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# Food supply chain management in disaster events: A systematic literature review

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ABSTRACT

The food supply chain (FSC) is considered to be a critical infrastructure by all governments, and multiple strategies have been proposed to make FSCs more resilient towards disruptions. However, major disasters such as COVID-19 have exposed the vulnerabilities in FSC that were previously invisible (or easily solved) during normal operation but become a major challenge in a major disaster situation. Researchers quickly responded to the challenge, as shown by the significant increase in the number of articles on FSC management in disaster events since COVID-19, providing the motivation for this article. This research conducts a systematic literature review on research into FSC management in disaster events. The articles identified are analysed using content analyses to distinguish research objectives, methodologies, threats from different types of disasters and proposed solutions. This article also uncovers research gaps and presents suggested research directions. One of the gaps identified is the lack of research on humanitarian FSC. Most articles are focused on the resilience of commercial FSC during disaster events, while lacking research focused on humanitarian FSC. There are several differences between commercial and humanitarian FSC, making further research on humanitarian FSC necessary.

## 1. Introduction

The food supply chain (FSC) is a network of activities to provide food for society and maintain food security [1]. As with other supply chain scenarios, various actors interact with one another in various FSC stages such as production, processing, distribution, and consumption. FSCs can be disrupted at any of the stages from the production to consumption. Disruptions in FSCs are defined as any significant breakdown events that affect one or more FSC stages [2]. Disruptions to FSCs can cause economic, social, environmental, and political challenges. Therefore, FSCs are considered critical infrastructure by all governments. Furthermore, FSCs have a crucial place in the achievement of food security and food safety monitoring [3]; hence, preparedness against the risk of disruption in FSC is essential.

Some of the greatest risks to FSCs are disasters (man-made or natural), and research has been conducted on FSC management in various disaster events [4–6]. Nevertheless, the major FSC disruption caused by COVID-19 demonstrated that more challenges in FSC management in major disaster events exist because the vulnerabilities in FSC that were previously invisible or easily solved were

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revealed. Hence, substantial research has emerged to address FSC issues resulting from the COVID-19 pandemic. Given the significant growth of research in FSC management in disaster events in recent years, systematic review of the literature on this topic is needed. Furthermore, major disasters are expected to occur more frequently resulting from climate change, making this topic has even more significant.

The objective of this article is to conduct a systematic literature review (SLR) on FSC management in disaster events. Our review complements existing reviews on this topic of supply chain resilience in general and FSC disaster management (Table 1). Table 1 also summarises the differences between our article (row 8) and previous review articles (rows 1 to 7).

Three articles [4–6] review FSC in the context of disasters. Umar et al. [5] review the literature on FSC resilience against natural disasters, finding that research into FSC resilience in a disaster scenario was in its infancy. However, the number of articles has significantly increased since the start of COVID-19. Furthermore, Umar et al.'s [5] review differs from ours as it is more focused on developing a conceptual framework to understand how an FSC can become more resilient to natural disasters using only content analysis. Manning and Soon [4] review the literature on FSC resilience focusing only on bioterrorism, whereas our review includes multiple disaster types, including bioterrorism. A recent review by Davis et al. [6] discusses FSC resilience from environmental shocks such as algal blooms, pest, coral bleaching, flood, and drought; hence, there is an intersection with our review. However, the research does not cover other major disasters such as outbreaks, bioterrorism, and nuclear accidents. Stone and Rahimifard [9] review articles on FSC resilience, identifying the multidisciplinary aspects of resilience that are applicable to FSC. The scope of the review covers a broader range of disruptions than our review, as we focus on disasters. Reviews by Singh et al. [10]; Mandal [7] and Tukamuhabwa et al. [8] examine overall supply chain resilience; hence, do not focus on FSC and do not engage disruptions from disasters. In summary, our article is among the first to systematically review the literature regarding FSC in disaster events with the longest timespan.

The remainder of this article is organised into four sections. We explain the SLR method applied in this article in Section 2, followed by an analysis of the articles identified in Section 3. The analysis begins with a discussion of the research objectives and methodologies applied in the articles and a discussion regarding the various threats to FSC from disasters and proposed solutions addressed in the articles. We dedicate a section to examining humanitarian FSC, which is a subset of FSC in disaster events. We end the discussion with a summary of research gaps. Section 4 discusses potential research directions and Section 5 concludes the article.

## 2. Materials and methods

In this review, we adopt the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines for the SLR [11]. PRISMA is chosen as it provides clear guidance for conducting a SLR [12]. PRISMA also improves methodological and reporting quality [13]. Fig. 1 presents the steps taken in the selection of articles for review.

For the identification phase, we selected Scopus, Web of Science and EBSCOHost database for our literature search. We limited our search to articles that were (1) published in peer-reviewed journals, (2) written in English, (3) related to FSC and (4) related to disaster. We searched the following words in the title, abstract and keywords of the articles to satisfy the third and fourth criteria: ('food supply chain' OR 'food logistics') AND (outbreak OR bioterrorism OR disaster OR earthquake OR flood OR 'extreme temperature' OR drought OR wildfire OR cyclone OR storm OR 'wave surge' OR epidemic OR endemic OR pandemic OR 'insect plague' OR 'animal plague'). In this phase, we identified 396 articles. The 396 articles were then filtered to remove duplications, identifying 111 duplicated articles and resulting in 285 unique articles to be further processed in the screening phase.

In the screening phase, two co-authors independently reviewed titles and abstracts of the 285 identified articles to ensure that the articles were related to FSC (the third criterion) and disaster (the fourth criterion). To minimise subjectivity, we used the following procedure. An article would move to the next phase when the two co-authors marked it for inclusion. When an article was only included by one co-author, they discussed it and decided. If they could not reach an agreement, the lead author independently read the abstract and made the final decision. In this phase, we retained 178 articles.

In the eligibility phase, we first excluded five articles because the full text was not available. Next, four co-authors read the articles independently to determine whether they were related to FSC and disaster and followed the same exclusion procedure as in the screening phase but based on the full text. An article would move to the next phase when the three co-authors marked it for inclusion. If an article was included by only two co-authors, the lead author made the final decision. From this, we retained the final 122 articles for analysis. The list of the articles is presented in the supplementary material.

**Table 1**
Differences between relevant literature review articles and our article.

| No | Paper | Content Analysis? | Articles Time Span | Food Supply Chain? | Disasters? |
|---|---|---|---|---|---|
| | | (Y/N) | (Year) | (Y/N) | (Y/N) |
| 1 | [7] | Y | 1980–2012 | N | N |
| 2 | [8] | Y | – | N | N |
| 3 | [4] | Y | – | Y | Y |
| 4 | [5] | Y | 2000–2015 | Y | Y |
| 5 | [9] | Y | – | Y | N |
| 6 | [10] | Y | 2000–2018 | N | N |
| 7 | [6] | Y | 2008–2019 | Y | Y |
| 8 | Our article | Y | 1974–2020 | Y | Y |

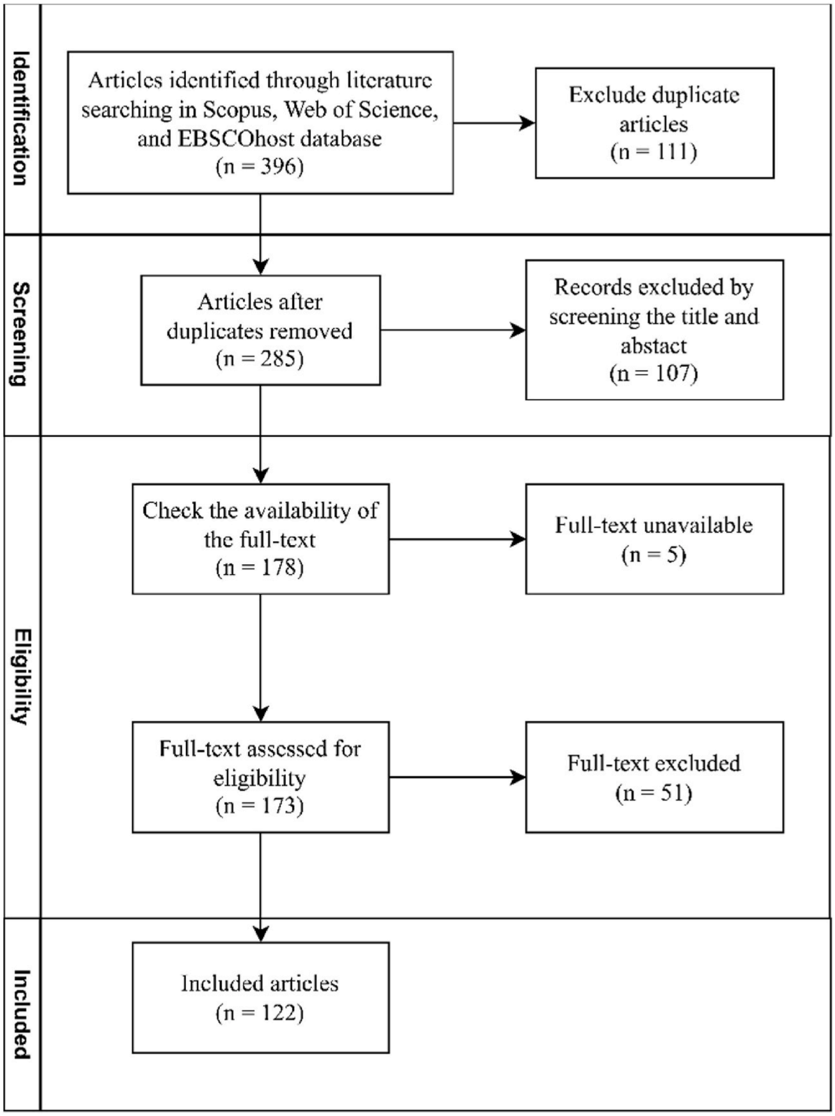


**Fig. 1.** PRISMA flow diagram.

## 3. Research landscape on FSC management in disaster events

This section begins with a discussion on the research objectives found among the articles retrieved via PRISMA to identify patterns in existing articles in this topic. We also map the methodologies used in the articles. Then, we deeply discuss the threats of each disaster found among the articles and the solutions proposed. A special discussion on humanitarian FSC management during disaster events is also discussed.

**Table 2**
Research objectives of identified articles.

| Index | Research Objective | Count of Research Objective |
| --- | --- | --- |
| A | To assess the risk/impact of disaster to FSC | 78 |
| B | To design/evaluate FSC strategy for disaster preparedness | 20 |
| C | To propose food tracing methods | 19 |
| D | To assess policy implications to food safety under disaster | 4 |
| E | To propose a method for community engagement | 1 |
| Grand Total | | 122 |

### 3.1. Research objectives

The most common research objective, accounting for more than half of the articles, is the assessment of the risk or impact of a disaster on FSC, as shown in Table 2. Risk is associated with the possible effect of a future disaster, whereas impact is associated with the effect of a disaster that has occurred. For example [14], assess the impact of the Bird Flu (H7N9) on the poultry meat supply chain in China, and Yadav and Sharma [15] review the potential risk of bioterrorism attack on FSC.

The second most common research objective is proposing an FSC design to manage disruptions from disasters or evaluating the preparedness of an existing FSC for future disasters. The typical performance measures for evaluations include the cost efficiency of the FSC operation (e.g., Refs. [16,17,18]), demand fulfilment (e.g. Refs. [19–21]), and resilience measures (e.g., Ref. [22–24]). Although this is the second most common objective, the number of articles is relatively low for such an important objective, revealing a research opportunity.

The next most common objective is research that proposes methods for tracing contaminated food products during foodborne outbreaks. For example, Schlaich et al. [25] propose a calibrated gravity model to identify the source of foodborne outbreaks. Another example is Keeratipibul et al. [26]; presenting a genotyping method called Multilocus Variable Number of Tandem Repeat High-Resolution Melting Analysis (MLV-HRMA) for screening Salmonella contamination. Matta et al. [27] use radio-frequency bio-sensing technology to detect pathogens in contaminated liquid. These technologies can be used to track the source of contamination in FSC.

In summary, our result shows that the research objective has been dominated by risk or impact assessment. This is understandable because we need to estimate the risk and impact of disasters on FSC before we can make decisions to manage the risk. However, understanding the impact or risk of disaster on FSC alone is not enough. We need more research on finding the best strategies to manage the risk of disaster on FSC.

### 3.2. Research methodologies

Both quantitative and qualitative research methodologies are used in the research on FSC in disaster events, as shown in Table 3. The quantitative research methodology applies assessment, statistics, simulation, and optimisation, whereas qualitative research articles use three main methods of phenomenology, grounded theory and critical theory.

Consistent with risk and impact assessment being the most common research objective, risk assessment is the most used quantitative method, a commonly applied analytical method to identify hazards and assess the associated risk. Examples include measuring the probability of future terrorist attack on FSC [28] and evaluating the potential implications of COVID-19 on FSC resilience [29].

The second most used quantitative method is statistical modelling. The statistical models can be as simple as descriptive statistics which describes the data by providing the summary through several metrics or a more complex inferential and predictive statistics to draw bigger conclusions from data sample. For example, Jacobs et al. [30] present a network model to trace the source of foodborne disease outbreaks. Several works employ big data analytics, which is also classified as statistical methods in Table 3. For instance, Kaufman et al. [31] use sales data, coupled with a likelihood-based statistical approach to identify contaminated food products. Erokhin and Gao [32] assess COVID-19 impacts to food security using various data sources such as the number of confirmed COVID-19 cases, food trade balance, food inflation and currency exchange. Nevertheless, the number of studies that use big data analytics remains limited (only three of 26 statistically based articles).

Combining optimisation and simulation, both of which are Operations Research/Management Science (OR/MS) methods, such methods are the third most used quantitative method and are primarily used to design or evaluate FSC. For example, Zhu and Krikke [23] evaluate the design of perishable FSC after an outbreak using system dynamics. Chaturvedi et al. [22] propose an agent-based simulation model to evaluate interventions that minimise the impact of a bioterrorism attack on FSC. Rancourt et al. [16] propose an optimisation model for food relief distribution in Kenya, optimising the location of distribution centres and coverage areas. Perdana et al. [21] developed an optimisation model for food supply networks during COVID-19. The model maximises the demand fulfilment with minimum logistics cost, considering several sources of uncertainty (i.e., production capacity, demand quantity and distribution cost). While risk assessment and statistical modelling are important, OR/MS methods have the potential to help decision makers solve FSC challenges in disaster events. However, the literature reveals that OR/MS methods have not been widely used for this research,

**Table 3**
Research objectives and methods of identified articles.

| Methods | Objectives | | | | | Grand Total |
|---|---|---|---|---|---|---|
| | A | B | C | D | E | |
| Phenomenology | 27 | 4 | | | | 31 |
| Statistics | 20 | 1 | 5 | | | 27 |
| Risk Assessment | 21 | | | 1 | | 21 |
| Microbiological Tracing | 2 | | 10 | | | 12 |
| Simulation | 7 | 3 | | | | 10 |
| Optimisation | | 7 | | | | 7 |
| Grounded Theory | | 3 | 2 | | 1 | 6 |
| Critical Theory | 1 | 1 | | 3 | | 5 |
| Investigational Tracing | | | 2 | | | 2 |
| Electrophysics Engineering | | 1 | | | | 1 |
| Grand Total | 78 | 20 | 19 | 4 | 1 | 122 |

opening space for further scholarly exploration.

The most used qualitative method is phenomenology. Phenomenology is a qualitative method for objectively evaluating and describing a phenomenon that begins without any hypotheses or assumptions [33,34]. The main purpose of phenomenology is to ground the foundation of knowledge so that any indecisive subject on rationality and its procedures could be quelled [35]. This is achieved by resembling particular patterns or possible relations among events in reality and characterize the situations [36]. The ability to accommodate the phenomena of a certain event probably explains why phenomenology becomes the most used method [37]. In this review, 31 articles apply phenomenological approaches to investigate the impact of disasters on FSC. For example, Attwood and Hajat [38] study the impact of COVID-19 on meat consumption behaviour. The next common qualitative method is grounded theory. Grounded theory constructs a theory based on the analysis of empirical data collected for a specific issue [39]. For example, Hecht et al. [40] collect historical data from 26 food system businesses and organisations when facing disasters in Baltimore City. The experiences include preparation, emergency response and recovery phases. Data analyses result in the theory that organisations that are larger, better resourced and affiliated with national or government partners have superior resilience. The next most common qualitative method is critical theory. Critical theory offers a qualitative method to obtain recommendations for an institution or other subjects to address a challenge [41]. For FSC, this method is typically used to provide recommendations or suggestions to decisionmakers. For example, recommendations for African governments to ensure food security during COVID-19 are proposed in Lawson-Lartego and Cohen's study [42]. Annamalai et al. [43] suggested several potential preparations for governments and aid groups in Pacific regions to counter the drought impacts of El Niño.

We can also use the cross-sectional analysis between research objectives and research methods in Table 3. The result shows that two methods - phenomenology and risk assessment – have been mostly used to conduct risk or impact assessment. They are hardly used for other research objectives. Statistical modelling has been mostly applied to assess risk or impact. Optimisation has only been used to evaluate designs (or decisions) for disaster preparedness. While simulation has been used both for risk/impact assessment and design evaluation.

In summary, our result shows that the dominance of risk/impact assessment in the research objective has led to the dominance of methods such as phenomenology and risk assessment. With the increasing need of research into managing the risk of disaster to enable better preparedness and faster response, there is a need to use OR/MS methods such as simulation and optimisation more often. Simulation and optimisation have been used in system design and evaluation. When combined with network analytics, they can also be used for research objectives such as tracing food and source of contamination. Finally, there is a clear lack of research into the policy assessment and stakeholder engagement. These two are critical when implementing solutions into the real world.

### 3.3. Disasters identified

This section identifies the disasters addressed in the literature. The most common disaster is outbreaks, with 91 articles, of which 49 articles focus on COVID-19. This confirms our earlier assertion that the COVID-19 pandemic has increased the amount of research addressing FSC management in disaster events. The next two most common types of disaster are drought (eight articles) and bio-terrorism (five articles). The complete result is shown in Table 4. The general (unspecified) articles claim that their findings are applicable to any disaster. Most articles address a specific disaster which is consistent with the fact that the threats on FSC differ depending on the types of disaster.

A further analysis on the cross reference between disaster types and methods is shown in Table 5. All the identified methods have been used to address the risk on FSC by outbreaks. This could be explained by the major disruptions due to the global COVID-19 pandemic. Hence, researchers from different subject areas work to address the many issues caused by the pandemic. Whereas other disaster such as drought, flood, earthquake, and storm are dependent on the geospatial factors; hence, a particular disaster has different prevalence in different countries [44]; Gocic and Trajkovic 2014). If we exclude outbreaks from Table 5, risk assessment is the most widely used and covers more disaster types, followed by phenomenology and statistical methods. Given that most methods in Table 5 are universal; there is a lack of studies that apply these methods outside outbreaks.

We conduct another analysis that cross-references research objectives against disaster types in Table 6. Despite the dominance of outbreaks, none of the studies look at into the stakeholder/community engagement which is essential for real-world implementation. Whereas for other disaster types, the number of articles is relatively low and most of them focus on risk/impact assessment and design

**Table 4**
Number of articles by FSC type and disaster type.

| Category | Disaster Type | Index | Total Articles | FSC Type | |
|---|---|---|---|---|---|
| | | | | Commercial | Humanitarian |
| Natural | Outbreak | I | 91 | 90 | 1 |
| | Drought | II | 8 | 4 | 4 |
| | Flood | III | 5 | 5 | – |
| | General (unspecified) | IV | 5 | 4 | 1 |
| | Other – Storm | V | 2 | 2 | – |
| | Other – Earthquake | VI | 2 | 1 | 1 |
| | Other - Extreme Heatwave | VII | 2 | 2 | – |
| Man-Made | Bioterrorism | VIII | 5 | 5 | – |
| Multi-disasters | Earthquake and tsunami | IX | 1 | 1 | – |
| | Earthquake, tsunami and nuclear accident | X | 1 | 1 | – |

**Table 5**
Methods and disasters of identified articles.

| Methods | Disasters | | | | | | | | | | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | I | II | IV | VIII | III | IX | X | VI | V | VII | |
| Phenomenology | 24 | 2 | | | 3 | 1 | | | 1 | | 31 |
| Statistics | 22 | 2 | | | 1 | | | 1 | | 1 | 27 |
| Risk Assessment | 11 | 2 | 3 | 3 | | | 1 | | | 1 | 21 |
| Microbiological Tracing | 12 | | | | | | | | | | 12 |
| Simulation | 8 | | 1 | 1 | | | | | | | 10 |
| Optimisation | 4 | 1 | | | 1 | | | 1 | | | 7 |
| Grounded Theory | 4 | | | 1 | | | | | 1 | | 6 |
| Critical | 3 | 1 | 1 | | | | | | | | 5 |
| Investigational Tracing | 2 | | | | | | | | | | 2 |
| Electrophysics Engineering | 1 | | | | | | | | | | 1 |
| Grand Total | 91 | 8 | 5 | 5 | 5 | 1 | 1 | 2 | 2 | 2 | 122 |

**Table 6**
Research objectives and disasters identified.

| Disasters | Objectives | | | | | | Grand Total |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | |
| I | 57 | 13 | 14 | 5 | 2 | | 91 |
| II | 5 | 3 | | | | | 8 |
| III | 4 | 1 | | | | | 5 |
| IV | 3 | 1 | | | 1 | | 5 |
| V | 1 | 1 | | | | | 2 |
| VI | 1 | 1 | | | | | 2 |
| VII | 2 | | | | | | 2 |
| VIII | 4 | | | | | 1 | 5 |
| IX | 1 | | | | | | 1 |
| X | | | | | 1 | | 1 |
| Grand Total | 78 | 20 | 14 | 5 | 4 | 1 | 122 |

evaluation. Hence, there is a lack of studies that aim to propose food tracing methods, to trace the source of contamination in FSC during foodborne outbreaks, to assess policy implications to food safety under disaster and to propose methods for community engagement.

### *3.4. Threats to FSCs from disasters and the proposed solutions*

Based on the identified disasters, we summarise the threats on FSC by disaster types and the solutions proposed by researchers in

**Table 7**
Proposed solutions in response to threats to FSCs under multiple disaster scenarios.

| Disaster | Threat | Vulnerable Stage of FSC | Solution |
|---|---|---|---|
| Outbreak | Food contamination, consumer demand shifting, temporary closure of restaurants and bars, worker illness, mobility restrictions, production speed slows down and food shortage | All FSC stages | Risk assessment [45], contaminant detection [26,27,46], food tracing [47–49], supply chain network optimisation [17,21,50], health protocol application [51–54] |
| Drought | Restricted water supply, crop failure | Growers, processors | Risk assessment [43], adopt water-saving technology, switching irrigation system, use drought-resistant varieties [55], food aid distribution optimisation [16] |
| Bioterrorism | Food contamination | All FSC stages | Preparedness workshop [56], food tracing [28] |
| Flood | Crop failure and loss, loss of transport access, damaged facilities, power outages, food shortage, increased food cost | All FSC stages | Risk assessment [57], use alternative routes and modes of transport [58], connecting FSCs (long and short) and local governments [59], relaxed quality standard [60] |
| Earthquake, Tsunami | Damaged facilities, power outages, insufficient emergency shelter | All FSC stages | Use potential shopping street with disaster-proof building as emergency evacuation shelter and use mathematical optimisation to calculate the optimum capacity of refugees that could be accommodated [20] |
| Extended Heatwave | Power outages, food processing and storing failure | Processors, distributors | Risk assessment [61], integrating food access into the emergency response planning [62] |
| Storm | Power outages, food processing and storing failure | Processors, distributors | Risk assessment [63], integrating food access into the emergency response planning [62] |
| Nuclear accident | Radioactive food contamination | All FSC stages | Review food residue limits of radioactive contents, food monitoring, apply region-based food restriction [64] |

Table 7 and a detailed explanation is given below.

### 3.4.1. Outbreak

An outbreak can pose multiple threats to FSCs. The first threat is food contamination [65], such as E. coli on salads [66], listeria monocytogenes on leafy green vegetables [67], listeria monocytogenes on milk and meat products [68], shigella sonnei on parsley [69], Salmonella on tomatoes [70], E. coli and Campylobacteriosis in livestock products [71], mycotoxins in livestock products [72] and human adenoviruses in berries [47]. Food contamination can occur at all stages of a FSC [26].

Another threat is related to mobility restrictions imposed to reduce the spread of a disease. For example, in the case of COVID-19, the disease's rapid spread forced countries worldwide to enact mobility restrictions [73,24,74], including border control and lockdowns [17,42,75]. A similar mobility restriction was also applied during the Ebola Virus Disease (EVD) outbreak [76]. Mobility restrictions generate complex challenges. First, they restrict the production and distribution of agricultural and livestock products [29,77–79]. In major outbreaks, such as COVID-19 and EVD, production and distribution capacity are further reduced by the infected or quarantined workers across the supply chains [51,76,80]. Mobility restrictions can also result in the large-scale closure of restaurants, bars and other commercial services [38,81,82]. This closure combined with reduced production and distribution capacity produces food shortages. To make matters worse, with the reduced distribution capacity, perishable food products cannot leave farms, becoming unnecessary food waste [23]. During COVID-19, several countries established export and trade restrictions [32,83], disrupting the global distribution of food products. Mobility restrictions and lockdown also slow down economic activities [24]. As a result, unemployment rates increase, reducing consumers' purchasing power of [84,85]. The most vulnerable may be unable to afford food products. Hence, all FSC stages are vulnerable to the threats from an outbreak [86].

The articles that address FSC outbreak events can be grouped into several streams. The first stream focuses on the management of FSC risk caused by the threats from an outbreak. The most common approach is conducting a risk assessment. For example, LeBlanc et al. [87] conduct the risk assessment of E. coli contamination on leafy vegetables, while Goldsmith et al. [45] assess the risk of the outbreak of foot-and-mouth disease in the United States on the distribution of agricultural products. Another approach is proposing criteria for certain processes to mitigate the risk of an outbreak. For example, Robinson et al. [88] proposed criteria for selecting companies to safely transport food, including traceability, transparency, trustworthiness, testability, time, and training. Risk mitigation can be accomplished through policies or interventions. For example, Talley et al. [89] evaluated strategies of replenishment policy, food detection, food inspection and recall, to mitigate the risk of a foodborne outbreak. Finally, applying health protocols in all FSC stages is critical for assuring food safety from farm to fork as well as the safety of the labour [38,51,90].

Research in the second stream applies sensing technology to detect food contamination and sanitation technology to deactivate contamination. For example, Clustered Regularly Interspaced Short Palindromic Repeats-Multi-Virulence-Locus Sequence Typing (CRISPR-MVLST) is presented in Ref. [91] to detect Salmonella. Carlson et al. [46] propose the use of several micro- and nanotechnology could be used to detect foodborne pathogens. Matta et al. [27] present radio-frequency bio-sensing technology for detecting pathogens in contaminated liquids such as milk to prevent foodborne outbreaks. To deactivate virus contamination in packaged food, cold plasma system can be used instead of chemical sanitisers [92].

The third stream focuses on food traceability, referencing the ability of food network structures to accurately perform source identification [93]. Food traceability is crucial for minimising risk to the population during an outbreak of foodborne diseases [48,49]. Researchers propose methods to support food traceability during an outbreak, e.g., effective distance network approach [30] or a gravity-based food flow model [25]. Several information technologies (e.g., RFID) can also be implemented to support food traceability [94]. Maunula et al. [47] track the enteric virus source in a berry fruit supply chain in Europe by taking samples throughout the food production chain. Inns et al. [95] trace the source of E. coli in catering venues in the United Kingdom conducting a matched case-control study among catering venues.

The fourth stream optimises the FSC network. For example, Yu and Nagurney [19] propose an optimisation model to analyse FSC networks before, during and after an outbreak to maximise profit, considering product perishability. Perdana et al. [21]. Investigate the optimisation model for food supply networks through establishing regional food hubs during the COVID-19 pandemic to maximise demand fulfilment with minimum operational costs. The model considers several sources of uncertainty such as food production capacity, food demand and operational cost. Chen et al. [17] construct an optimum strategy for contactless distribution service, proposing a multi-vehicle multi-trip routing solution to maximise the freshness of food delivered.

### 3.4.2. Drought

The impact of drought on FSC differs across producer groups (e.g., crop producers, cattle producers) [55]. However, in most cases, the direct impact is the limited water supply which affects food production and processing [43,96]. For example, in Brazil, orange and sugarcane production was reduced by 30–40% during an extreme drought in 2014–2015 [96]. When facing drought, multiple crops are at risk of failure and livestock are at risk of death [97–99]. The impact of drought is worse in countries where food insecurity is already an issue. As drought typically affects a large area, all FSC stages may be vulnerable to the threats from drought.

To manage the threats from drought, researchers initially assess the risk and impact of drought on FSCs (e.g., Refs. [97–100]). Some researchers propose the implementation of closed-circuit processes to reuse water in food production and processing [96]. Another solution proposed is fresh produce growers' transferring to a more efficient water irrigation system, shifting to more drought-resistant varieties, and eliminating lower value crops [55]. Livestock producers are also encouraged to purchase additional feed and reduce the herd size.

### 3.4.3. Bioterrorism

In bioterrorism preparedness, the main threat is food contamination. This threat can lead to illness among those who consume the contaminated food, and in severe cases, it can lead to fatalities. Mohtadi and Murshid [28] present several historical bioterrorism attacks on FSCs. In one case, recorded on September 14, 2002, in Tangshan, Nanjing, China the breakfast in a fast-food restaurant was poisoned with rat poison, resulting in 41 fatalities and 400 others affected. This kind of attack can happen at all FSC stages.

To address the threat of bioterrorism on FSC, Levin et al. [56] examine the effectiveness of a workshop on preparedness against bioterrorism attack on FSCs facilitated by the US Centre for Disease Control and Prevention's National Institute for Occupational Safety and Health Southwest Centre for Agricultural Health, Injury Prevention, and Education. The workshop was designed to engage local community leaders in preparing for and responding to bioterrorism FSC attacks. The authors observe a statistically significant improvement in participants' knowledge following the workshop.

Other researchers assess the risk of bioterrorism attacks on existing FSC networks. For example, Liu and Wein [101] investigate the risk of bioterrorism attack on FSCs through calculating the possible number of people affected by contaminated food under various scenarios (purchase time, dose of the poison and incubation period). Yadav and Sharma [15] conduct a risk assessment study of bioterrorism attack, applying a risk assessment tool developed by Sandia National Laboratories and the US Food and Drug Administration to determine the vulnerable points/segments within a supply chain. The tool identified the points of vulnerability in a supply chain by assessing each point using seven criteria of criticality, accessibility, recuperability, vulnerability, effect, recognisability and shock.

#### 3.4.4. Flood

The most common threats from flood disasters on FSCs are crop losses and failures [60]. For example, more than two million tonnes of rice crops were lost in the 1998 Bangladesh floods [57]. Similarly, the 2011 flooding in Queensland caused US$792 million in vegetable crop losses, e.g., potatoes, lettuce, pumpkins, onions and tomatoes [59]. Another threat is the loss of transportation access which disrupts the flow of food products [102,103]. For example, milk processor, Queensland Dairy Farmers, reported that processing capacity decreased to only 10% of usual volume as access to transport milk from farms to processing plants was hampered [60]. The threat of floods can lead to food shortages and increase food prices [63,58].

Floods also affect residential areas, making households at risk of food insecurity from extra expenses or loss of income. Although food banks and other charity organisations can temporarily help with food insecurity, further assistance is often required, sometimes for a prolonged period [62]. Therefore, an effective protocol should involve coordination and communication between government, non-governmental organisations, and private sector businesses. Collective community resilience can also have a significant function [59]. assert that community resilience depends on the availability of resources as well as strong social network relationships in the community.

Multiple solutions are proposed to mitigate the risks of flooding on FSCs. The first solution is to improve collaboration between FSCs. Long FSCs are more vulnerable to floods because more points exist for flooding to disrupt (e.g., damaged transportation access or damaged warehouses); therefore, a short FSC is more resilient. Such collaboration will allow a short FSC to function as a distribution hub for a long FSC [60]. FSC collaboration also allows the distribution of alternative food sources. In general, collaboration between FSCs increases redundancy in the network, making the network more resilient. Transportation diversity during disaster events can also increase FSCs' resilience. For example, during the 2011 flood crisis in Queensland, barges, helicopters, planes, and army vehicles were used to deliver food throughout the state [60]. Relaxing food quality standards to the lowest acceptable benchmark has also been applied by several retailers to maintain food supply [60,59,58].

#### 3.4.5. Other disasters

*Earthquakes:* The most common threats from earthquakes on FSCs is the damage to facilities and infrastructure (e.g., road, water, gas, electricity). Damaged roads and transportation infrastructure can cause losses in accessibility and disrupt FSCs [102]. Citizens are at the risk of losing homes and capabilities to fulfil food needs, resulting in many evacuees. The two articles addressing the impact of earthquakes on FSC [104,105] present risk assessment studies. Nozhati et al. [104] assess the risks of earthquakes on FSCs, studying the impact of earthquakes on infrastructural interconnectedness of electrical power, water and transportation that affect FSCs. Rathore et al. [105] use failure mode and effect analysis and fuzzy VIKOR to estimate the risk of an earthquake on FSCs.

*Heatwave and storm*: Heatwaves and storms can lead to power outages [104]. For example, in December 2013, a storm in Ontario caused a 72-h power outage [62] which led to failures in many FSC stages, including food processing and storage. Food processing and storage equipment cannot operate without power backup, and these conditions can cause food loss. Moreover, power outages can also disrupt payment and ordering systems, forcing food retailers to close. Therefore, such disasters can potentially disrupt the processors, distributors, and retailers along an FSC.

To manage the risk caused by heatwave and storm, Zeuli et al. [62] examine the risk of Toronto's food supply under several weather extremes, such as extended heatwaves and storms. The respective critical points for analyses when assessing the risk of extreme weather on FSCs include public transportation, road networks, electrical power systems, telecommunications, fuel supply and food storage and distribution facilities. Governments can assist FSC actors in identifying and establishing alternative backup power sources and storm drainage pumps.

*Nuclear accident*: In nuclear accidents, the main threat to FSCs is radioactive food contamination. A nuclear accident can release radioactive materials into surrounding environments and can affect the production centres (e.g., farms), and the contamination can spread to FSCs. Gilmour et al. [64] describe the steps taken by the Japanese government to minimise the risk caused by the 2011 Fukushima Dai-ichi nuclear accident on FSCs. The immediate step taken by the Japanese government was to issue a temporary guidance on food safety, including setting the Caesium food residue limit on several types of food. The distribution of food products from Fukushima prefecture was also restricted, and a continuous food monitoring system was implemented to ensure food safety. The food monitoring system showed the highest contamination in wild animal meats and fishery products, also finding that the coastal areas in the two neighbouring prefectures, Ibayaki and Miyagi, were affected by the nuclear accident, causing the government to issue additional prefecture-based food restrictions.

### *3.5. Humanitarian food supply chains*

A special case within the research on FSC management during disasters is humanitarian FSCs that focus on providing food for disaster victims or evacuees. In contrast to commercial FSC, one of the main differences with humanitarian FSC as discussed by Pullman and Wu [106] is that humanitarian FSC aims to minimise loss of life and quickly appease suffering, whereas commercial FSC aims to produce high quality products at lowest cost possible. Hence, the measures taken to evaluate the performance of humanitarian FSC are typically demand fulfilment and response time. Meanwhile, performance measures for commercial FSC are typically related to profit, cost, market share and resource utilisation. Other differences include the demand patterns and lead time (humanitarian FSC is more unpredictable with high variation), supply chain configuration (humanitarian FSC includes temporary organisations) and quality of data (data during humanitarian operations are often unreliable and incomplete). Hence, these differences create different challenges for humanitarian FSC management. Our review shows that there are only five articles on humanitarian FSC (out of 122 articles in our analysis). This finding indicates a lack of research in this area. A summary of the five articles is given below.

Lindtjørn [98] assesses the impact of drought on food security in Ethiopia, observing that drought caused food shortages that force people to migrate to seek food access; however, such migration increases the risk of death, particularly among children. The author suggests that adequate food relief should be distributed as soon as possible in the early phase of droughts to prevent migration. Anderson and Woodrow [99] emphasise leveraging existing community capacities (labour, animal tracks, educated youth and pack animals) for food aid distribution, and the importance of empowering communities by increasing capacities (agricultural practices and other skills) for long-term development.

Food relief distribution is a complex operation that requires expedient response to prevent hunger among evacuees. Food relief distribution is often obstructed because of roads' inaccessibility; therefore, Kotani et al. [20] propose evacuation to accessible local places where food is available while awaiting the arrival of food relief. The authors suggest locations such as shopping streets with disaster-proof buildings for use as emergency shelters and food distribution centres, discussing the example of Taisho-Suji Shopping Street as an emergency shelter. They also proposed methods for estimating the amount of food and drink available in the shopping street, the optimum serving capacity for the evacuees each day and establishing capabilities to accommodate evacuees. OR/MS methods, such as simulation and optimisation, can be leveraged for better decision-making in humanitarian food distribution. For example, Manzoor et al. [107] apply an agent-based simulation for food relief distribution in disaster areas with obstacles resulting from the disaster. Moreover, Rancourt et al. [16] construct three network optimisation models inspired by field-based research in Kenya to determine the optimal locations for food distribution centres (DCs) location and the food aid distribution network. The three optimisation models propose to minimise total cost, maximise demand coverage and minimise the number of DCs.

In summary, there is a lack of study on humanitarian FSC. Most research in disaster supply chain focuses on medical relief and general relief, represented as optimisation challenges in location, allocation, vehicle, and inventory routing [108].

## 4. Research gaps and directions

We identified four research gaps based on the previous section. These gaps and research directions are presented below.

### *4.1. Lack of research on humanitarian FSCs*

Our literature review demonstrates that most articles focus on the resilience of commercial FSCs experiencing disaster events, while there is minimal research into humanitarian FSCs as presented in Table 4. With the increasing number of disasters, more research into humanitarian FSCs is needed.

Considerable research on advancing commercial FSCs' preparedness and resilience towards disruptions from disaster events are relevant to humanitarian FSCs, particularly during the mitigation phase of disaster management. For example, water-saving technologies have been used for farms' irrigation systems to mitigate the effects drought (at least temporarily). Food tracing and identification have also been used by commercial FSCs to ensure food safety and authenticity (e.g., organic food, halal food). During a foodborne outbreak or bioterrorism, the existing infrastructure for food tracing and identification can be used to trace contaminated food items while waiting for the additional capacity to cope with a greater need for food identification and inspection.

There are also notable differences between commercial and humanitarian FSCs that necessitate further research on humanitarian FSCs. The first difference is that research into commercial FSCs in disaster events often does not consider labour constraints. As has been learned during COVID-19, an outbreak can affect the capacity of labour due to infections, health protocols (e.g., social distancing, quarantine) and mobility restrictions (e.g., lockdown). The second difference is that distribution in commercial FSCs primarily focuses on identifying the most efficient distribution networks to maximise revenue or minimise cost. This is not an appropriate objective for humanitarian FSCs; for example, in the nuclear accident condition, the objective is to find the safest food distribution network subject to region-based food restrictions due to potentially contaminated food. The third difference is related to consumers' purchasing behaviours. In commercial FSCs, consumers are more likely to buy food directly from a seller and can easily choose preferred food items. In a disaster event such as a pandemic, consumers tend to purchase food items via e-commerce to avoid any possible infection or due to mobility restrictions. In some countries, this can lead to a more prominent role for short FSCs [109]. These differences, among potential others, demonstrate the necessity of specific research into humanitarian FSC.

### 4.2. Lack of research on policies implication to food safety

Food safety is becoming an important point in the context of the globalization of our FSC. The impacts of unsafe food are significant. One of the most significant impacts is the loss of life as approximately takes 2 million people annually [110]. Unsafe food can also lead to other impacts e.g., medical costs, productivity losses, and costs incurred by the food safety authorities [111]. Another significant impact is for the implicated manufacturer, having temporary and sustained negative financial impacts due to product recall and disposal, business interruption and damage to their brand [112].

Enforcement of food safety standards and effective surveillance networks at all levels starting from regional, country, and global levels are required [113]. Moreover, these systems need to be practically and economically feasible to engage and enable more trades and smallholder FSCs have the better food safety practices [114]. Hence, harmonization and equivalence of standard and regulatory frameworks are critical [112]. The lack of scientific study in this topic highlighted by our article justifies a large opportunity to further explore and assess policy implication on food safety to have a better implementation for the food safety itself.

### 4.3. OR/MS methods have not been widely used

From a methodological perspective, our literature review indicates that optimisation and simulation techniques (and OR/MS methods in general) are still lacking as given in Tables 3 and 4. Considering the widespread application of OR/MS methods in disaster management (e.g. Refs. [115,116]), potential for additional assessment of the application of OR/MS methods in FSC management in disaster events remains. For example, optimisation methods can advance the determination of ideal FSC design or policy to mitigate the threats of disasters. The approach can also be used to identify optimal responses when a disaster event disrupts FSCs, and recovery strategies for resilience following disruptions. Simulation methods can be used to evaluate the performance of FSC designs, policies or strategies under uncertain conditions such as uncertain supply, uncertain price, uncertain damage to infrastructure and uncertain location of contaminated food products [117].

Given the common use of OR/MS applications to identify optimal system design and evaluate system performance, it is not surprising that the lack of OR/MS application in this research is also reflected in the lack of research to evaluate (existing or new) FSC design performance in managing the risk of disaster disruptions. Among the OR/MS articles reviewed, we noted a lack of OR/MS models using an objective function that includes social and ethical measures, such as fairness. This is an important research direction given the significance of ethics, diversity, and inclusivity in modern society.

### 4.4. New research methods using big data analytics and recent IT advances

Several works use big data analytics, as classified in the statistics method in Table 3. For instance, Kaufman et al. [31] investigate sales data coupled with likelihood-based approach statistics to identify contaminated food products. Erokhin and Gao [32] use autoregressive models with several sources of big data (number of confirmed COVID-19 cases, food trade balance, food inflation and currency exchange) to assess the impacts of COVID-19 on food security. Nevertheless, the number of works using big data analytics is less than those employing other statistical methods. Blockchain technology could also be implemented to enhance FSCs' food transparency and traceability and improve information security [118,119]. This technology could be significantly beneficial for relief operations under emergency conditions to ensure that food relief came from trusted sources [120].

## 5. Conclusions

In response to the significant increase in the number of articles on FSCs and disaster events, we conducted a SLR on the topic. Our review used Scopus, Web of Science and EBSCOHost databases to enlarge our coverage in capturing the relevant articles.

In this review, we identified and analysed the research objectives, research methodologies, threats caused by disasters and proposed solutions. When discussing the threats caused by disasters and proposed solutions, we analysed them by disaster type. Based on the review, we identified four main research gaps, including lack of research on humanitarian FSCs, lack of research on policies implication to food safery, minimal use of OR/MS methods and lack of research applying big data analytics and recent advances in IT, suggesting several research directions. First, there is a need for further research on humanitarian FSCs because of existing unique challenges. Second, there is a need for research on the optimisation and evaluation of FSC designs and policies to mitigate the risk of disruptions due to disasters. This is where OR/MS methods are needed; hence, more research using OR/MS methods on the topic of FSCs and disasters is encouraged. Furthermore, we recommend that the OR/MS methods applied include social and ethical measures, as ethics and inclusivity are important in modern society. Finally, there remains a wide opportunity to implement and explore big data analytics to increase FSCs' performance when facing a disaster.

Our literature review is not without limitations. First, although we used three major databases, it is possible that some articles that are not in the databases were excluded. Second, this literature review is based on content analysis; hence, although we used procedures to minimise subjectivity when selecting the articles, bias may not have been completely eliminated. Bibliometric analysis could be used to complement our content analysis to provide a more quantitative evaluation of the literature. However, it is extremely challenging to perform bibliometric analysis of articles from different databases due to the difference in each database's metadata configuration. Third, the limitation of our study is at the higher-level point of view of FSC. It is interesting to also explore deep down to some certain types of FSC, e.g., perishable FSC, cold FSC, and further study the risks and challenges they might have.

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### Data availability statement

Data are available within the supplementary materials.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijdrr.2022.103183.

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