Food supply chain resilience to pandemics

A rapid review

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Abstract

As a research field, food supply chain resilience to pandemics has recently emerged due to the COVID-19 pandemic. There is a growing recognition of the value of knowing how resilience to catastrophic events emerges in critical supply chains and how resilience can be promoted. This study aims to further develop the existing understanding of supply chain resilience in the contexts of the food industry and pandemics by carrying out a rapid literature review and assessing the findings against an a priori framework. 30 papers from different regions of the world met the criteria for inclusion. The conceptual framework provided 30 different interventions which were later used for coding the data and summarizing the evidence. This study provides synthesized notions on various enablers and impediments of supply chain resilience, discusses intricate trade-offs between them, and considers optimal strategies for building resilience to pandemics in the future.

Keywords: supply chain resilience, pandemics, food supply chain, COVID-19.

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1. Introduction

1.1 Background

The topic of this thesis lies in the intersection of two broader research agendas that underpin it: resilient food research and improving pandemics governance.

Resilient food research

How can we keep food supply chains operating and ensure people are fed in case of an extreme event happening and causing significant disruptions to national and international food systems? Various disasters like pandemics and armed conflicts create a complex set of interlinked effects that result in major supply chain disruptions and decreasing food security (World Bank 2023). Yet, there are conceivable scenarios which may result in an even more harmful future if extreme shocks disrupt existing food systems. Within the pessimistic climate change scenarios, it would be highly likely to experience disruptive weather events threatening agricultural systems (European Commission 2020). The developments in agriculture and biotechnology might increase the risk of deliberate hostile attacks towards agricultural environments (Govern 2008). There is also a risk of a severe decrease in sunlight due to natural reasons (e.g., a collision of a large asteroid, an eruption of a supervolcano) or nuclear war and consequent nuclear winter (Rivers et al. 2022). The agricultural systems and infrastructure are also vulnerable to events like epidemics, cyberattacks, high-altitude electromagnetic pulses caused by nuclear attacks, and intense solar storms (Cole et al. 2016). Keeping in mind potentially disastrous consequences, it is crucially important both to enhance our foresight to avoid foreseeable and preventable scenarios and to develop long-term resilience in food systems to mitigate unforeseeable or unpreventable ones.

Improving pandemics governance

Widespread disease outbreaks cause tremendous loss of lives. For example, COVID-19 has induced more than 17 million deaths in the first two years of the

outbreak, but people are still suffering from it now (Wang et al. 2022). Current estimations of the death toll of the exceptionally deadly influenza pandemic in 1918 range from 1% to 5% of the global population (Taubenberger & Morens 2006). There also were smaller outbreaks of influenza in 1957 and 1968 that caused the deaths of up to 4 million people and indicated that new outbreaks have started to become a recurring issue in an increasingly globalizing world (Barry 2005). Besides the direct loss of life, outbreaks generate considerable negative economic and social impacts, undermining the overall quality of life; for instance, the global economic decline caused by the COVID-19 pandemic is regarded as the most profound since the end of the Second World War (Yeyati & Filippini 2021). Added to the value of lives lost, the monetary loss of just the US economy due to this pandemic is estimated to fall in the range between 7 and 16 trillion dollars, exemplifying the sheer amount of social and economic damage that a pandemic may inflict (Bruns & Teran 2022).

In order to properly address the challenges of future pandemics, advances in technology, better governance, and better management are needed. Natural outbreaks harsher than recently observed COVID-19, or anthropogenic diseases caused by artificially created pathogens, might severely disrupt global systems and undermine humanity's progress, possibly even causing the disintegration of global civilization via the collapse of critical infrastructure (Ord 2020). Therefore, an improved understanding of how to enhance systems' capabilities to respond to pandemic threats, safeguard critical infrastructure during an outbreak, ensure supply chains' resilience, and allow for quick and trustworthy communication may yield significant long-term benefits.

COVID-19 and the confluence of two fields

The latest pandemic has served as a strong factor in bringing public and academic attention to the conjunction of the aforementioned fields. Food security has already been an established field of research, however, it mostly focused on issues connected with climate change, poverty, gender, and diet structure while resilience to extreme events including pandemics was generally neglected (Xie et al. 2021). Similarly, pandemics governance has also been researched before, but scholars had been focused primarily on healthcare systems' preparedness, mathematical modelling of disease spread, and necessary institutional environment whilst the stable performance of food supply chains in times of a pandemic was not properly considered (ibid.). The situation has changed during COVID-19: the outbreak highlighted high and low levels of resilience within existing food systems and provided many cases that scholars have started investigating (Stephens et al. 2020). Previously, the research into factors making food systems resilient specifically to a pandemic was scarce and has gained much attention since the beginning of the

COVID-19 pandemic. Thus, a substantial amount of research with enough data points (i.e., articles) that lie in the intersection of resilient food research and pandemics governance has recently emerged - and now it is appropriate to carry out a systematic review of collected evidence.

1.2 Problem statement

An empirical problem that is raised and addressed within this work is preventing and mitigating food supply chains being disrupted by pandemics. When a severe epidemic emerges and spreads, many supply chains may experience significant stress both from the demand and supply sides. From the demand side, there might be significant changes in consumer behaviours, including hoarding and radical dietary changes (Baddeley 2020). Even though the choice of products that are going to be stockpiled by individuals may be to some extent predicted with the current understanding of social media impacts and social cognitive biases, supply chains often adjust slowly, slow enough to cause panic buying (ibid.). In turn, disruptions in critical food supply chains have a high chance to exacerbate other social risks, causing political instability that is added to other stresses nations experience during a pandemic (Deaton & Lipka 2015). From the supply side, firms all along the supply chain may experience disruptions in their primary operations due to quarantine measures, travels restrictions, and staff getting sick. Thus, firms involved in farming, food transportation and retail may encounter significant challenges or even face business failure. Developing sound strategies for prevention or effective mitigation of the worst-case scenarios is a complex problem faced by individual firms, supply chains (i.e., groups of firms), and food systems (i.e., structures governed by institutional actors).

The theoretical problem of this thesis belongs to a more general cluster of supply chain resilience with two additional aspects that narrow down the scholarly endeavour: focus on the food industry and one particular source of disruption (pandemics). Research into supply chain resilience attempts to discover and characterize the relationships between supply chain risks, disruptions, resilience and performance, identify the factors influencing these relationships and conceptualize their intricate nature (Macdonald et al. 2018). There is an established body of knowledge on supply chain resilience but the author argues existing suggestions shall not be directly applied to the issue raised because it is likely insufficient to generate valuable, robust insights for management and policy-making. Firstly, many food supply chains are characterized as critical for national food security (e.g., wheat), products are often perishable, and production is seasonal (Orengo Serra & Sanchez-Jauregui 2022). Combined, this may change the priority of resilience attributes and generate unique vulnerabilities. Secondly, a pandemic

is a distinctive source of disruption due to its uncertain essence - it is difficult to predict and estimate its probability and effects beforehand, therefore traditional risk management practices are less relevant for dealing with it (Taubenberger et al. 2007). Moreover, a pandemic is to some extent unavoidable after an epidemic scales up to become global, so it is certain to affect the business directly or indirectly via containment measures. Lastly, a pandemic comes with a set of multifarious effects that affect economic, social, and safety issues that hardly fit into a single component of existing conceptualizations. Thus, the theoretical problem addressed in this work can be described as 'resilience of food supply chains to a pandemic' - which refers to the same questions of general supply chain resilience but in a more specific context.

1.3 Aim and research questions

This work aims to extend the current understanding of the emergence and dynamics of resilience in food supply chains during pandemics and contribute to conceptualizations of supply chain resilience in this context. To fulfil the aim, two main objectives were set; first, to systematically collect, review, and summarize the available literature on the matter; and second, to disentangle the findings and provide analytical thoughts highlighting pathways for future research and policymaking.

Research questions guiding the review and analysis are formulated as follows:

1. What is known about interventions in food supply chain resilience to disruptions caused by severe pandemics?
2. What valuable learnings about food supply chain resilience can be synthesized from the available evidence?

1.4 Scope and delimitations

The first delimitation of the study is the choice of the focus industry and a particular type of disrupting event. For the reasons stated above, this review was limited only to food supply chains, thus its findings are directly relevant exclusively to firms and systems operating within such chains. Arguably, many learnings about generalized supply chain resilience should also apply to food supply chains, but the author decided to exclude other domains from the analysis and act on the premise that generalized lessons about resilience should be re-stated if confirmed for food supply chains. Similarly, the same premise was enacted for pandemics as a source of disruption. This work is a review of evidence gathered and knowledge created on a precise topic, and the author does not attempt to make claims about supply

chains in general. To exemplify this point, there are several potential scopes of the review that were considered and the last one was chosen: *food systems* and *catastrophic events*; *food systems* and *pandemics*; *supply chain resilience* to *catastrophic events*; *supply chain resilience* to *pandemics*; *food supply chain resilience*; *food supply chain resilience* to *catastrophic events*; ***food supply chain resilience* to *pandemics***. As this work does not focus on a particular geographic context, it will include studies from different parts of the world.

The second delimitation that defines the scope of the study is the focus on interventions to supply chain resilience. There is plenty of studies describing the manifold impacts of pandemics on food supply chain actors (e.g., farmers) where authors present their suggestions for better resilience based on the documented impacts. However, instead of gathering evidence specifically about impacts, this study gathers evidence on actual responses to these impacts (e.g., new activities, strategies, policies, and pivots) that food supply chain actors deployed and that affected their resilience.

Another significant limitation is the recency of the papers that were reviewed and analyzed. As supply chain resilience as a term was coined in the early 2000s, the search of the literature published before that with resilience (or its synonyms) as a keyword is unlikely to retrieve relevant results. Therefore, the period of investigated research was organically limited to approximately 20 years.

1.5 Structure of the study

Chapter 1 provides background information on resilient food research and pandemics governance, highlights the importance of the latest pandemic of COVID-19, describes empirical and theoretical problems, establishes research aim and questions, and outlines the scope of the study. In Chapter 2 existing literature on resilience theory, supply chain resilience, and food supply chains resilience to pandemics is reviewed. Besides the literature review, a description of the conceptual framework used in the study and justification for the choice of the framework are presented. Chapter 3 describes the research philosophy, defines and justifies the research design, and reports a transparent description of the step-by-step process of data collection and analysis. Chapter 4 presents the results of the literature search and summarizes the gathered evidence on each element of the conceptual framework. Chapter 5 synthesises gathered evidence into several analytical thoughts on resilient supply chain design and provides suggestions for enhancement of the conceptual framework. Chapter 6 offers a conclusion, mentions the limitations of the study, and outlines potential future research.

2. Literature review and conceptual framework

2.1 Literature review

The core concept of this work is supply chain resilience. However, before reviewing previous studies of it, an overview of the literature on resilience and supply chains is presented.

Resilience

Resilience is a multifaceted and cross-disciplinary concept that has been researched and developed within diverse scientific disciplines in recent decades and that is often brought up in discussions of environmental and social issues, disaster recovery, and worst-case scenario risk management. The fields vary, yet the interpretation of the word seems to follow the same pattern. Aggregating various definitions, it may be generalized that resilience refers to the strengths that people and systems develop that allow them to cope with adversity (Van Breda 2001). The development of this concept is related to a meta-disciplinary transition from an emphasis on pathology to an emphasis on strengths and capabilities (Rak & Patterson 1996).

The shared use of the word does not, nevertheless, indicate a homogeneity in definitions of resilience nor the theories in which it is juxtaposed. Resilience in ecology is understood as the capacity of a system to undergo disturbance and maintain its functions and controls while constantly moving through an adaptive cycle of growth, conservation, creative destruction, and renewal - instead of drifting towards a stable state (Gunderson & Holling 2001; Carpenter et al. 2001). From the perspective of social sciences, resilience may be defined as the capacity of a system, community or society likely exposed to hazards to resist or adapt in order to achieve and hold an adequate level of functioning and structure (United Nations 2018). Within developmental psychopathology (the field of psychology that particularly focuses on resilience), the term refers to how people not only survive a variety of

challenging circumstances but thrive in the face of such adversity, and highlights the importance of control, coherence, and connectedness as key components of resilience (Reich 2006). In economic theory, resilience is defined as a system's capacity to absorb loss from an intense shock and successfully recover from it (Perrings 1994). An organizational perspective of resilience partly shares the understanding of the concept with economic and social sciences and accentuates such substantial elements of resilience as flexibility, anticipation, adaptability, and recovery (Mitroff & Alpasan 2003). Exemplified with this range of definitions, common denominators between them are present but the context and adjacent concepts used to explore resilience differ noticeably.

Emergency management is another field exploring system resilience which is particularly relevant for this paper. Scholars in this field examine the design and performance of disaster-resilient systems and their capacity to learn from acquired experience (Lindell et al. 2007; Ponomarov & Holcomb 2009). The importance of learning capacity is specifically highlighted in the process of emergency management which includes four phases: threat mitigation, preparedness, response, and recovery (ibid.). As it would be seen further, these phases resemble the stages of supply chain resilience conceptualizations.

Supply chain

A supply chain is a well-established concept in the scholarly literature that has been studied for more than 50 years. According to one of the more recent definitions provided by Kenton (2020), the supply chain is commonly perceived as a complex network connecting a company and its suppliers, encompassing various elements such as individuals, processes, organizations, data, and materials, which collaborate to manufacture and deliver a particular product to the end consumer. Similarly, Chopra and Mendi (2016) put forth a definition of the supply chain which involves a specific arrangement, as depicted in the figure below, wherein various participants including suppliers, manufacturers, distributors, and retailers at distinct phases are interconnected and collaborate directly or indirectly to meet the demands of the end user.

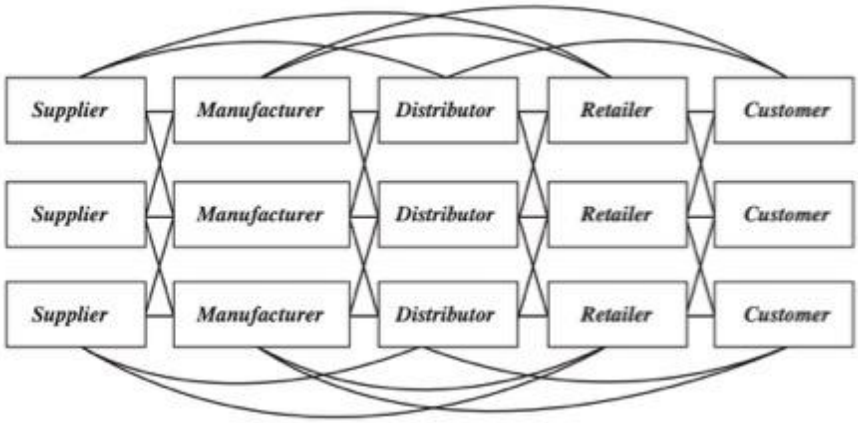

Figure 1. Supply chain (Chopra & Mendi 2016)

Presented conceptualizations contrast with the traditional depictions of supply chains as unidirectional combinations of industrial and logistics processes - contemporary scholars characterize supply chains as intricate systems of reciprocal relationships between multiple organizations, in which each entity contributes resources and materials to support the others (Garnett et al. 2020). They argue that this interdependence among supply chain actors brings a new perspective to the traditional understanding of how such networks ought to function with respect to their ability to withstand and recover from unexpected shocks or disturbances (ibid.). According to Christopher and Peck (2004), the complexities arising from such interdependencies among organizations and their supply chains can pose a dual challenge, as the risk of potential harm or disruption can either emanate from a business itself or from its supply chain partners. Following this view, the purpose of supply chain management expands from sole optimization of performance for the minimum possible cost to a more holistic one that encompasses sustainable and resilient management of relationships with supply chain partners (Shukla et al. 2011).

Supply chain resilience

Scholars commonly understand supply chain resilience as the ability of a supply chain to cope with unexpected adverse events. However, as it is mentioned by several authors, the combination of the fact that resilience is an essential characteristic of a supply chain extensively studied by many researchers with its multidisciplinary and multidimensional essence led to a wide disarray of conceptualizations and definitions (e.g., Ponomarov & Holcomb 2009; Bhamra et al. 2011). The notion of supply chain resilience has been introduced in the academic literature by integrating and extending the various viewpoints and interpretations of 'resilience' that have been advanced in different fields where the concept of resilience is relevant. Therefore, some dispersion among the developed definitions

and their emphases is inherent due to the various domains which researchers were borrowing from (e.g., ecology, engineering, studies of complex adaptive systems etc.).

Firstly, developed definitions of supply chain resilience differ in scope. Some scholars view supply chain resilience as a reactive capacity that enables firms to respond to and recover from unexpected disruptions, while others consider it as a proactive capacity aimed at preparing firms to manage such events more effectively (Melnyk 2014). However, Pires Ribeiro and Barbosa-Povoa (2018) argue that the concept of supply chain resilience is not merely limited to one of these, but should encompass both. This distinction determines whether a definition of resilience should consider pre-disruption and post-disruption stages whereas a phase of ongoing disruption is consistently considered in all definitions. Moreover, what attributes or elements of resilience are considered also differs. While most of the conceptualizations include flexibility and collaboration as resilience capabilities, many ignore economic efficiency, organizational culture, robustness and others (Tukamuhabwa et al. 2015). Thus, although developed works are informative, they often present a fragmental perspective of resilience that depends on the issues and elements of resilience included (Ponomarov & Holcomb 2009).

Secondly, besides differences in what elements of resilience are included in the conceptualizations, structural interrelations among them also vary. The words robustness, reliability, agility and flexibility are sometimes used interchangeably while each of them can be understood as a separate element of supply chain resilience (Christopher & Rutherford 2004; Schmitt & Singh 2012). In some works, agility and flexibility are seen as elements of supply chain resilience (Christopher & Peck 2004; Ponomarov & Holcomb 2009; Pettit et al. 2010), whereas other authors consider these concepts to be separate from resilience (Charles et al. 2010; Carvalho et al. 2012). Flexibility is regarded as an element of agility in some works (Tang & Tomlin 2008; Carvalho et al. 2012), whereas other authors understand them as dissimilar concepts (Christopher & Rutherford 2004). Overall, the academic understanding of the structure of supply chain resilience has not achieved a consensus yet.

Besides the lack of theoretical alignment among researchers of supply chain resilience, there are other aspects of research into supply chain resilience considered neglected. Tukamuhabwa et al. (2015) point out a need to explore strategies for achieving and sustaining supply chain resilience other than ones focused on flexibility, collaboration, and redundancy. Moreover, how different strategies for resilience could synergize or trade off with each other remains unclear and untangling that should extend our understanding of strategic choices supply chain actors make (ibid.). Finally, there are organizational and regional contexts that

remain overlooked and where supply chain resilience is still insufficiently explored: developing countries, SMEs, and non-manufacturing industries (ibid.).

2.2 Conceptual framework

In this work, the understanding of supply chain resilience follows the conceptualization developed by Kochan and Nowicki (2018). Their work aimed to address ambiguity in relationships between supply chain resilience and its elements and provided a foundation for an examination of such relationships. The conceptual model developed by these authors is a product of a systematic review of 383 papers on supply chain resilience published between 2000 and 2017 (ibid.). Other distinct features of this model are that it follows the context-interventions-mechanisms-outcomes (CIMO) classification; and, secondly, draws upon articles from various industries including manufacturing, energy, military, retail, and agri-food (ibid.).

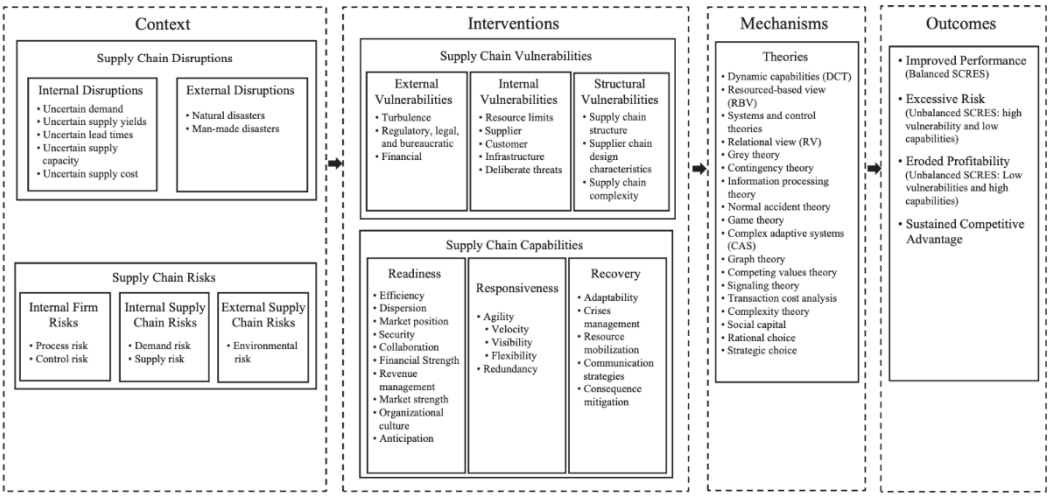

Figure 2. Conceptualization of supply chain resilience (Kochan & Nowicki 2018)

Within the scope of this review, the most relevant part of the framework considers interventions, however, it is essential to outline the whole structure of the model and how its parts fit together.

Firstly, there are contexts in which supply chains operate. From the perspective of resilience, the authors highlight two features that are important and common across a variety of industries: supply chain disruptions and supply chain risks (ibid.). Disruptions are differentiated based on their source - whether they are internal or external to a supply chain. Similarly, supply chain risks can be classified as internal to a single firm, internal to a supply chain (but external to a single firm), or external

to a supply chain. The authors point out an important relationship: as supply chain risks increase, firms become more vulnerable to unexpected shocks (ibid.). The goal of supply chain risk management is to reduce such vulnerabilities via effective risk mitigation - however, if the probabilities and potential impacts of shocks are uncertain, the conventional approach of risk management yields significantly poorer results (Pettit et al. 2010). Overall, the landscape of possible disruptions and risks provides a context where interventions to supply chain resilience take place.

By interventions, authors understand a set of drivers that reduce resilience levels (i.e., supply chain vulnerabilities) and a set of drivers that increase resilience levels (i.e., supply chain capabilities). Vulnerabilities may emerge from sources external to a supply chain (e.g., broader economic turbulence), internal (e.g., deficient infrastructure in one of the nodes of a supply chain) or be a consequence of the poor structure of a whole supply chain (Kochan & Nowicki 2018). Capabilities, in turn, are distinguished based on the phase they relate to: pre-disruption (readiness), ongoing disruption (responsiveness), and post-disruption (recovery).

Finally, mechanisms refer to the theories researchers utilize to understand resilience and outcomes consider the ratio between vulnerabilities and capabilities. Theories which scholars use to examine supply chain resilience vary significantly, but dynamic capabilities and resource-based view remain the most used lenses for it (ibid.). Classification of the outcomes follows Pettit et al. (2010) conceptualization that improved performance of a supply chain is achieved when capabilities and vulnerabilities are balanced, high supply chain risk is observed when vulnerabilities exceed capabilities, and profitability is eroded when capabilities exceed vulnerabilities.

This review focuses primarily on interventions, therefore, all definitions for the items mentioned in the framework as vulnerabilities and capabilities are presented in Appendix 1. For the sake of transparency, it is important to note that Kochan and Nowicki did not provide their definitions but completed a literature review and created a hierarchy of concepts that constitute supply chain resilience. Hence, the definitions are borrowed from the papers Kochan and Nowicki reviewed and synthesized.

Justification of the choice of the framework

Numerous conceptualizations framing supply chain resilience have been developed in recent years. Nonetheless, the author has considered this framework to be optimal to achieve the research aim due to several reasons. Besides the general quality of frameworks, their academic rigour and the transparency of the framework formulation process, there have been additional three criteria that were emphasized.

Firstly, the selected framework should have been flexible and extensive enough to decrease the risk (or extent) of forcing data into the framework. Secondly, the framework should have provided helpful delimitations between somewhat ambiguous terms often used in supply chain resilience literature (e.g., between flexibility, agility, and adaptability). Thirdly, the framework should have adequately addressed the practical variety of strategies and responses employed by firms during an unforeseen event. Following these criteria, some frameworks like the ones suggested by Dwaikat et al. (2022) were discarded due to the level of detail insufficient to address the aim of this research. The conceptualization by Pettit et al. (2010) is helpful and suitable, however, the chosen framework captures its benefits by encompassing and extending it. The framework by Shishodia et al. (2021) provides an insightful overview of supply chain resilience but is barely helpful for classifying different responses to a disruption event. After the search and comparison of different frameworks carried out by the author, the chosen framework seems to be the best fit. Frameworks that were rejected are presented in Appendix 2.

3. Methodology

3.1 Research philosophy

According to Guba and Lincoln (1994), a researcher's beliefs and perspectives inevitably affect and shape their research philosophy. They argue that it is crucial to attain a fit between a researcher's ontological and epistemological perspectives and chosen methodology (ibid.). Ontology in this context refers to the philosophy and characteristics of reality while epistemology, in turn, refers to the process of acquiring knowledge about reality (Guba & Linkoln 1994; Bell et al. 2022).

This work is inclined to a positivist approach which is commonly described as being based on empirical methods to observe, gather and measure objective and quantifiable data in order to produce knowledge (Bell et. al., 2022). Systematic reviewing is understood as a research approach that utilizes the available scientific literature on a specific subject as its primary source of data (Letelier et al. 2005). The primary objectives of these reviews are to identify, assess, and present a comprehensive and often synthesized account of the findings from previous studies published in the relevant literature, using rigorously specified and impartially administered methods (ibid.). Hammersley (2001) suggests that positivism is evident in systematic reviews in two ways. Firstly, many systematic reviews prioritize the inclusion of experimental and quantitative studies as sources of reliable evidence over other types of studies. Secondly, systematic reviews place a high value on carrying out literature reviews with utmost objectivity which is achieved through the use of statistical methods to integrate scientific evidence and eliminate bias. Both of these criteria are not directly relevant to this review: the chosen design did not prioritize quantitative studies over qualitative ones and the synthesis of the mixed evidence was based on the author's analysis and interpretation (rather than statistical methods). However, the author followed clearly defined protocols to conduct the review, carried out thorough searches, and used objectivity, reproducibility, and transparency as criteria of academic rigour - which drives this review to be more positivist.

According to Holman (2019), it is crucial to recognize the importance of virtues such as objectivity, rigour in establishing rules for evaluating evidence, and transparency in the developed reviews. These virtues not only act as a constraint on research, but they can also lead to constructive disagreement and the resolution of methodological disputes. However, there is insufficient reason to claim that systematic reviews are necessarily positivistic (de los Santos et al. 2022). Therefore, it is possible to adopt diverse methodologies and use mixed evidence to address different issues. This approach has become more prevalent, as demonstrated by the advancements in the synthesis of mixed and qualitative evidence (Pluye & Hong 2014; Thorne 2017), and the incorporation of non-randomized or observational quantitative studies (Moosapour et al., 2021).

3.2 Research design

The design of this study consists of two methodological choices: *a rapid literature review* as a method of literature search and *framework synthesis* as a method of data analysis.

Rapid literature review

The rise of empirical and theoretical research in various scientific disciplines during the 20th century has necessitated the creation of techniques for scientists and experts to examine and integrate evidence relating to a particular topic, as argued by Sánchez-Meca (2010). Scientific knowledge is cumulative, and, Mebius et al. (2016) claim, as the body of knowledge grows, there is a need for the development of methods and techniques to assess and consolidate scientific discoveries. This requires reducing biases in the selection of evidence, which is closely tied to the principle of total evidence (ibid.). Gough et al. (2012) note that conventional scientific literature reviews have traditionally provided a critical summary of various research works but without specific criteria for determining which of these works should be included or excluded from the review. These reviews typically present information of interest to the reviewer in a narrative format and are commonly known as narrative reviews (Letelier et al., 2005). Systematic reviews aim to overcome some of the issues of traditional literature reviews, such as selection bias resulting from a lack of explicit criteria for selecting and integrating literature (Torgerson, 2003). Such reviews aim to find, assess, and synthesize the results of all relevant individual studies on a chosen issue, thus making the evidence more accessible to decision-makers and other scholars and revealing flaws, inconsistencies, and contradictions in the literature (Paré et al. 2015).

Despite being widely recognized as having the highest rigour in consolidating knowledge, systematic reviews have certain drawbacks (Khangura at al. 2012). One that was crucial for this review is that a systematic review typically entails a considerable time investment that starts from 6 months (ibid.). Therefore, the author has decided to use rapid review - an approach to systematic reviews in which some elements of the review are simplified, allowing for quicker but less rigorous results. This rapid review followed the strict guidelines of systematic reviewing with two major simplifications. Firstly, it was conducted by a single researcher (which increased the risk of selection bias affecting the screening of studies). Secondly, the initial protocol of the review has not been uploaded to PROSPERO (a database of completed and ongoing systematic reviews) for an open examination by a community of researchers. Other typical differences of rapid review are presented in the table below.

Table 1. Rapid reviews and systematic reviews (adapted from Khangura et al. 2012)

	Rapid review	**Systematic review**
Timeframe	≤ 5 weeks	From 6 months to 2 years
Question	Question specified *a priori* and may be broad	Question specified *a priori* and has to be focused
Sources and searches	Sources may be limited but sources/strategies made explicit	Comprehensive sources searched and explicit strategies
Selection	Criterion-based; uniformly applied	Criterion-based
Appraisal	Rigorous; critical appraisal	Rigorous; critical appraisal
Synthesis	Descriptive summary/categorization of the data	Qualitative summary +/- meta-analysis
Inferences	Limited/cautious interpretation of the findings	Evidence-based

Framework synthesis

While rapid review describes an approach to searching and selecting the evidence, framework synthesis describes an approach to analyzing and making sense of evidence after the literature is selected.

It is often discussed how qualitative or mixed data synthesis is limited - some researchers even question the value of carrying it out at all (Thomas & Harden 2008). One of the developing approaches that attempt to address these limitations is framework synthesis, which is based on framework analysis (Barnett-Page & Thomas, 2009). Framework synthesis belongs to a broader set of synthesis methods that examine common and specific patterns in qualitative data and then concentrate on associations between various parts of collected evidence, thereby aiming to

produce descriptive or explanatory insights about formulated themes (Gale et al. 2013). This approach is designed as an exceptionally structured one: numeral and hierarchical indices are used to tag data, charts are used for presenting it etc. Another distinct feature is that it requires themes for coding data in included studies to be ready before the start of the synthesis. Unlike thematic synthesis, which is an inductive approach, framework synthesis is predominantly deductive - which gives it some practical benefits when there are important time constraints (Carroll et al. 2011). Moreover, a chosen or constructed framework may both be used as a tool for analysis and also as a structure to arrange and present the findings from different sources (ibid.).

It is important to acknowledge a wide variety of methods developed for the analysis of literature reviews' results: textual narrative synthesis, metasummary, meta-analysis, Bayesian meta-analysis, critical interpretive synthesis, thematic synthesis, meta-ethnography, and ecological triangulation are just some of them. Framework synthesis was chosen among them due to three main reasons. Firstly, it is suited to make sense out of a sample of mixed data which was attained in the process of literature search and selection. Secondly, a deductive approach was considered favourable as rigorous enough supply chain resilience models have already been established. Thirdly, it allowed to proceed with the synthesis in adequate time with available resources. Overall, the strengths of framework synthesis were considered highly relevant in the context of this research.

Table 2. Pros and cons of some qualitative evidence synthesis methods (adapted from Flemming et al. 2019)

	Pros	**Cons**
Framework Synthesis	Derives value from the pre-existing theory. Easier to use with novice teams and/or when time is limited. Yields good results when there is consensus on the nature of impacts and interventions.	It is needed to identify, select and justify the choice of a framework. A framework may be seen as unsuitable only once synthesis is ongoing. May incentivize to force data into a framework.
Thematic Synthesis	Clear and accessible approach to work with descriptive and in-depth analytical themes. Provides an opportunity to do an audit trail. Synthesis can be designed to answer review questions directly.	Can be very time-consuming and demanding with a large sample of papers. Sometimes requires a high level of analytical skills.
Meta-ethnography	A mainly interpretive method that leads to the creation of new constructs of higher order. Requires high richness in initial data.	Requires a highly experienced team. Requires a lot of time and resources. Theoretical findings combine empirical evidence, expert opinions and conjectures. May not offer audit trail. Sometimes it is not clear how to translate results into actionable advice.

3.3 Literature search

It is commonly recommended that a systematic literature review should start with an initial search to spot relevant papers, confirm the validity of the suggested idea, ensure the questions have not been already addressed, and confirm that there is a sufficient number of papers for carrying out a review (Tawfik et al. 2019). After preliminary, draft versions of research questions were formulated, the author proceeded with a scoping search in several academic databases. Scoping search can be used as a way of mapping the key concepts that underpin a research area and achieving better navigation for a further literature examination (Arksey & O'Malley 2005). The main goals of the scoping search were to develop better search blocks (i.e., words, phrases and synonyms for the actual search), to map the literature that has already been written, and to find out if other systematic reviews of the issue have been conducted. Aside from the search in Google Scholar, Scopus and Web of Science, the author also checked completed and ongoing systematic reviews in PROSPERO database. The scoping search provided the author with a confirmation

of the validity and relevance of postulated questions and clarified a better wording for the research questions.

According to Higgins et al. (2019), after the scope of a review and the questions it will address are determined, the next step is to define inclusion or exclusion criteria. Tawfik et al. (2019) argue that the rules for the inclusion or exclusion of evidence should be stated before the start of the actual search to avoid unintentional bias. In this rapid review, eight exclusion criteria were deployed. Firstly, the duplicates of the same studies were excluded. Secondly, studies without access to the full text were excluded. Thirdly, other reviews and editorial pieces were excluded. Fourthly, studies that were written in languages other than English were excluded. Fifthly, studies published earlier than 1990 were excluded. Sixthly, the results of the search that consisted of several papers (e.g., a set of conference proceedings) were excluded. Seventhly, studies that did not relate to the food sector, supply chain resilience and pandemics in conjunction were excluded (i.e., studies should include all three of these). Finally, studies that did not address observed interventions into supply chain resilience (i.e., actions, decisions and strategies to address supply chain vulnerabilities and capabilities) were excluded.

According to the systematic review guidelines, the search should be designed in such a way that would retrieve as many relevant results as possible to avoid publication bias (Higgins et al. 2019). For this review, the author chose a wide search strategy - the search query was not overly precise to avoid the risk of omitting relevant studies and presented more exhaustive results but with a lower total precision rate. When executing a systematic review, it is also advised to search in several different databases (ibid.). Six databases were used in this review. Scopus and Web of Science were chosen as general databases. EconLit was chosen as a database focusing on economics and managerial studies. CAB Direct (that consists of CAB Abstracts® and Global Health® databases) was chosen as one focusing on food science and agriculture. AGRIS and BASE databases were chosen for the search of 'grey' literature - i.e., literature produced by governments, academics and businesses and which is not controlled by commercial publishers (Gelfand 2005). For internal consistency, identical search blocks were used for all databases except BASE, in which engine it was impossible to use the same search logic. Detailed search queries are presented in Appendix 3.

The screening of studies consisted of three stages: pre-screening, title and abstract screening, and full-text screening. At the pre-screening stage, the results of seven searches were merged and duplicates were removed. During title and abstract screening, results which clearly met exclusion criteria were removed. At the full-text screening stage, full studies were examined and removed if they met exclusion criteria.

The final stage of the search was the quality appraisal. Each study that was included at this stage was re-read, and quality assessment checklists were filled in. The author used several checklists developed by Joanna Briggs Institute that provides a selection of critical appraisal tools based on different types of studies (Joanna Briggs Institute 2023). Each checklist consists of 8-9 quality assessment questions and ends with an overall inclusion/exclusion decision. Studies that received a 'low quality' tag were excluded from the final sample.

3.4 Data analysis

The process of data extraction and analysis consisted of three stages which closely resemble the process of thematic synthesis: coding the texts, developing summaries for 'descriptive themes', and developing 'analytical themes' (Thomas & Harden 2008). At first, the author carried out line-by-line coding of the Results and Discussion sections of all included papers against an a priori framework, highlighting verbatim quotations that related to any descriptive theme. Each element of the conceptual framework was used as a separate code and constituted a descriptive theme - i.e., descriptive themes were pre-defined by the choice of the framework. Next, the author wrote up summaries of 30 descriptive themes which referred to supply chain vulnerabilities and capabilities. These summaries, presented in the next chapter, provide a resumptive view of what selected studies say about each relevant element of the conceptual framework. According to Thorne et al. (2004), what distinguishes a synthesis is an attempt to 'go beyond' findings of the primary papers and develop more ideas, insights or hypotheses. Hence at the last stage of the synthesis, descriptive themes were grouped and analyzed further to address the research questions.

3.5 Quality criteria

The analysis of selected studies follows a qualitative method which is a widespread approach to gaining an in-depth interpretation of an underexplored phenomenon. This thesis was conceived to discover how food supply chain resilience to pandemics materialised, characterize complex relationships between diverse elements of resilience and synthesize valuable learnings from collected evidence. Since the intersection of such issues with the context of a pandemic remains a novel field, the author decided a qualitative approach would be appropriate for the stated aim.

To enhance the trustworthiness and methodological quality of this review, the author employed a set of quality criteria developed by Lincoln and Guba (1985).

Credibility was ensured by data triangulation (included studies had diverse data sources) and theoretical triangulation (included studies were based on diverse theories). *Transferability* was ensured by providing thick descriptions of the circumstances this review focused on (i.e., pandemics context) and employed methodology; however, the author argues that the findings are transferable to various food supply chain actors but transferring findings to other contexts should be done with extreme caution. A highly detailed description of the methodology and research process, providing justifications for the methodological choices, and acknowledging risks of bias and peer scrutiny were employed to ensure *dependability*. *Confirmability* was addressed with an explicit description of the search queries, databases, exclusion criteria, and by referencing every study every finding was mentioned in.

4. Findings

4.1 Literature search

The flow diagram illustrating the process of literature screening is presented in Appendix 4. The search in databases retrieved 1602 records with 23% of them coming from the databases of grey literature. Duplicates amounted to 47% of the sample and were excluded before the start of the screening process; the initial sample consisted of 853 studies after duplicates were removed. 534 studies were excluded during the title screening stage: 436 studies addressed irrelevant topics (these studies made it to the search results due to an employed wide search strategy, and their irrelevancy was clear from the titles); 56 studies were not written in English; 34 other reviews and editorials; 4 studies were published before 1990; 4 records were collections of more than 20 conference proceedings. 258 studies were excluded during the abstract screening stage: 187 studies did not utilize the concept of supply chain resilience; 55 studies did not address the context of pandemics; 16 studies examined supply chains in industries other than food. 3 studies were excluded due to unretrievable full-text versions. 25 studies were excluded during the full text screening stage: 14 studies did not utilize the concept of supply chain resilience (that was not clear at the abstract screening stage) and 11 studies did not examine interventions in supply chain resilience and focused on pandemics' impacts. 3 studies were excluded after quality appraisal due to their insufficient rigour. Ultimately, 30 studies were included in the review.

4.2 Description of the final sample

The final sample comprised studies that varied in utilized approaches and explored contexts. The sample covered diverse geographies: 8 studies focused on European contexts; 6 studies explored supply chains in the United States and Canada; 1 study examined food supply chains in India; 1 study focused on China; 1 study focused on South Africa; 1 cross-country study analysed 25 Asian agri-food systems; 1 study focused on Australia and New Zealand; 3 studies did comparative analyses of Global North and Global South food supply chains and included Pakistan,

Tanzania, Peru, Indonesia and other countries; 8 studies used global data and did not address any specific national contexts. There was also a balance between quantitative and qualitative approaches as the sample included case studies, comparative case studies, regression analyses, simulation studies, studies with mixed methods etc. Some studies explored one 'node' of a supply chain (e.g., farms, fisheries, food banks) while others focused on supply chains in general and examined seafood supply chains, farming systems, food transportation networks etc. However, the sample was much more heterogeneous in one aspect - 29 out of 30 studies focused on the context of COVID-19.

4.3 Contribution of studies to the synthesis

The tables illustrating the contribution of included studies to the synthesis are presented in Appendix 5. Overall, the author observed a variation in how many interventions to supply chain resilience selected studies covered. Several works were more exhaustive in that aspect and addressed more than 15 different vulnerabilities and capabilities. Several studies were mostly focused on particular capabilities and, therefore, contributed only to the synthesis of 4 or 5 pieces. Out of all supply chain vulnerabilities, structure vulnerability was addressed the most often with 12 studies contributing to its synthesis. Vulnerabilities to deliberate threats were not mentioned in any of the studies. Among supply chain capabilities, the three most often mentioned were collaboration, flexibility and anticipation (>15 studies) whereas market position, market strength and resource mobilization were addressed only in 4 studies.

4.4 Supply chain vulnerabilities

Turbulence

There are several observations on turbulence emphasised in the included studies. Firstly, several authors highlight the multifaceted effects of pandemics-induced turbulence. Lockdowns perturb the balance between supply and demand and cause market instability, business and public information flows are distorted, livelihoods are significantly affected (Coopmans et al. 2021; O'Connell et al. 2021; Bassett et al. 2022). Social and economic turbulence amplify each other and require more resources to deal with them compared to if addressed separately. Secondly, vulnerability to turbulence seems to depend on previous exposure to similar events - firms that experienced market disturbances before were less vulnerable to the new source of turbulence (Meuwissen et al. 2021). Thirdly, vulnerability to turbulence

is dynamic, being the highest at the initial stages of a pandemic, and, as pandemics' impacts unfold, short-term turbulence evolves into long-term, more stable macroeconomic stresses (ibid.).

Regulatory, legal, and bureaucratic vulnerability

Governments generally want to keep food supply chains operating smoothly, but state policies can be strict and inflexible, inadequate or untimely, or have unintentional effects which undermine the operations of unprepared firms. Some businesses did not foresee the risk of potential lockdowns or the introduction of policies restricting workforce mobility and international travel; such regulatory measures took these firms by surprise and highlighted the vulnerability of their operations (Ali et al. 2022b). Lacking or limited governmental support made entrepreneurs feel frustration and abandonment and extended the negative market effects of a pandemic (Grigorescu et al. 2022; Ali et al. 2022b). Another common observation was that policymakers did not regard firms supporting 'essential' supply chains as 'essential' too (i.e., did not exclude them from regulations) - which caused labour, materials, and transportation disruptions within 'essential' sectors (Meyer et al. 2022). Policies deployed to support the agri-food sector in some cases had unintentional adverse impacts: for example, state provision of food aid in the form of alternative proteins may have indirectly reduced demand for fish and meat while also failing to support the livelihoods it was deployed for (Bassett et al. 2022). Overall, scholars observed food supply chains' vulnerability to excessive, insufficient, or blinkered regulation.

Financial vulnerability

Many companies experienced a drop in income and a rise in costs during the last pandemic, however, truly severe financial vulnerability was encountered by actors who relied upon other stakeholders and did not receive adequate support from them. Food supply chains often include numerous small and medium enterprises (especially in the upstream) that might have fewer options to mitigate their financial vulnerability than larger companies. As these enterprises experienced financial insecurity caused by reasons out of their control, they relied on the government to financially support them and were disappointed by the insufficiency and inconsistency of such measures (Ali et al. 2022b; Bassett et al. 2022). Already financially vulnerable firms were abandoned by insurance companies and could not access enough bank credit which hardened their financial struggle (Mangano et al. 2022; Ali et al. 2022b). Aside from stakeholders turning away from vulnerable

firms, financial hardship could also deepen due to the unfortunate timing of capital investments, lack of financial buffer and poor liquidity management (Coopmans et al. 2021; Raassens et al. 2022). Another finding is that export-oriented small-scale businesses in developing countries were particularly vulnerable to exchange rate fluctuations caused by pandemic-induced economic instability (Mangano et al. 2022).

Resource limits

The most significant manifestation of this vulnerability during the pandemic was the commonly observed shortage of labour. Unpredictable illness, quarantine measures and movement restrictions caused losses of current employees, complicated hiring of additional labour, and, overall, caused substantial labour shortages in agri-food companies (Ali et al. 2022a; Ali et al. 2022b; Capodistrias et al. 2022; Coopmans et al. 2021; Hobbs 2021; Ladyka et al. 2022; O'Connell et al. 2021; Schreiber et al. 2022). Even though in some sectors, particularly in rural farming, a lack of workforce is typical and was evident before the crisis, a pandemic seemed to aggravate this bottleneck (Schreiber et al. 2022). Besides limiting output capacity, the shortage of available workforce also reduced firms' adaptability to new market environments (Stoll et al. 2021). Additionally, in some developing countries, small and medium enterprises experienced reduced access to bank credit and struggled to attract new capital necessary for uninterrupted functioning (Ali et al. 2022b).

Supplier vulnerability

Even if a node is not directly vulnerable to a certain disruption, nodes upstream from it might easily be; a supply chain is an interconnected system where a supply failure emerging upstream can cause a chain effect moving downstream. Many upstream agri-food companies have lost their key suppliers of spare parts and fertilizers (Ali et al. 2022a; Ali et al. 2022b). The loss of key suppliers, combined with a shortage and volatile prices of raw materials, resulted in the upstream supply disruptions that travelled downstream towards retailers and final consumers (Ali et al. 2022b). From the perspective of food retailers, farms that focused on perishable products turned out to be one of the most vulnerable suppliers - aside from leisure and recreational farms that retailers seldom work with (Dixon et al. 2021; Grigorescu et al. 2022; Shanker et al. 2022). Farming is generally characterized by low flexibility to adjust production after the first stages (planting crops, hatching chicks, breeding calves etc.), and the high products' perishability further decreased

the farms' capacity to quickly alter production and change delivery schedules during the pandemic (Dixon et al. 2021; Grigorescu et al. 2022; Marusak et al. 2021). Another often-mentioned cause of supply failures and delays was the limited availability of land, sea and air transportation services that are required to move products along the whole supply chains; the halting of sea trade routes was particularly damaging to aquaculture supply chains that critically depended on them (Marusak et al. 2021).

Customer vulnerability

Customer vulnerability unfolded in two major ways: the closure of the hospitality industry and the decrease in consumers' purchasing power. A common state reaction to the pandemic was to restrict or forbid mass gatherings. Hence, now it is evident that food producers that focused on wholesaling to the hospitality industry, schools, public venues, open markets and other points of people gatherings felt the severest demand disruptions (Jones et al. 2022; Mangano et al. 2022; O'Connell et al. 2021; Stoll et al. 2021). The loss of household income due to the economic crisis caused by the pandemic impacted entire supply chains as consumer behaviours and dietary choices changed towards more economical in the face of uncertainty (Dixon et al. 2021). However, several authors highlight that these impacts were not equally distributed: consumers in low-income countries, low- and middle-income households and elderly people were affected much more (Bassett et al. 2022; Dixon et al. 2021; Grigorescu et al. 2022).

Infrastructure vulnerability

There were two contexts where infrastructure vulnerability was highlighted: perishable food supply chains and small traditional farms. The performance of a perishable supply chain is more sensitive to any unforeseen deviations in required storage capacity, therefore, when the pandemic inflicted supply and demand disruptions, farms of different sizes lacked enough cold storage spaces, were unable to rapidly expand them and had to dispose of expired food (Dixon et al. 2021; Grigorescu et al. 2022). Small traditional farms were vulnerable to demand disruptions due to their low storage capacity, poor refrigeration systems and low processing capacity (Grigorescu et al. 2022). Evidently, small traditional farms that focused on perishable products have experienced particularly harsh infrastructure deficiency (ibid.). Other interesting findings were that the quality of the transportation network was one of the main causal factors for other infrastructure failures and that low modularity of used infrastructure increased asset specificity

and did not allow for quick infrastructure expansion (Shanker et al. 2022; Meuwissen et al. 2021). Contrary to popular intuition, it was problematic to adjust highly automated food production processes because of technical inelasticity (Coopmans et al. 2021).

Deliberate threats

No included study mentioned this type of vulnerability.

Supply chain structure vulnerability

Excessive use of low-cost offshore suppliers and long international logistics networks is likely to hinder supply chain resilience. Globalized, long supply chains that stretch over several countries or even continents and that were built to catch price benefits were more vulnerable to disruptions caused by the pandemic - which supports pre-COVID findings (Ali et al. 2022a; Ali et al. 2022b; Bassett et al. 2022; Sharma et al. 2021). Supply chains that depended on imports for critical inputs were significantly disrupted by exchange rate fluctuations, seaports halting and various restrictions in exporting countries (Måren et al. 2022). In globalized, interconnected supply chains, vulnerabilities were likewise teleconnected and quickly travelled along the chains, sometimes achieving ripple effects that reached producers and final consumers (Bassett et al. 2022). Addressing such vulnerabilities during a pandemic required strong and quick international and intergovernmental cooperation which proved to be rather complicated (Ali et al. 2022b; Bassett et al. 2022). Current findings show that firms keeping an adequate balance between local, regional and international networks tend to demonstrate more resilience during a pandemic than ones embedded only in global food supply chains (Ali et al. 2022a). High self-sufficiency combined with a strong focus on local distribution networks significantly decreased supply chain structure vulnerability but may have resulted in overall lower levels of resilience compared to a balanced approach (Dixon et al. 2021; Måren et al. 2022; Perrin & Martin 2021). Interestingly, it was suggested that a sufficient amount of such shock-tolerant firms in a region can noticeably contribute to the resilience of the whole regional food system (Kumar et al. 2022; Stoll et al. 2021). However, despite a wide range of observed disruptions, the last pandemic did not seem to undermine the integrity of international food supply chains in those regions where close cross-border collaboration was observed before - e.g., between the US and Canada or within European Union (Hobbs 2021).

Supply chain design vulnerability

Both high supply chain density (i.e., low geographical dispersion) and node criticality were mentioned as sources of increased supply chain vulnerability. Seafood supply chains with production and processing plants densely clustered along the coasts experienced more pressure from trade and logistics restrictions (Bassett et al. 2022). In contrast, supply chains that were more geographically diffuse demonstrated higher levels of resilience and competitiveness during the last pandemic (Ali et al. 2022a). Developed simulation models highlighted an existing trade-off: dense supply chains are better suited to deliver high outputs whereas sparse supply chains are better suited to guarantee that outputs do not decline below a certain minimum level (Hobbs 2021). In some cases, it was not the high complexity of a supply chain that undermined its resilience but the vulnerability of its critical nodes: if such nodes (e.g., cattle auctions for the beef supply chain or ports for aquaculture chains) were unable to quickly pivot, then the whole supply chain got seriously disrupted (Meyer et al. 2022). Untimely identification of such critical nodes, key suppliers and critical infrastructure hindered the effective alleviation of observed supply chain disruptions (Ali et al. 2022a; Hobbs 2021).

Supply chain complexity

Complex supply chains are characterized by a large amount of nodes and/or a large number of different flows among them (Craighead et al. 2007).

Long and complex supply chains, when optimized, can allow for higher resource flow than short and simple ones; however, swift identification of disruptions' root causes in such networks might be problematic (Bassett et al. 2022). As supply chain shocks could interact, accumulate and travel, high complexity made interconnected supply chains prone to the propagation of such shocks (Meyer et al. 2022; Sharma et al. 2021). If these shocks reached a node of a supply chain that was not capable of dealing with them and failed, it could cause a deadlock effect in the whole network (Sharma et al. 2021). Another finding supports the previously conceptualized trade-off between complexity and dispersion. Even though dispersion (i.e., diversification) is generally assumed to improve firms' resilience, diverse distribution networks are more complex - and drawbacks of higher complexity could outweigh the benefits of higher dispersion at some point, thus making firms less resilient overall (Durant et al. 2023).

4.5 Supply chain capabilities

Efficiency

The evidence on the role of efficiency is mixed: it is clear that a firm's capacity to optimally execute is crucially important, but an excessive focus on performance optimization seems to amplify vulnerability to unforeseen negative events. On the one hand, firms that reduced excessive expenses, employed digital solutions for optimization of production and logistics processes, pursued forward and backward integration, and developed ways to optimally supply food to available customers were better prepared to face rough pandemics-induced disruptions (Ali et al. 2022a; Bassett et al. 2022; Kumar et al. 2022; Marusak et al. 2021). They leveraged modern technology and economies of scale and were able to use accumulated experience in a new environment (Hobbs 2021; Marusak et al. 2021; Sharma et al. 2021; Snow et al. 2021). On the other hand, there is evidence that intensive farms that focused on improving efficiency were more sensitive to supply chain disruptions due to their higher fixed costs, lower margins, and higher dependence on migrant labour (Helfenstein et al. 2022). Overall, resilience-seeking supply chain actors may sacrifice some of their profitability as they try to reach a desired balance between efficiency and redundancy. While having extra resources was suboptimal in usual times, when a pandemic hit, it provided businesses with a resource buffer that they used to either endure the turbulence or make organizational changes (Hobbs 2021; Raassens et al. 2022).

Dispersion

Pettit et al. (2010) define dispersion as the 'broad distribution or decentralization of assets' and, in this section, the author will use the term interchangeably with diversification and diversity.

A highly diversified firm is generally more likely to be hit by an unforeseen shock but is less likely to experience severe impacts, however, included evidence on dispersion is mixed. Diversification was observed in various domains: production processes, marketing channels, export markets, revenue streams, and supplier portfolios (Bassett et al. 2022; Snow et al. 2021; Måren et al. 2022; Kumar et al. 2022). Although it was generally argued that diversity of production and distribution processes is associated with greater firm resilience and there was sufficient evidence for it, there also were several clarifications (Bassett et al. 2022; Coopmans et al. 2021; Durant et al. 2023; Dixon et al. 2021; Helfenstein et al. 2022; Jones et al. 2022; Måren et al. 2022). Firstly, increased diversification comes with

a price of higher complexity, higher operation costs, and weaker connections among supply chain partners, which may foster internal and external frictions (Raassens et al. 2022). Secondly, the association of diversification of farmers' marketing channels with resilience was found to be not statistically significant (Durant et al. 2023). Thirdly, while leisure and recreational farms explicitly follow a diversification strategy that can be advantageous during other disruptions, during the pandemic such farms were hit the most as their non-agricultural activities belonged to 'a non-essential sector' and were shut down (Grigorescu et al. 2022). On the system level, the role of dispersion is yet to comprehend: some authors claim that high diversity contributes to higher resilience of food supply chains and food systems while others point out that there is insufficient evidence that a more diffuse food system would have performed better during a pandemic (Coopmans et al. 2021; Hobbs 2021). Another finding is that if diversification is pursued for spreading existing risks, then it may decrease a firm efficiency due to weaker economies of scale (Coopmans et al. 2021).

Market position

Market position refers to an ability to consumer's perception of a firm's status, its brands or products (Pettit et al. 2010).

Findings highlight the increased capacity of brands with high domestic recognition, developed niche customer bases, and previously established online presence to withstand the adverse effects of pandemics. Traditional farms (and cooperatives of traditional farms) that had managed to establish a local customer base loyal to their products before the pandemic demonstrated higher resilience (Grigorescu et al. 2022). Organic farms that focused on niche markets and narrow, selective target audiences also were more capable of dealing with pandemic-induced shocks as their regular customers often stayed loyal even after disrupted sales or deliveries (ibid.). Firms that did not focus on exports and instead concentrated on building brand recognition within national borders were less exposed to international trade decline and were more competitive when export-oriented actors shifted to domestic markets (Meuwissen et al. 2021). Similar dynamics were observed in online food delivery: those who have previously invested in building recognition as 'first choice food delivery companies' were better positioned when numerous other firms started to pivot there - and sometimes could even benefit from the pandemic (Hobbs 2021).

Security

Security as it is understood by Pettit et al. (2010), i.e. *defensive mechanisms against deliberate threats,* was not brought up in the included studies. However, the author decided to qualify quotations on worker health and safety as belonging to this capability. Several authors unanimously highlighted the crucial role of proper hygienic standards (wearing masks, social distancing etc.) and proactive regular screening of workers for operations' resilience, especially in labour-intensive chains such as meat, fresh fruits and vegetables (Ali et al. 2022a; Ali et al. 2022b; Bassett et al. 2022; Coopmans et al. 2021; Hobbs 2021).

Collaboration

Collaboration was the most often mentioned capability in the sample and also one of the most frequently prioritized focus by firms, hence, there is plenty of evidence describing it. Three major directions of collaboration were highlighted: with government agencies, national industry bodies (e.g., sector associations), and supply chain partners. Businesses that were able to set up a collaboration with governmental agencies received better, more relevant support and provided information and feedback in exchange, gaining in observed resilience levels (Ali et al. 2022a; Ali et al. 2022b; Capodistrias et al. 2022). Horizontal cooperations in the forms of membership in industry federations, sector associations or cooperatives also boosted actors' resilience (Ali et al. 2022a; Ali et al. 2022b; Mangano et al. 2022; Stoll et al. 2021; Coopmans et al. 2021; Meyer et al. 2022). Sufficient vertical cooperation with suppliers, customers or even final customers (i.e., people and local communities) allowed supply chain actors to signal their issues, receive more support and be more flexible during the harshest period of the pandemic (Durant et al. 2023; Stoll et al. 2021; Perrin & Martin 2021; Ladyka et al. 2022). The most commonly mentioned forms of cooperation included information exchange and consulting, collaborative procurement and planning, resource sharing, and complementary use of actors' strengths and redundancies (Ali et al. 2022b; Bassett et al. 2022; Grigorescu et al. 2022; Ladyka et al. 2022; Raassens et al. 2022). Researchers highlighted the importance of the proactive building of such connections, as developing completely new collaborations during a period of increased turbulence is problematic, and it was the pre-existing connections and social capital that produced the most benefits (Jones et al. 2022; O'Connell et al. 2021; Stoll et al. 2021; Xu et al. 2022). Another finding was that actors from supply chains with low inherent resilience (e.g., because of their design for a steady output like in the poultry industry) could offset that weakness by increased collaboration with governments and their competitors (Snow et al. 2021).

Financial strength

Collected from various sources, the evidence emphasized the importance of having an adequate financial buffer. Statistical analysis showed supply chain actors with a larger financial buffer were better fit to withstand financial adversity from the pandemic (Coopmans et al. 2021). Farmers mentioned one of their key learnings was to create a sufficient financial buffer for the future (Raassens et al. 2022). Interviewed experts suggested that keeping fixed costs low and leasing facilities and resources instead might help with securing sufficient cash (Kumar et al. 2021). These buffers, in most cases, were used either as additional resource stacks to proceed with a reorganization of production and marketing or as salary funds for skilled employees (Coopmans et al. 2021; Ali et al. 2022b).

Revenue management

This capability refers to the ability of a supply chain actor to leverage its resources in such a way that the total revenue is maximized (Tang & Tomlin 2008). If efficiency directs attention to decreasing resource use, revenue management alludes to improving revenue streams.

Three distinct features relating to the management of revenue streams were highlighted. Firstly, an omnichannel marketing approach was considered valuable as it allowed to reach different customer segments and/or provided alternative ways for customers to reach a company (Ali et al. 2022a). Secondly, businesses that developed online sales and used digital platforms to connect with their customers were better prepared for the pandemic's impacts and could even gain while offline-only traditional business models fought for survival (Schreiber et al. 2022; O'Connell et al. 2021). Thirdly, food producers that had built direct-to-consumer marketing channels experienced less adversity from the pandemic (Grigorescu et al. 2022; Jones et al. 2022). However, despite the evident positive effect of such elimination of additional downstream intermediaries on food producers' revenues, the total impact of this practice for the whole supply chain was not covered (i.e., it is clear that it adds to the resilience of a node, but not clear if it adds to the resilience of a chain).

One important delimitation is that this capability relates to *'readiness'* - a pre-disruption stage; therefore, if supply chain actors changed their approach and employed these strategies *during* the pandemic, that instead qualified as an example of flexibility.

Market strength

Scholars described three aspects that related to markets' strength and respectively influenced the whole supply chains aimed at these markets: pandemics' timing, market plasticity, and state support. The timing of the crisis was critically important and significantly defined which chains and actors would be exposed to the disruption. Some markets significantly struggled due to, for example, their 'high season' being skipped (e.g., spring for ornamental plants market) or cumulative effects with previous shocks - like African Swine Fever in the pig industry (Coopmans et al. 2021). At the same time, some agri-food sectors were barely affected (ibid.). These observations and speculative claims that they could be very different if the pandemic struck in another period indicate that market strength is indeed dynamic. Another feature that affected all actors within a supply chain was market plasticity. While there is inherent high plasticity in some sectors - which means that companies can delay, halt or hasten their production, processing and distribution (e.g., in red meat production or cropping industry), there are sectors structured for continuous production (e.g. pork or chicken) and that have inherent low plasticity (Snow et al. 2021; Hobbs 2021). Companies producing for markets with low plasticity generally had lower capacities to store the outputs in their systems which undermined their resilience (Snow et al. 2021). Finally, markets that were supported by governments with, for example, social protection policies or regular procurement with set minimum prices were less likely to experience adverse effects of the pandemic (Dixon et al. 2021).

Organizational culture

Organizational culture can potentially refer to a wide variety of activities, however, included studies mainly pointed out how culture may boost individual psychological resilience and support people in turbulent times with training. If organizational culture cultivated individual psychological resilience via the provision of free mental health networks and other social services, employees could better process and cope with unusual sudden change (Snow et al. 2021; Stoll et al. 2021). This likely contributed to the resilient functioning of production and logistics systems (Stoll et al. 2021). However, some scholars argue that seeing supply chain resilience only as a combination of production-related factors is reductionist and such an approach omits examination of the system of values that motivate people to lead changes or participate in them (Stoll et al. 2021). Values centred around community and social bonding (both within a company and with its partners) were mentioned as ones encouraging resilience development (Ladyka et al. 2022; Raassens et al. 2022). Culture of training and development (both formal and informal) also contributed to resilience as firms could pivot easier and do more effective hiring and onboarding of new staff (Ali et al. 2022a; Ali et al. 2022b; Kumar et al. 2021; Meuwissen et al. 2021).

Anticipation

Several quantitative studies determined adequate continuity management as one of the most important predictors of resilience (Kazancoglu et al. 2021; Kumar et al. 2021; Xu et al. 2022). Continuity management addresses both known and unknown factors, builds on scenario analysis and introduces short-term response plans and long-term risk management strategies (Xu et al. 2022). Simulation analysis revealed that supply chain fortification and development of a portfolio of backup suppliers were strategies the most resilient to unforeseen pandemics (Gholami-Zanjani et al. 2021). Robust incorporation of such scenarios in decision-making still requires a lot of extra data and advanced computation (ibid.). However, there were some advancements in that field as several Public Health agencies have been developing big data models to analyze the spread of COVID-19 and sharing their insights with relevant stakeholders (Ali et al. 2022b). It exemplifies the point that if enough cooperation is achieved, the benefits of anticipatory capabilities can be shared. Another common finding is that anticipation capability is highly dependent on previous exposure to other crises; organizations and systems that experienced an unforeseen severe shock invested more in resilience and anticipated a new shock better (Coopmans et al. 2021; Meyer et al. 2022; Snow et al. 2021). Entrepreneurs that have not experienced such shocks before state that they understood the need to prepare for the 'unplannable' now, and researchers agree with that and communicate the need for better anticipatory capabilities at all levels (Meuwissen et al. 2021; Snow et al. 2021).

Velocity

This capability refers to the swiftness of essential supply chain operations and is also regarded as highly influential on overall resilience level (Ponomarov & Holcomb 2009; Xu et al. 2022). In this context, velocity may refer to the speed of operations, communications and supply chain reconfigurations.

As the complex nature of the pandemic caused supply chain shocks hit both the demand and supply parts of the chains, conventional strategies to enhance velocity (e.g., zero inventory) were mostly inappropriate for food supply chain actors (Xu et al. 2022). However, the challenge was not the same for different firms: smaller firms typically faced fewer issues with velocity as their size allowed for better organizational agility; and agri-food firms that met the shock in the 'busy' stages of their business cycles were affected much more severely as they could not pivot right away (Måren et al. 2022; Meyer et al. 2022). The ones that experienced disruptions mentioned that ensuring rapid and effective communication with upstream and downstream partners was essential to understand the market situation better and be

able to quickly pivot accordingly (Kumar et al. 2021). Researchers argued that, on the tactical level, employing time and location delay strategies could reduce excessive pipeline time during a disruption, whereas a stronger focus on digital technologies that provide improved traceability and access to real-time data could help to boost velocity on the strategic level (Xu et al. 2022, Kumar et al. 2022; Sharma et al. 2021).

Visibility

Scholars highlighted the crucial role of supply chain visibility, its reliance on existing communication strategies, and ways how IT technologies can enhance it. Visibility of the supply chain is of paramount importance to the adaptive actions of its actors as it determines the available amount and quality of information needed to make decisions in times of crisis (Bassett et al. 2022; Kumar et al. 2021). Improved visibility allowed for better authenticity, privacy, and general reliability, which all contribute to resilience in volatile environments (Kumar et al. 2022). Ensuring an adequate level of end-to-end visibility and timely feedback was significantly complicated by the length and complexity of modern food supply chains (Xu et al. 2022; Sharma et al. 2021). Visibility levels were strongly dependent on the existing configurations of communication strategies within a supply chain: if its actors proactively established effective ways to equitably distribute information and aligned communications' frequency, directionality, modality and content, then the whole supply chain was able to benefit from increased visibility (Bassett et al. 2022; Raassens et al. 2022). Several studies pointed out the observed use cases of digital technologies to enhance internal and external visibility that included facial recognition solutions for tracking mask usage, real-time tracking of workers' health status, supplier alert management based on AI, and blockchain-based solutions boosting food traceability (Bassett et al. 2022; Kumar et al. 2021; Kumar et al. 2022; Sharma et al. 2021).

Flexibility

Organizations exercised flexibility in various domains that included remote work arrangements and contracting with trade partners (e.g., dedicated shipment, prolonged payables, shortened receivables); however, entrepreneurs and managers considered flexibility in distribution strategies critical (Ali et al. 2022a; Ali et al. 2022b; Bassett et al. 2022; Capodistrias et al. 2022; Coopmans et al. 2021). With the cease of previously used sales channels, the pandemic pushed supply chain actors to employ an omnichannel approach or completely switch to direct-to-consumer and digital market channels - and the ones who were not able to pivot

may have been at a disadvantage (Ali et al. 2022b; Bassett et al. 2022; Capodistrias et al. 2022; Stoll et al. 2021). Although widely observed, flexibility-related decisions were not equally useful or straightforward for all firms. Organizations within long supply chains and weaker relationships with their consumers and suppliers experienced more difficulties when transitioning to new distribution strategies (Hobbs 2021). Following the common trend and shifting to the supply of those goods with increased demand (e.g., milk, fresh potatoes) could be a successful exercise of flexibility but may not yield better overall resilience due to infrastructure limitations and market saturation dynamics (Coopmans et al. 2021). Firms that owned assets of high specificity, had high sunk costs and high specialization were much less flexible in using their assets for alternative purposes and faced intrinsic limits to their flexibility (Coopmans et al. 2021; Meuwissen et al. 2021). Medium-sized farms appeared to be the most flexible as they had enough reserves to deal with a series of shocks but depended less on global trade than large ones (Grigorescu et al. 2022; Helfenstein et al. 2022; Måren et al. 2022; O'Connell et al. 2021). Another finding is that even though both quantitative and qualitative evidence suggests the paramount importance of flexibility for resilience, supply chain actors' willingness to follow this path and take the connected risks varies noticeably (Kazancoglu et al. 2021; Sharma et al. 2021; Marusak et al. 2021; Stoll et al. 2021).

Redundancy

Building redundancy in the form of safety stocks proved valuable both for withstanding the pandemic and deriving market benefits from it. Experienced shortages of labour, safety equipment (e.g., masks) and spare parts highlighted that successful coping with them was based either on building such redundancies into the existing systems or on the ability to quickly find alternative ways to supply what is lacking (Coopmans et al. 2021). Supply chains where even small stocks of critical inputs like seed and grain existed (sometimes even located in a decentralised manner) demonstrated higher and better adaptive capacity as its actors could survive for longer periods with declined income levels (Dixon et al. 2021; Jones et al. 2022; Ladyka et al. 2022; Raassens et al. 2022). Another key prospect that redundancy provided was increased capacity to scale up production if the demand for some products rose - there are cases when food companies used their redundant resources to expand their activities during the pandemic and achieve a better market position compared to pre-pandemic years (Jones et al. 2022; Kumar et al. 2022). As already mentioned, redundancy and resource slacks make a supply chain less efficient but can provide critical value during a disruption - thus, optimizing for

resilience is not fully compatible with optimizing for profitability (Meyer et al. 2022; Raassens et al. 2022).

Adaptability

Supply chain actors exercised adaptability in three main ways: introduction of new internal structures and approaches, diversification, and launch of digitalization initiatives. Internal restructuring could aim to streamline operations, reconfigure infrastructure, and implement a new food collection or allocation approach (Capodistrias et al. 2022). Besides operational enhancement, adaptability was observed in new managerial approaches: for example, in the creation of a central response team comprised of high-level managers with the purpose of addressing adverse contingencies (Kumar et al. 2021). Another interesting shift was that, in order to survive, some businesses compromised their values and started to build connections with new suppliers that did not share them (Jones et al. 2022). Increased diversification was a widely observed way to adapt and could regard market diversification, additional distribution strategies or even business diversification done to achieve multi-functionality of assets (Bassett et al. 2022; Grigorescu et al. 2022). Besides a well-seen development of digital marketing channels (which the author regards as an example of a new distribution strategy), increasing digitalization can be a long-term strategy of adaptation by itself. Some firms recognized the value of these technologies and planned a stronger emphasis on the implementation of sensors technologies, RFID, Electronic Data Interchange, robots and drones in their operations (Ali et al. 2022b; Hobbs 2021). Another finding is that different markets that food supply chains deal with exuded different levels of adaptability: local markets, markets of perishable and veterinary products had adapted the quickest whereas consultancy services, fuel and seed markets were the slowest to adapt and recover (Dixon et al. 2021).

Crises management

Three important practicable general learnings on crisis management were found. Firstly, productive crisis management requires actors to combine and leverage several innovations at the same time to effectively address an unforeseen disruption (Capodistrias et al. 2022). Secondly, it is worthwhile to investigate what is the priority of available strategies to address a crisis and then concentrate on the top-ranked strategies initially, gradually including the lower-ranked ones (Kumar et al. 2021). Thirdly, the ability to deliver effective crisis management is disruption-driven and requires first-hand experience of unforeseen shocks (Ali et al. 2022a).

Several studies highlighted the crucial role of governmental institutions in decreasing the effects of adversity firms have to face in pandemics, numerous food organizations held a view that better governmental supervision, funding, and development are needed to respond to pandemics in the future (Coopmans et al. 2021; Måren et al. 2022; O'Connell et al. 2021). Governments were expected to step in and support short supply chains that deliver essential products to vulnerable rural communities to avoid a humanitarian crisis (Grigorescu et al. 2022). Aside from supporting vulnerable communities, adequate governmental response to the pandemic included welfare policies in the forms of cash transfers, tax deferrals and financial support for small and medium enterprises (Dixon et al. 2021). Nevertheless, some governmental policies designed to support society during the crisis could have unintentional harmful side effects for businesses - for example, an unemployment benefit could decrease the supply of labour for temporary jobs that are typical in farming (Schreiber et al. 2022). If policy design was not nuanced enough, it could follow a uniform approach and benefit mainly big firms as a result (ibid.).

Resource mobilization

This capability refers to actions and decisions aimed to acquire new or additional resources to meet new organizational needs (Villanueva et al. 2012). Resource mobilization was not seemingly a widespread strategy for resilience, however, several types of it were mentioned. Food producers and processors, as they experienced volatility in demand, were able to hire additional external storage to deal with oversupplied products (Coopmans et al. 2021). New hiring was relatively rare and was done mainly by organizations experiencing a demand surge (Capodistrias et al. 2022). However, what several studies mention is the influx of available and motivated volunteers that could be leveraged to address the less skill-requiring tasks (Jones et al. 2022; O'Connell et al. 2021). Finally, membership in sectoral associations could be used to jointly argue for additional financial support from the government (Coopmans et al. 2021).

Communication strategies

Effective communication strategies are not contributing to supply chain resilience by themselves but are needed for leveraging other capabilities or decreasing vulnerabilities. Communication with the government, employees and supply chain partners was mentioned as particularly influential on potential resilience capacity. As information flows were especially distorted during the first wave of the pandemic, the government was expected to provide essential information on lockdown status, labour dynamics, movement restrictions, minimum support prices

and other updates with a clear, single-window solution to avoid disorder (Kumar et al. 2021). Within a firm, frequent communication of high-level management with those 'in the trenches' was necessary to encourage, aid and counsel staff facing unanticipated issues (ibid.). Sufficient and quick communication with supply chain partners was needed to ensure visibility and understand the dynamics of supply and demand (Raassens et al. 2022). Several studies highlighted the role of information and communication technologies, particularly having access to reliable and fast Internet, in ensuring communication efficiency and effective knowledge management (Bassett et al. 2022; Snow et al. 2021). However, access to such technologies can be impeded by scarcity of telecommunication infrastructure, individual socioeconomic classes, or historical power distributions which contributes to inequalities in adaptive capacity (Bassett et al. 2022).

Consequence mitigation

As the effects of a pandemic are multifaceted and multidimensional, scholars observed a wide variety of measures, both governmental and otherwise, but those measures that tried to tackle and regulate 'cause factors' were more successful in easing the crisis (Shanker et al. 2022). Impact-export regulations and disrupted information flows were among such most important cause factors (ibid.). Another highlighted issue was that governments and sectoral organizations generally sought to support the food producers but it was the implementation, choices of support strategies, lack of comprehensive real-time data or faced systemic issues which complicated effective consequence mitigation (Bassett et al. 2022; Dixon et al. 2021).

5. Discussion

5.1 Problematic trade-offs

Both previous conceptualizations and collected evidence underscore existing relationships between interventions to supply chain resilience. Enhancements in one capability may support developments in other capabilities or decrease supply chain exposure to some vulnerabilities. Inverse relationships were observed between dispersion and supply chain complexity, efficiency and redundancy, and efficiency and flexibility. The trade-offs that include efficiency seem particularly impactful and important if long-term resilience of food systems is desired.

Market dynamics and profit motive push organizations to optimize for efficiency, as a result, they decrease excessive expenditures, follow the lowest available prices and try to optimize storage capacities. There is a constant and strong incentive to turn a profit and steadily grow. At the same time, if an organization enjoys a long period without any severe adverse unforeseen events happening, perceived incentives to develop resilience to such scenarios gradually decline. If we consider that resources available to food chain actors are limited, and organizations regularly make decisions about which projects to fund, it is plausible that the longer the period of an 'uninterrupted peace' is, the more resources companies divest from building flexibility and ensuring redundancy and invest them in efficiency instead. This inherent drive towards efficiency is extremely important to recognize when dealing with 'black swans' (i.e., unpredictable risks with low probability and high damage) as it makes supply chains more vulnerable to disruptions like pandemics.

As severe pandemics remain a rare event, it seems that food supply chain actors systematically overlook small probabilities of catastrophic events. Certainly, after COVID-19 some firms would develop procedures and policies to address the next pandemic, but if the next pandemic is not going to happen in the next 40-50 years, it is conceivable that their readiness will start to dissipate. To prevent such dissipation, a better conceptual understanding of such decision-making is needed.

In this discussion, I would like to propose two possible explanations for these dynamics. The first one is based on concepts from cognitive psychology. Today we understand that human judgement is subject to many heuristics and biases. Human intuition is especially prone to cognitive fallacies when dealing with uncertainty and low probabilities (Tversky & Kahneman 1973). Tversky and Kahneman (1973) discovered and described availability bias - an inherent mental tendency to overestimate information that was recently obtained and is easier to recall. This bias also refers to the perceived magnitude of events' impacts - if it is easy to recall the consequences of an event, these consequences appear more significant (ibid.). Perhaps, individual cognitive biases may aggregate into an organizational bias and cause insufficient emphasis on preparing for 'black swans' events as the last happenings of such 'black swans' become more distant in time. To my knowledge, no research can currently substantiate this claim and also there are no institutions that can help incorporate this risk into collective decision-making (e.g., pandemics insurance). Therefore, it is important to improve our understanding of 'organizational memory' to discover if this bias accounts for risk perception on the collective level. The second possible explanation is rooted in business reality. Businesses usually invest in projects if they consider the benefits to outweigh the expenditures. Regarding projects aimed to improve supply chain resilience, it could be clear and straightforward how to estimate their costs (extra inventory, decreased productivity, CAPEX) but how to properly estimate long-term benefits may be unclear. Such intractability and lack of incentives to deal with long-term issues (especially for firms that are 'too big to fail') might cause small probabilities of catastrophic events being systematically overlooked.

The trade-offs between different elements of resilience have been observed and described. An excessive focus on efficiency decreases supply chain flexibility and redundancy while an excessive focus on flexibility or redundancy decreases efficiency - and both may decrease the overall resilience of a supply chain. However, these relationships are absent from the current conceptual frameworks. It will be valuable to represent the trade-offs in the supply chain resilience frameworks and carry out more research into how supply chain actors make decisions regarding these trade-offs.

5.2 Short supply chains

Findings of several included studies discovered that pandemics-induced disruptions emanated from hotspots of vulnerability (i.e., the weakest nodes) and started to travel upstream and downstream throughout supply chains. Successful mitigation of such disruptions required an actor to: 1) expect it and be ready (*anticipation*); 2) if not anticipated, then notice it in advance and avoid it (*visibility*); 3) if not noticed

in advance, be flexible and collaborative enough to find ways to deal with it (*flexibility* and *collaboration*); 4) if not able to find ways to deal with it, have enough resource stacks to endure it (*redundancy*).

Short supply chains have proven to perform at two of these tasks better than long-stretched ones, while there is no evidence that long supply chains outperform short ones in the other two. Short supply chains generally had higher visibility, were more flexible and more collaborative, thus could better address teleconnected vulnerabilities. At the same time, no studies mentioned that long supply chains had improved anticipatory capabilities or relatively larger resource stacks. Ability to anticipate a pandemic seems to depend on previous exposure to other pandemics and established collaboration with other stakeholders. Long supply chains are built to obtain the price benefits and increased revenues and scholars have not observed higher profits being invested into more redundancy. Therefore, it is plausible that short supply chains may outperform long ones even in anticipating and enduring pandemics.

This notion may be relevant in food system governance. If setting a limit to capitalistic optimization for efficiency (i.e., developing policies that set limits to growth) is not realistic or appropriate, then supporting shorter supply chains might yield similar results from the resilience perspective. Pushing already established firms to decrease their margins in order to build food system resilience could be problematic - nevertheless, establishing mechanisms and institutional support that would nurture firms working within short supply chains could be an alternative way to increase the overall resilience of the agri-food sector without directly compromising the interests of actors from long supply chains.

5.3 Effectiveness of interventions

Firms may carry out a wide variety of projects focusing on developing certain capabilities or reducing certain vulnerabilities. However, several included quantitative studies discovered that these capabilities are not equal in terms of their impacts - some contributed to resilience much more than others. Findings indicated that flexibility, visibility, and collaboration were among the most significant enablers of food supply chain resilience to pandemics (Kazancoglu et al. 2021; Xu et al. 2022; Sharma et al. 2021). These capabilities are important by themselves, but besides that, supply chain vulnerabilities and capabilities are interconnected with an intricate web of cause-and-effect relationships, and the increase in these three capabilities seemed to cause developments in multiple other capabilities. If there

are limited resources dedicated to boosting supply chain resilience, knowledge of which strategies are the top choices could be of paramount value.

However, there are substantial limitations to this learning. More research is needed to confirm these findings and find out how generalizable they are. The studies that provided these estimations employed graph theory matrix approach, Fuzzy DEMATEL and simulation methods and could be biased toward resilience attributes that are most easily quantified and modelled within such approaches, hence more quantitative and qualitative insights are needed to corroborate discovered order of effectiveness. Moreover, the authors of those studies modelled different supply chain capabilities but did not adequately address vulnerabilities. It is also not clear if these findings are robust for firms from different parts of food supply chains: the key resilience enablers for food producers, processors, and retailers may differ. Overall, there is high potential value in the continuation of attempts to discover or establish a better academic understanding of optimal ways to develop resilience for a firm, supply chains, and food systems as it might allow for a better treatment of future disruptions.

5.4 Reflections on the conceptual framework

The chosen framework was versatile and extensive enough to cover various manifestations of food supply chain resilience. It provided a set of 30 different categories that could be used to distinguish between capabilities and vulnerabilities, internal and external vulnerabilities, and readiness, responsiveness and recovery capabilities. An abundance of provided categories significantly decreased the risk of forcing data into the framework. It also successfully synthesized previously developed frameworks into a single conceptualization that can arguably be used both for academic and practical endeavours.

However, there are some areas where it could be enhanced (besides the aforementioned trade-offs that lack conceptualization). First and foremost, the delineations between some interventions were blurry in practice. Partly it was due to a specific class of disruptions a pandemic brings. Capabilities differ depending on the stage of a disruption (readiness refers to the pre-disruption period, responsiveness refers to dealing with ongoing disruption, and recovery refers to the post-disruption phase). A pandemic hits in an easily identifiable period, therefore, there is a clear distinction between readiness and responsiveness phases, but the stages of responsiveness and recovery were hard to distinguish as the pandemic caused both short-term and prolonged shocks. It caused significant difficulty in understanding if some decisions, for example, should have qualified as examples of either flexibility, adaptability, or crisis management. The framework is also

suited best for the examination of individual firms and does not fully fit the analysis of supply chains in general or food systems. An example of corresponding ambiguity would be a distinction between supplier and customer vulnerability - the difference is clear when judging from the point of view of a certain firm, but if analysing the whole supply chain where most nodes are both suppliers and customers, these categories largely overlap. Finally, not all definitions were useful. The definition of particular ambiguity was *consequence mitigation*, which was not specific enough and thus helpful in defining what activities and strategies could be tagged as examples of this capability. One dimension that was noticeably lacking during the analysis was worker and production safety. This issue is of essential importance during a pandemic, and, if disrupted, could cause a total halt of operation. Not to omit this important issue, it was a rather arbitrary decision to qualify relevant safety measures as examples of 'security', but there is a certain need to establish an additional capability or vulnerability that will address that.

6. Conclusion

The purpose of this study is to contribute to the current understanding of the emergence and dynamics of resilience in food supply chains during pandemics and contribute to conceptualizations of supply chain resilience in this context. In order to accomplish set objectives and answer two research questions, a rapid literature review was carried out to find and select the evidence and framework synthesis was employed to analyze and present included evidence.

To find out what is known about food supply chain resilience to severe pandemics, the author followed a transparently described process of literature search and narrowed down the initial sample of 853 discovered studies from 6 scientific databases to a sample of 30 studies of high quality and relevance. Coding and classifying data from these studies were done with the use of an a priori framework of supply chain resilience proposed by Kochan and Nowicki (2018). This study provides summaries of quantitative and qualitative findings from selected papers that refer to 30 distinctive interventions to food supply chain resilience.

Besides descriptive summaries of evidence on each intervention, the author of this study produced analytical insights on important learnings that can be derived from the collected evidence. The study highlights existing intricate connections between different interventions to supply chain resilience as well as provides some possible explanations for why problematic trade-offs may perpetuate. It supports earlier conceptualizations of existing trade-offs between efficiency and flexibility or redundancy and develops a hypothesis that disregarding the latter two could be caused by organizational bias or intractability of calculations. The author also argues that short food supply chains were more resilient to pandemics due to their better visibility, flexibility and collaboration. This study stresses the importance of careful examination of available strategies for building resilience as, according to several included studies, strategies focused on improving flexibility, cooperation, and visibility seem to be considerably more effective than others. Finally, the author reflects on the adequacy of chosen conceptualization of supply chain resilience, points out lacking elements or existing blur in the framework and provides several suggestions for its improvement.

This study provides a better understanding of how different elements of resilience emerge, perform, and interact in food supply chains, which can be useful in improving continuity management, designing strategies for resilience to pandemics both in the for-profit context and in policymaking, and generating ideas for future research.

6.1 Limitations

This study has several significant limitations. First and foremost, the lack of other reviewers and not having enough time to carry out a full-scale systematic review should have considerably increased the risks of bias. Different biases could manifest themselves both at the exclusion stages (other papers could have made it to the final sample) and at the coding stage (other findings could have been highlighted or the same findings could have been tagged as different interventions). However, the provided approach is highly repeatable and the study can be adjusted if researchers would decide to upgrade it to a systematic review.

Secondly, 56 studies were excluded from the initial sample because they were not written in English. They constituted 6,5% of the initial sample and their exclusion introduced a significant language bias and might have led to the exclusion of highly relevant studies that happened to be published in Spanish or Arabic.

Thirdly, it is not clear how generalizable the findings are to any pandemic. Consistent research agenda of food supply chain resilience to pandemics emerged only during the last pandemic and, consequently, an overwhelming portion of papers in the sample considered evidence only from the COVID-19 pandemic. It remains uncertain if (and by how much) supply chain abilities developed to address disruptions from COVID-19 (or from the same class of infections) are transferable to other viruses.

Another limitation was imposed by the choice of the method. The author has chosen framework synthesis that was used to analyze only supply chain resilience, but several themes regularly appeared in the studies and were either omitted due to their 'irrelevancy to the questions' or forced into the framework's categories they do not belong. An example of the former would be the distributional aspects of a pandemic's impacts; several studies brought up the evidence that marginalized rural communities suffered more and more often experienced food insecurity - but there was no place in the framework to recognize that and it did not directly connect with the formulated question, thus such findings were not highlighted. An example of the latter would be forcing safety measures into 'security' capability. This limited

the academic rigour of this review and could be potentially avoided if the method of *best-fit framework synthesis* was used.

Finally, this review does not provide an extensive overview of existing research gaps in the field. This study explored and summarised what was known about resilience and was recently observed, analyzed the evidence and extracted learnings from it, but it did not aim to reveal overstudied and understudied areas (neither thematic nor geographical). Although it is mentioned that collaboration and flexibility remain the most studied capabilities in this review, its approach does not suit the objective of studying research gaps. Following such an objective would likely require carrying out a more quantitative analysis of a larger sample of studies.

6.2 Future research

As it was mentioned in this study, more research is needed in several directions. As the trade-offs between different supply chain capabilities and vulnerabilities are evident now, it would valuable to examine how organizations perceive these trade-offs, what is their understanding of equilibrium, and how decisions considering these trade-offs are made. More and better knowledge on hotspots of supply chain vulnerability could be obtained: if the strength of the chain is defined by the strength of its weakest node, a better understanding of how to proactively locate and defend such vulnerable points could yield immense empirical value. Moreover, additional research is needed to explore how generalizable the discovered findings are for different firms in food supply chains (e.g., are flexibility, visibility, and collaboration going to stay similarly relevant and effective for downstream and upstream actors) and during different pandemics. The latter could be problematic without new unexpected pandemics happening, however, resilience dynamics could be studied on smaller epidemics that hit food supply chains or with the help of simulation techniques. Conceptual endeavours could be addressed to further develop existing conceptualizations of supply chain resilience to include causal connections and trade-offs between different parameters. Moreover, as supply chain operations remain subject to optimization and data-driven decision-making, theoretical research into how long-term benefits from resilience can be estimated and incorporated in business models and corporate strategizing could generate invaluable insights that might help foster more system resilience. Finally, to overview and characterize the recently emergent field of pandemics-resilient food research, a more quantitative systematic literature review could be carried out to underscore where most of the effort has been put and which areas keep being underresearched.

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Popular science summary

How do we ensure feeding everyone no matter what? The purpose of the research into food supply chain resilience is to understand the reasons behind supply chain failures and successes in the face of disruptions and shocks. This work focuses on one particular type of catastrophic event - pandemics - and seeks to review and expand the existing understanding of how food supply chains could persevere during pandemics. To achieve that, 30 recent papers of high quality and high relevance are reviewed and summarized within a comprehensive framework of supply chain resilience. These summaries describe how different elements of resilience emerge, perform, interact with each other, and impact the overall resilience of a food supply chain to a pandemic. The author goes beyond summarizing; he reflects on problematic issues that can hinder resilience and provides promising strategies that can be employed by supply chain managers and/or policymakers to effectively facilitate resilience.

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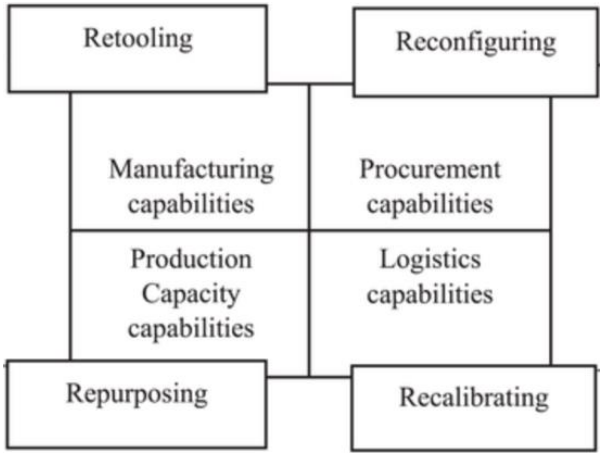
Appendix 1: Definitions of interventions

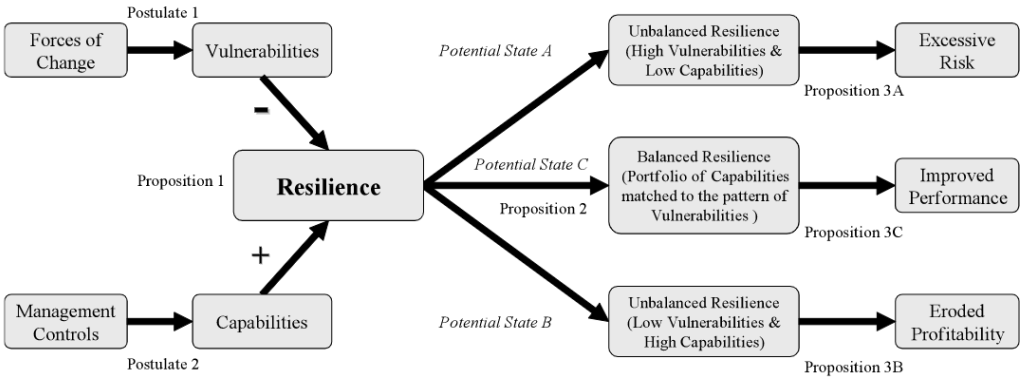
Term	Definition	From
Turbulence	Environment characterized by frequent changes in external factors beyond your control	Pettit et at. (2010)
Regulatory, legal, and bureaucratic vulnerability	Vulnerability that stems out of legal enforceability and execution of supply chain-relevant laws and policies as well as the degree and frequency of changes in these laws and policies.	Wagner & Bode (2008)
Financial vulnerability	Vulnerability to uncertain broader financial conditions, including stock market volatility, foreign exchange, budget overruns, and inflation	Sheffi (2005)
Resource limits	Constraints on output based on availability of the factors of production	Pettit et at. (2010)
Supplier vulnerability	Vulnerability of the supply base that may result from the financial instability of suppliers, their inability to adapt to technological or product design changes, their opportunistic behaviours etc.	Sheffi (2005)
Customer vulnerability	Vulnerability of the downstream supply chain operations that may be caused by high customer dependence, the uncertain financial situation of the customer, certain product characteristics (e.g., high complexity), intricate distribution and transportation networks etc.	Wagner & Neshat (2010)
Infrastructure vulnerability	Vulnerability to disruptions that materialize from the infrastructure that is used for supply chain operations. It includes socio-technical accidents such as equipment malfunctions, machine breakdowns, disruptions in the supply of electricity or water, IT failures, in addition to local human-centered issues (vandalism, sabotage, labor strikes, industrial accidents)	Wagner & Bode (2008)
Deliberate threats	Intentional attacks aimed at disrupting operations or causing human or financial harm	Pettit et at. (2010)
Supply chain structure vulnerability	Vulnerability that is caused by disintegration of supply chains, globalization and off-shoring of value-adding activities	Wagner & Neshat (2010)
Supplier chain design characteristics	Vulnerability that stems from supply chain density (the extent to which nodes within a supply chain are clustered closely together) or nodes' criticality (existence of exceptionally important nodes in the chain with the extreme cost of failure)	Craighead et al. (2007)
Supply chain complexity	Vulnerability that stems from a large number of nodes in a supply chain and the number of flows among them	Craighead et al. (2007)

Term	Definition	From
Efficiency	Capability to produce outputs with minimum resource requirements	Pettit et at. (2010)
Dispersion	Broad distribution or decentralization of assets	Pettit et at. (2010)
Market position	Status of a company or its products in specific markets	Pettit et at. (2010)
Security	Defense against deliberate intrusion or attack	Pettit et at. (2010)
Collaboration	Ability to work effectively with other entities for mutual benefit	Pettit et at. (2010)
Financial strength	Capacity to absorb fluctuations in cash flow	Pettit et at. (2010)
Revenue management	Ability to allocate resources so that the total revenue is maximized	Tang & Tomlin (2008)
Market strength	The measure of market strength can be either relative or absolute. In relative terms, it evaluates a market's capacity to perform compared to other markets, while in absolute terms, it assesses a market's performance in relation to its own historical levels.	Rice & Caniato (2003)
Organizational culture	Human resource structures, policies, skills and culture	Pettit et at. (2010)
Anticipation	Ability to discern potential future events or situations	Pettit et at. (2010)
Agility	The ability to respond rapidly to unpredictable changes	Christopher & Peck (2004)
Velocity	The speed of critical supply chain operations	Ponomarov & Holcomb (2009)
Visibility	Knowledge of the status of operating assets and the environment	Pettit et at. (2010)
Flexibility	Ability to quickly change inputs and outputs or the mode of receiving and delivering them	Pettit et at. (2010)
Redundancy	Capacity to respond to disruptions in the supply network, largely through investments prior to the point of need	Rice & Caniato (2003)
Adaptability	Ability to modify operations in response to challenges or opportunities	Pettit et at. (2010)
Crises management	The process through which an organization manages an unforeseen shock or disruptive event that poses a risk to either the organization itself or its stakeholders.	Bundy et al. (2017)
Resource mobilization	Activities undertaken by an organization to secure new and additional resources to meet its needs	Villanueva et al. (2012)
Communication strategies	Functional strategy that creates focus and aligns internal and external organizational communications	Steyn (2004)
Consequence mitigation	Activities and decisions designed to make the consequences of a disruption less severe	Kochan & Nowicki (2018)

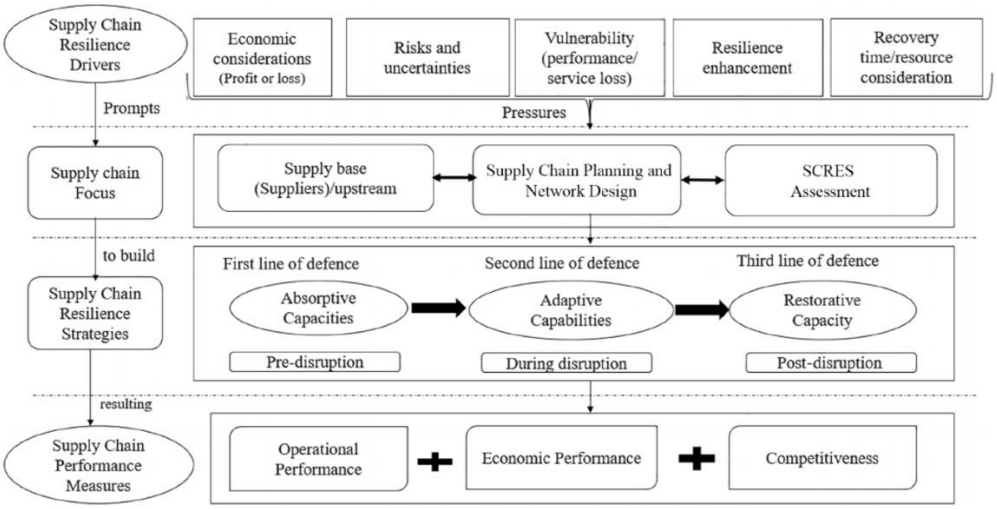
Appendix 2: Alternative frameworks of supply chain resilience



Concept of 4R of supply chain resilience (Dwaikat et al. 2022)



Theoretical concept of supply chain resilience (Pettit et al. 2010)



Supply chain resilience framework (Shishodia et al. 2021)

Appendix 3: Search queries

Search query for Scopus

(TITLE-ABS-KEY((food OR agricultur* OR farm* OR agri-food) AND ((supply OR value) AND (chain* OR network* OR system*))) AND TITLE-ABS-KEY((resilien* OR brittle*)) AND TITLE- ABS-KEY((pandemi* OR epidemi* OR "catastrophic biological ris*" OR ncov* OR 2019ncov OR 19ncov OR covid19* OR covid OR sars-cov-2 OR sarscov -2 OR sars-cov2 OR sarscov2 OR "SARS coronavirus 2" OR "Severe Acute Respiratory Syndrome Coronavirus 2" OR "Severe Acute Respiratory Syndrome Corona Virus 2")))

Search query for Web of Science

((TS=((food OR agricultur* OR farm* OR agri-food) AND ((supply OR value) AND (chain* OR network* OR system*)))) AND TS=((resilien* OR brittle*))) AND TS=((pandemi* OR epidemi* OR "catastrophic biological ris*" OR ncov* OR 2019ncov OR 19ncov OR covid19* OR covid OR sars- cov-2 OR sarscov-2 OR sars-cov2 OR sarscov2 OR "SARS coronavirus 2" OR "Severe Acute Respiratory Syndrome Coronavirus 2" OR "Severe Acute Respiratory Syndrome Corona Virus 2"))

Search query for AGRIS

((food OR agricultur* OR farm* OR agri-food) AND ((supply OR value) AND (chain* OR network* OR system*)) AND ((resilien* OR brittle*)) AND ((pandemi* OR epidemi* OR "catastrophic biological ris*" OR ncov* OR 2019ncov OR 19ncov OR covid19* OR covid OR sars-cov-2 OR sarscov-2 OR sars-cov2 OR sarscov2 OR "SARS coronavirus 2" OR "Severe Acute Respiratory Syndrome Coronavirus 2" OR "Severe Acute Respiratory Syndrome Corona Virus 2")))

Search query for CAB Abstracts® and Global Health®

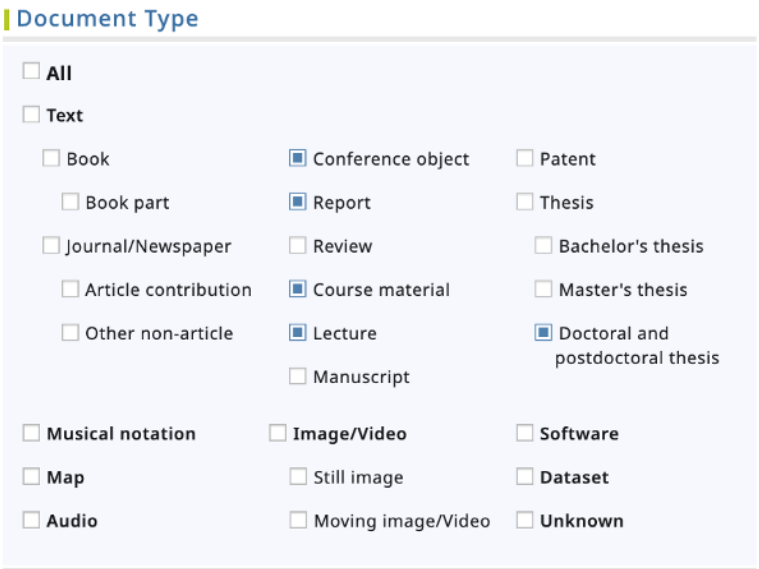
((TS=((food OR agricultur* OR farm* OR agri-food) AND ((supply OR value) AND (chain* OR network* OR system*)))) AND TS=((resilien* OR brittle*))) AND TS=((pandemi* OR epidemi* OR "catastrophic biological ris*" OR ncov* OR 2019ncov OR 19ncov OR covid19* OR covid OR sars- cov-2 OR sarscov-2 OR sars-cov2 OR sarscov2 OR "SARS coronavirus 2" OR "Severe Acute Respiratory Syndrome Coronavirus 2" OR "Severe Acute Respiratory Syndrome Corona Virus 2"))

Search query for EconLit

noft(((food OR agricultur* OR farm* OR agri-food) AND ((supply OR value) AND (chain* OR network* OR system*)) AND ((resilien* OR brittle*)) AND ((pandemi* OR epidemi* OR "catastrophic biological ris*" OR ncov* OR 2019ncov OR 19ncov OR covid19* OR covid OR sars- cov-2 OR sarscov-2 OR sars-cov2 OR sarscov2 OR "SARS coronavirus 2" OR "Severe Acute Respiratory Syndrome Coronavirus 2" OR "Severe Acute Respiratory Syndrome Corona Virus 2"))))

Search queries for BASE

Three search queries were executed: "food supply chain resilience pandemic", "food value chain resilience pandemic", and "food system resilience pandemic". Further queries with synonyms produced only duplicates, therefore, the author decided to stop the search. The settings of the search are presented in the figure below.



Filters for the search in BASE database

Appendix 4. Flow diagram

Appendix 5. Contribution of studies to the synthesis

	Turbulence	Regulatory vulnerability	Financial vulnerability	Resource limits	Supplier vulnerability	Customer vulnerability	Infrastructure vulnerability	Deliberate threats	SC structure vulnerability	SC design characteristics	SC complexity
Ali et al. (2022a)				✓	✓				✓	✓	✓
Helfenstein et al. (2022)											
Hobbs (2021)	✓			✓	✓				✓	✓	
Jones et al. (2022)						✓	✓				
Kazancoglu et al. (2021)							✓				
Kumar at al. (2021)											
Kumar et al. (2022)									✓		
Ladyka at al. (2022)				✓							
Mangano et al. (2022)			✓		✓	✓	✓				
Marusak et al. (2021)											
Meuwissen et al. (2021)	✓						✓				
Ali et al. (2022b)	✓	✓	✓	✓	✓	✓			✓		
Meyer et al. (2022)		✓							✓	✓	✓
Måren et al. (2022)					✓				✓		
O'Connell et al. (2021)	✓			✓		✓					
Perrin & Martin (2021)									✓		
Raassens et al. (2022)			✓								
Schreiber et al. (2022)				✓							
Shanker et al. (2022)			✓				✓				
Sharma et al. (2021)					✓				✓		✓
Snow et al. (2021)									✓		
Stoll et al. (2021)				✓	✓	✓			✓		
Bassett et al. (2022)	✓	✓	✓			✓			✓	✓	✓
Xu et al. (2022)											
Capodistrias et al. (2022)				✓							
Coopmans et al. (2021)	✓		✓	✓	✓		✓				
Dixon et al. (2021)					✓	✓	✓		✓		
Durant et al. (2023)											✓
Gholami-Zanjani et al. (2021)											
Grigorescu et al. (2022)		✓			✓	✓	✓				

Supply chain vulnerabilities

	Efficiency	Dispersion	Market position	Security	Collaboration	Financial strength	Revenue management	Market strength	Organizational culture	Anticipation	Agility_velocity	Agility_visibility	Agility_flexibility	Redundancy	Adaptability	Crises management	Resource mobilization	Communication strategies	Consequence mitigation
Ali et al. (2022a)	✓			✓	✓		✓		✓	✓		✓	✓		✓	✓		✓	
Helfenstein et al. (2022)	✓	✓											✓		✓				
Hobbs (2021)	✓	✓	✓	✓				✓					✓		✓	✓			✓
Jones et al. (2022)		✓			✓		✓				✓		✓	✓	✓	✓	✓		
Kazancoglu et al. (2021)					✓					✓			✓						
Kumar at al. (2021)	✓				✓	✓			✓	✓	✓	✓	✓		✓	✓		✓	
Kumar et al. (2022)		✓			✓					✓	✓	✓	✓	✓					
Ladyka at al. (2022)			✓		✓				✓				✓	✓	✓				
Mangano et al. (2022)	✓	✓			✓								✓	✓	✓				
Marusak et al. (2021)	✓				✓								✓						
Meuwissen et al. (2021)		✓	✓		✓				✓	✓			✓						✓
Ali et al. (2022b)				✓	✓	✓			✓	✓			✓		✓	✓			✓
Meyer et al. (2022)					✓					✓	✓			✓					
Måren et al. (2022)		✓			✓						✓		✓			✓		✓	
O'Connell et al. (2021)					✓		✓						✓			✓	✓		
Perrin & Martin (2021)			✓		✓		✓			✓					✓				
Raassens et al. (2022)	✓	✓			✓	✓			✓	✓		✓	✓	✓	✓			✓	
Schreiber et al. (2022)					✓		✓						✓	✓	✓	✓			
Shanker et al. (2022)				✓						✓						✓			✓
Sharma et al. (2021)	✓										✓	✓	✓						
Snow et al. (2021)	✓	✓			✓	✓		✓	✓	✓			✓					✓	
Stoll et al. (2021)					✓				✓				✓						
Bassett et al. (2022)	✓	✓		✓	✓							✓	✓		✓	✓		✓	✓
Xu et al. (2022)	✓				✓					✓	✓	✓							
Capodistrias et al. (2022)					✓								✓		✓	✓	✓	✓	
Coopmans et al. (2021)		✓	✓	✓	✓	✓		✓		✓			✓	✓		✓	✓		
Dixon et al. (2021)	✓							✓		✓				✓	✓	✓			✓
Durant et al. (2023)		✓			✓								✓						
Gholami-Zanjani et al. (2021)										✓									
Grigorescu et al. (2022)		✓	✓		✓		✓						✓		✓	✓			

Supply chain capabilities

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