlled, agriculture production will resume back to normal levels gradually. However, cereal production often needs six months or longer for a single harvest. The locust invasion has resulted in severe losses in these countries, and therefore a gross reduction by 2.28% is estimated in 2020. Among the affected areas, North Africa, West Africa, and East Africa are the most significantly affected, with a cereal production loss of up to 50%, 10%, and 20%, respectively, in 2020. Due to the adoption of effective preventive measures, Southern Africa and Near East Asia should have good outputs, with increases of 39.9% and 2.9%, respectively. The increase in Southern Africa is mainly because the countries in this area are less affected by the locust invasion before the autumn harvest in 2020 [55]. In this scenario, the cereal production would be reduced by 20.4 and 7.5 million tons in 2020 and 2021, respectively.

In pessimistic scenario 2, the delayed mass vaccination, in conjunction with a new wave of COVID-19, would motivate the tightening of restrictions. Although some of the most vulnerable people would be protected by the vaccine in an emergency, mass vaccination determines market confidence and is essential for economic recovery. The movements of workers, equipment, fertilizers, seeds, and other necessities for farming would be restricted by the imposed COVID-19 prevention plans. The food processors and retailers would have to mitigate the rising cost of operation by increasing food prices and cutting down on staff numbers, leading to a higher unemployment rate and lower food availability for people in deprived areas. Furthermore, the locust crisis will continue and threaten 3.4 billion people's food supply. A cereal production loss of 5.5% is estimated in 2020 and 14.9% in 2021. In particular, output loss in North, West, and East African countries will be up to 90%, 90%, and 70%, respectively, in 2021. Notably, one of the main cereal production and export areas, South America (including Brazil and Argentina), has been invaded by locusts, potentially resulting in a 0.35% increase in production yield in 2021. South America provides around 27% of cereal output of the areas affected by locust swarms. Similarly, a slight loss in South Asia, including India and Pakistan, is anticipated and cereal production will increase by 0.88% in 2021. Since COVID-19 incurs restrictions on food trading and drives up food prices, the imbalance in food supply and consumption in global FSCs will be exacerbated.

6. Risk Mitigation and Resilience Enhancements of the Food Supply Chain

A failure of any one element in a supply chain would cause disruptions for all upstream and downstream partner companies [65]. However, the ongoing damage caused by COVID-19 and the locust invasion affects not only the single FSC of a specific food but also almost all FSCs of the affected countries and districts. Thus, it is essential to examine the resilience of FSCs at a sector level rather than a firm level or supply–demand chain level. Both reactive and proactive solutions are required for recovery and improving the resilience of FSCs. The ability of the FSC to respond to and recover from threats to operations is critical for public health and food security. The recovery plan for supply chain disruptions varies based on the severity of supply chain disruptions [19]. It is thus critical to establish resilience in FSCs to enhance recovery capability during the crisis by smoothing the food demand, supply, delivery, production, and processing in the short term. Proactive strategies can be introduced by developing an intertwined food supply network in the long term.

6.1. Reactive Solutions: Smoothing the Flow of Information and Food Products

6.1.1. Smooth Food Demand

Normal demand for food should be stable in the long term, but imbalance may occur between supply and consumption due to asymmetric information. Enhancement of visibility and coordination among FSCs not only contributes to eliminating the information distortion but also paves the way for transparency of production and processing activities of food products. For end consumers, publicly available food supply information is the key to maintaining confidence and preventing panic buying [66]. Local food organizations, large retailers, and the government should work together to collect and disseminate market prices and information at both the global and local levels.

Humanitarian food demand should be dealt with without delay. Families living close to or below the poverty line are highly vulnerable to the effects of the pandemic. Many

African countries that are invaded by the locusts are net importers of food. Ensuring the continued availability of essential food to vulnerable communities during the disruptions should be a priority of any implemented policy [67]. Reduced or slowed delivery of humanitarian assistance may be catastrophic in these contexts. Furthermore, governmental and non-government agencies should be sensitive to food prices and ensure that vulnerable populations can afford food products. A subsidy for selected food products offering essential nutrients to low-income families should be provided to importers, farmers, and small retailers to restrict pricing.

6.1.2. Smooth Food Supply and Delivery

Protectionist policies exacerbate disruption to global value chains and amplify the already elevated levels of uncertainty [68]. For food products relying on foreign farms, the short-term priority is to evaluate the effects of the crises on international logistics and suppliers as well as production loss in the coming harvest season. The hurdles that delay inspection and quarantine measures for food products should be re-evaluated and immediately removed. A procedure of green lanes, rather than the general constrictive measures as a response to mitigate COVID-19, for border checks of vehicles carrying fresh foods should be established. As mentioned before, alternative transportation modes can be established to increase the flexibility of FSCs by diversifying the logistic channels. Air cargo may be effectively utilized by taking advantage of the current extra capacity, as successfully implemented by Qatar Airways over the last ten months.

The main constraints to food purchases due to lockdown should be removed. The aim is to connect food outlets and consumers while ensuring safe working conditions. An emerging phenomenon is a boom in online ordering and home delivery accelerated by COVID-19 in many countries. Online shopping allows customers and retailers to be connected but also to maintain social distancing to prevent the spread of COVID-19 [69].

6.1.3. Smooth Food Production and Processing

One of the major barriers to farming or food processing is the lack of a sufficient labor force, such as home-returning farmers in India and seasonal farmworkers in Europe. Personal protective equipment, such as masks, goggles, gloves, and handwashing materials, should be made available. Green channels with a simplified procedure could expedite employee visas to prevent labor crunches on farms and food plants. Plans for personal welfare, testing, and treatment of COVID-19 should cover traveling migrant workers. Moreover, to cope with the shortage of farmworkers, unemployed individuals or those who have lost their jobs could be temporarily hired for harvesting work. For instance, internet platforms such as "Let's take action to secure our bread" in France and "The country helps" in Germany have helped bring farmers and potential harvest workers together [44].

In addition to human resources, agricultural production relies on other factors, such as seed, pesticide, fertilizer, machines, and fuel [5]. The smooth flow of these productive factors should avoid disruption of specific farming stages. In general, the timing and quantity of demands for these factors can be estimated in advance. Thus, one effective action would be to increase inventory levels. However, an extension of warehouse capacity or extra rental warehouse inventory may incur a cost increment, potentially resulting in financial difficulties. Consequently, farmers, including those affected by locust plagues, need cash handouts that potentially improve productivity. Banks should be incentivized by the government to waive fees on farmers' loans and grant extended payment deadlines.

Another vital task is to provide technicians, machines, special-purpose aircraft, and pesticides and develop effective plans to control the locust plague. The governments of the affected countries are encouraged to develop regional and national contingency plans for the locust crisis, promote learning across countries to boost competencies in forecasting, surveillance, and control, and explore new technologies for surveillance, such as drones.

6.2. Proactive Solutions: Developing Multi-Level Short Intertwined Food Supply Network

Elucidation of the vulnerability of FSCs in the context of COVID-19 and locust swarms should pave the way to build resilience at all levels of the food supply chain. From a strategic perspective, the root of the FSC fragility is the unreliable and erratic connections of the elements. One effective way to improve FSC resilience is to develop multi-level short intertwined FSCs (MSI-FSC), as shown in Figure 3. The extra links among the activities of sourcing and importing, farming, collecting, and distributing are developed to reunite the FSC components, rather than sole connections (See Figure 1). These features contribute to the resilience of FSCs by improving flexibility in case of disruption at any stage of the supply chain. This MSI-FSC is characterized by diversifying food consumption, developing local food production capability, and interconnecting the entities of the FSCs.

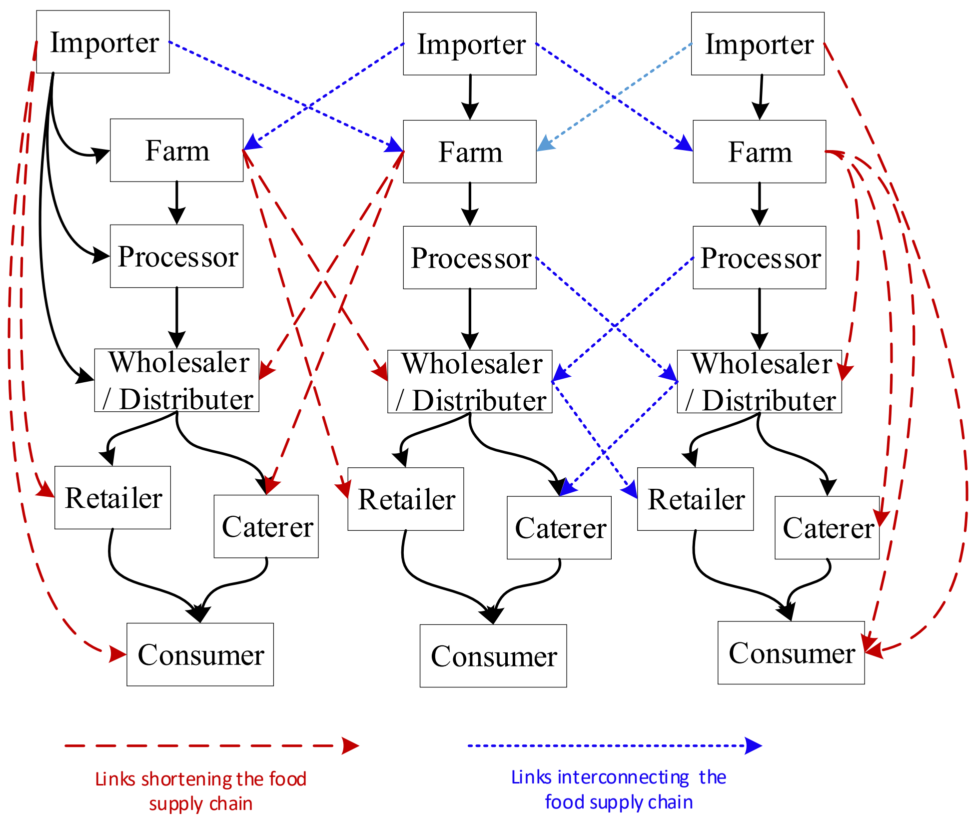

Figure 3. Illustration of multi-level short intertwined food supply chain network.

6.2.1. Promotion of Local Food Consumption

Local food refers to the region where the food is produced, sold, and consumed within a limited geographical area [70]. A local FSC is one of the most popular solutions that have been mentioned by academics and governments. The main barriers to consuming local food are higher prices, accessibility, and availability [71]. From the government side, a subsidy to retailers or farmers would increase the competitiveness of the local foods. The U.S. Department of Agriculture has invested more than USD 20 million each year since 2017 to promote local food consumption [71]. Moreover, food producers and retailers also need to label local foods to ensure they are easily visible among the thousands of food products in the supermarkets. These measures have proved effective in Qatar for many local foods, including poultry, meat, dairy, and some vegetables [72]. Local consumption promotions from 2017 onwards due to the perception of food security have become long-term changes, providing Qatar with more flexibility when facing global food supply disruptions.

6.2.2. Development of Local Food Production Capability

Local production plays a vital role in developing resilient FSCs. However, local food is often connected with high costs. Online shopping and the application of smart technologies in FSCs not only help promote the local food in the market but also reduce its cost by improving business efficiency. The promotion of foods from local farmers can be implemented in various ways, such as direct sales to individuals, collective direct sales, and partnerships [73,74]. The innovations in information and communications technology, such as the Internet of Things, big data, digital supply chain twins, and artificial intelligence technology, are revolutionizing agriculture and provide the supporting technologies to establish the effective trust-based communication between farmers, researchers, and policymakers [75]. For instance, the farmers of the local greenhouse in Qatar have used social media, such as Twitter and Facebook, to connect their customers and deliver fresh vegetables with smart logistics. The development of the local food capability can be performed with local food consumption promotion in the context of e-commerce and smart logistics solutions.

The local food processing capacity is one of the elements often neglected in reality. For instance, if a country needs wheat, flour, noodles, and bread from foreign farmers or producers, these products need to be directly imported. Consequently, the food chain is very long and vulnerable to international disruptions. However, if the country only imports wheat from farmers abroad and domestically produces the food products, the FSC is more flexible. Enhancement of food processing capacities often leads to a cost increase; thus, this policy should be implemented carefully not only because of financial consideration but also to avoid protectionism. Moreover, a localized strategy in FSCs is diversification and a supplement, rather than a substitute for food importation for most of the countries.

6.2.3. Interconnecting Entities of the Food Supply Chain

An effective set of methods may be adopted to develop links among the elements in FSCs. First, the barriers to diversified sourcing must be urgently reassessed and removed. Dual or multiple sourcing not only facilitates a stable food supply but also competitive pricing. The government is advised to develop compulsive rules for large importers to ensure that the import of the same food product from a country does not exceed a certain proportion (for example, 20–30%). Local and international sourcing should be simultaneously performed. This principle should also work for other products related to food, such as chemical fertilizer and seeds. The second diversification depends on transportation. For instance, ships and trains can also be used for fresh foods by adopting high-tech preservation techniques, such as selective inactivation of micro-organisms [76,77].

The links between the nodes can be established through various connections. The dimension of the FSC can also be achieved by diversifying and decentralizing the facilities of food processors and distributors. Overconcentration of facilities in a particular location often means that the food supply chain is at a larger risk of disruption in a crisis. Building resilience in food systems is about building capacities [10]. Thus, an improvement of the inventory—in particular, food products that can be preserved for a long time—would increase redundancy in the FSC.

7. Conclusions

COVID-19 has significantly disrupted the availability of labor forces, imports, agricultural inputs, processing plants, shipping, wholesalers, and retailers, leading to a strain on both global and local FSCs. The locust outbreak has further exacerbated the food shortage in the affected countries. The protracted pandemic crisis presents an opportunity to identify the constraints and bottlenecks of FSCs to develop strategies for generating a more resilient food system. This investigation analyzed and assessed the detrimental effects of COVID-19 and the locust crisis on food demand, production, and delivery as well as the logistics in FSCs. The solutions for risk mitigation and resilience enhancements are proposed using the content analysis approach.

To the best of the authors' knowledge, this study is the first attempt to assess the effects of the COVID-19 pandemic coupled with the locust invasion and propose mitigation strategies in FSCs. The contribution of this study is twofold. First, the doubled consequent damages caused by COVID-19 and the locust crisis to food production of the most vulnerable areas are evaluated in the context of both optimistic and pessimistic scenarios. Second, as a response to the disruption caused by the crisis in FSCs, reactive and proactive solutions are proposed to develop resilience in the food sector. Reactive solutions, which aim to recover the FSC functions, consist of smoothing the demand, supply, production, processing, and delivery of food. Proactive solutions, which aim to enhance the ability to sustain FSC functions, have been proposed to develop the MSI-FSC.

Our collective findings can help governments, farmers, food processors, and delivery organizations, as well as researchers, identify the resilience elements in diverse operations and develop potential strategies to improve resilience in the face of ongoing and growing global threats. In the short term, the organizations should recover the function of the FSC by smoothing the flow of information and food products. In the long term, the organizations are advised to diversify their food system by promoting local food consumption and production, as well as developing interconnections among the entities in FSCs. However, the implementation of the proposed solutions must be careful, not only because the solution should be matched to the relevant phases of disruption and their broader impact on the supply chain assessed, but also because some solutions are expensive and the additional costs should be counted.

Limitations

There were two limitations of this study that should be noted. Due to the complexity of the food system and multiple effects of the current crises, the disruptions in the scenarios are estimated based on multiple-source information and the authors' expertise, rather than quantitative models. The risk mitigations proposed in this study do not consider constraints of the implementation, such as the expenditure of the financial situation of a country and the economy development level. However, future review research can be carried out using simulation models to mimic the damages of COVID-19 and the locust invasion and develop solutions with cost consideration.

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Appendix A

Table A1. People and agriculture of the 35 countries affected by both COVID-19 and the locust invasion.

Country	District	Population (million)	Cases/1 Million Population	Arable Land (Million Hectares)	Cereal Production in 2019 (million tons)
Argentina	South America	45	33,122	39.20	84.10
Brazil	South America	213	32,495	80.98	119.10
Turkey	Near East Asia	85	22,022	20.38	34.30
South Africa	Southern Africa	60	14,521	12.50	13.88
Iraq	Near East Asia	40	14,177	14.69	6.80
Iran	Near East Asia	84	13,208	14.69	21.70
Morocco	North Africa	37	10,801	8.13	5.40
Saudi Arabia	Near East Asia	35	10,269	3.48	1.43
Tunisia	North Africa	12	9378	2.90	2.40
Nepal	South Asia (not including Sri Lanka)	29	8486	2.11	10.80
India	South Asia (not including Sri Lanka)	1383	7147	156.46	324.80
Namibia	Southern Africa	3	6529	0.28	0.06
Botswana	Southern Africa	2	5425	0.26	0.01
Bangladesh	South Asia (not including Sri Lanka)	165	2976	7.76	59.90
Algeria	North Africa	44	2095	7.40	6.10
Pakistan	South Asia (not including Sri Lanka)	222	1989	31.04	43.30
Kenya	East Africa	54	1695	5.80	4.10
Ghana	West Africa	31	1690	4.70	4.30
Egypt	North Africa	103	1183	2.79	24.10
Lesotho	Southern Africa	2	1059	0.35	0.04
Ethiopia	East Africa	116	1009	15.12	29.70
Uganda	East Africa	46	599	6.90	3.50
Mozambique	Southern Africa	32	537	5.65	2.84
Angola	Southern Africa	33	488	4.90	2.14
Sudan	East Africa	44	487	19.82	6.00
Nigeria	West Africa	207	352	34.00	29.90
Somalia	East Africa	16	285	1.10	0.19
Mali	West Africa	20	285	6.41	10.30
Burkina Faso	West Africa	21	199	6.00	5.00
Chad	West Africa	17	106	4.90	3.00
Niger	West Africa	24	94	16.80	5.70
Yemen	Near East Asia	30	69	1.25	0.04
Zimbabwe	Southern Africa	30	69	4.00	0.97
Zambia	Southern Africa	30	69	3.80	2.27
Tanzania	East Africa	60	8	13.50	9.90

The population and the COVID-19 cases are given based on Worldometers [48]; arable land is given based on the World Bank [49]; cereal production is given base on the FAO [42] and the Office for the Coordination of Humanitarian Affairs (OCHA) [50].

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