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Review

Building Resilience in Food Security: Sustainable Strategies Post-COVID-19

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Abstract: The outbreak of COVID-19 has posed formidable challenges to the food industry, exacerbating threats to food security worldwide. In response to this crisis, this comprehensive review systematically maps the existing literature concerning sustainability and resilience within the realm of food security. A meticulous categorization of the identified papers is performed, focusing on elucidating the underlying causes of food insecurity, assessing their profound impacts on public health, delineating the requisite strategies and actions, and discerning the commonalities and distinctions between sustainability and resilience. Systematic searches across reputable databases, including PubMed, Google Scholar, Scopus, and Springer, were conducted to retrieve pertinent papers published from 2019 to 2022, specifically addressing the threats to food security in the post-pandemic landscape. From an initial pool of 105 papers, 26 met the stringent inclusion criteria for subsequent in-depth analysis and categorization, employing thematic content analysis to elucidate their thematic focus on causative factors, repercussions, mitigation strategies, and intersections between sustainability and resilience. Drawing insights from the amalgamated findings, this study proposes a holistic, systematic conceptualization for integrating sustainability and resilience principles within the food sector. This structure offers a roadmap for fortifying food security, ultimately advancing the cause of public health and well-being. It is poised to serve as a valuable resource for researchers, facilitating the exploration of sustainability and resilience in the context of food supply chains and providing policymakers with actionable insights for implementing these vital approaches.

Keywords: food security; resilience; sustainability; thematic analysis; mitigation strategies; post-pandemic; supply chains

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1. Introduction

In recent years, the concept of sustainability has garnered increasing attention from scholars and practitioners. Sustainability encompasses a holistic evaluation of human life encompassing social, environmental, and economic dimensions, all with a forward-looking perspective to benefit future generations. Researchers have recognized a compelling opportunity to explore the intricate interplay between sustainability and resilience within the realm of food supply chains (FSCs) due to their observed interconnected influences. FSCs constitute a pivotal component of supply chains, and their dynamic relationship with resilience has substantial implications for organizational supply chain performance [1].

The emergence of the global COVID-19 pandemic in December 2019 sent shockwaves across the international landscape, inflicting profound financial repercussions on businesses and economies worldwide while simultaneously precipitating a global health crisis [2]. This crisis posed significant threats to public health and the economic well-being of communities [3].

Against this backdrop, a compelling need exists to foster an understanding of the interrelatedness of sustainability and resilience in food supply chains in the aftermath of disruptive events such as the COVID-19 pandemic. Such a systematic conceptualization should integrate technology and sustainable networks seamlessly to bolster market

presence, ecological responsiveness, and distinctiveness. Strategies encompassing lean, green, and resilient approaches, coupled with sustainability practices, have been pivotal in meeting market demands and mitigating supply and demand disruptions. The most recent and impactful paradigm in supply chain management seamlessly integrates sustainability and resilience principles.

1.1. Background

Supply chain sustainability and resilience are integral components of modern business strategies, each addressing distinct yet interconnected facets of supply chain management. Sustainability entails maintaining business operations while mitigating long-term risks, emphasizing the importance of responsible practices. In contrast, resilience focuses on a system's capacity to recover and restore itself to its original or desired state when faced with disruptions, highlighting the need for adaptability and preparedness.

These two concepts share common ground in strategic decision-making, often converging to shape a supply chain's overall performance. Public health emerges as a critical factor within the realm of social sustainability, warranting specialized attention in today's global landscape.

Developing models and decision-support tools is pivotal for enhancing the decision-making process for resilient and sustainable supply chains. Unfortunately, the existing body of literature in this field remains somewhat limited, impeding the formulation of comprehensive frameworks for effective decision-making in production systems. Past studies have introduced various structures, with some positioning resilience as a subset of sustainability, others considering sustainability within the scope of resilience, and occasional conflicts between these perspectives complicating their seamless integration [4]. In general, standalone literature reviews have evolved into an established genre and are essential in advancing research in many academic disciplines, including social sciences, health sciences, and management [5]. Specifically, with this literature review, we make a critical contribution to the existing body of knowledge about food security in the light of COVID-19; for that, we identify a research gap in the interrelationship of sustainability and supply chain resilience through systematic deduction. Identifying a research gap is generally considered a scientific contribution [6,7]. This review explores the evolving landscape of supply chain sustainability and resilience, shedding light on their intertwined dynamics and potential synergies to address these gaps.

1.2. Impact of COVID-19 on FSC

The COVID-19 pandemic has had profound implications for global food security, underscoring the critical importance of ensuring access to an abundant, safe, and nutritious food supply. Sustainable food consumption practices have become increasingly pivotal in pursuing healthier lifestyles and enhanced well-being, strongly emphasizing preventing food loss and promoting healthier dietary choices. However, the pandemic brought about a seismic shift in lifestyles worldwide, significantly impacting every facet of the food supply chain (FSC)—from production to distribution.

This impact manifested in a multitude of ways, including labor shortages, evolving consumer demands, disruptions in food production, restrictive trade policies, and financial pressures, which, in turn, triggered incidents of food product counterfeiting. Consequently, the pandemic presented formidable food safety and security challenges, driving the need for innovative solutions.

These challenges encompassed a spectrum of issues, from limited supply chain flexibility. They eroded trust due to the absence of government incentives, communication gaps, security vulnerabilities within supply chains, and supply and demand dynamics imbalances. It has become increasingly apparent that the FSC necessitates reliable, robust, and sustainable tools for tracing food items from their point of manufacture to their ultimate availability to consumers, ensuring transparency throughout the process to address these issues.

In light of the evolving food landscape, a pressing need exists to implement resilient strategies and comprehend their far-reaching impacts across sustainability's social, economic, and environmental dimensions. Addressing this need is pivotal for effectively responding to and adapting to the pandemic's new market challenges.

The United Nations Food and Agriculture Organization (FAO) defines food security as the universal accessibility of adequate, safe, and nutritious food, fulfilling dietary requirements and preferences for a healthy life. Unfortunately, the pandemic severely disrupted progress towards Sustainable Development Goals (SDGs) related to food security in many developing countries, especially during lockdowns. COVID-19 negatively affected the four core dimensions of food security: availability, stability, access, and utilization. The sufficiency of food supply hinges on land utilization, agricultural practices, infrastructure, transportation, farmers' role, and retailers' performance. In response to these challenges, there is a growing consensus, as suggested by the European Commission, on the need for a more comprehensive, diversified, resilient, adaptable, and sustainable food system [8].

1.3. Post-Pandemic Impact on Food Security

The post-pandemic impact on food security has been intensely scrutinized and concerned. The effects on food security remain palpable as the world begins to emerge from the shadow of the COVID-19 pandemic. The disruption of global supply chains, labor shortages, and shifts in consumer behavior during the pandemic have left a lasting imprint on the food industry. Amidst the post-pandemic discussions and efforts to enhance food security, a prevailing sense of scrutiny and concern remains. The experience of the COVID-19 pandemic has served as a stark reminder of the vulnerabilities in our global food supply systems. The lessons learned from this crisis have prompted a collective awareness of the need to be better prepared for future pandemics or global disruptions that could once again challenge our food security. The scrutiny extends to assessing the resilience of supply chains, exploring alternative food production methods, and developing strategies to ensure equitable food access, particularly in times of crisis. While progress is being made, there is an overarching recognition that the scrutiny and concern surrounding food security will persist as we work to build more robust and adaptable systems to withstand the uncertainties of an unpredictable world.

Ensuring a consistent and reliable food supply has become a more significant challenge. While efforts are being made to build more resilient and adaptable food supply chains, questions about long-term sustainability, equitable access to food, and the ability to address future crises loom large. The pandemic has underscored the critical importance of safeguarding food security as a fundamental human right and a cornerstone of public health and well-being. Post-pandemic, stakeholders across the globe are faced with an imperative to strengthen food systems, enhance supply chain resilience, and promote equitable access to safe and nutritious food to mitigate future risks and foster global food security.

1.4. Novelty of the Study

The COVID-19 pandemic affected the global community [9]. Some authors argue that new integrated risk management systems are needed in general [10], while other authors focus on the increased relevance of sustainability in the food processing sector [11]. Common to those views is the need to integrate sustainability and resilience [12]. Within this focus, some authors highlight natural resources regarding sustainability [13], while others shed light on systemic views of sustainability and their impacts on human health [14]. Hence, conceptual frameworks are necessary in this research field [15].

This study introduces a novel perspective by bridging critical gaps in the existing literature surrounding the impact of the COVID-19 pandemic on food security. While previous research has explored various aspects of sustainability, resilience, and supply chain management in the food sector, this study uniquely combines these elements, shedding light on their interconnectedness. Notably, no prior study comprehensively covered

food security, analyzed its implications for public health, and explored the avenues of sustainability and resilience in this context. By addressing this gap, the research provides a holistic view of the challenges posed by the pandemic and offers valuable insights into strategies for mitigating these challenges. An extensive review of the literature from the onset of the COVID-19 pandemic to the present revealed a significant research gap in food security. Despite numerous studies exploring various facets of sustainability, resilience, and supply chain dynamics, none have comprehensively tackled the intricate intersection of food security, its implications for public health, and the integration of sustainability and resilience. While select papers have delved into sustainability within the food supply chain (FSC) or examined the resilience of different sectors, the holistic exploration of both aspects across FSCs has been notably absent. The existing literature, such as the work by Khan and Manzoor [16], has indeed explored the application of technologies in supply chain management during the pandemic, highlighting their potential to address challenges. Other studies, like Ranjbari et al. [17], ventured into the consequences of COVID-19 from a sustainability perspective, offering valuable research directions for sustainable development. However, gaps persist, with a shortage of studies comprehensively investigating resilience, sustainability, and their synergy within FSCs. The novelty of this study lies in bridging these gaps, exploring the multifaceted relationship between food security, sustainability, and resilience, and proposing integrated strategies for enhancing the safety and security of food products. By doing so, this research contributes significantly to understanding these critical dimensions and offers a robust foundation for future research and practical applications in food security.

Furthermore, the study offers an original structure for integrating sustainability and resilience in food supply chains, underlining the significance of this approach in ensuring the safety and security of essential food products. This research thus contributes to advancing our understanding of the intricate relationship between sustainability, resilience, and food security, offering a comprehensive foundation for future studies and practical applications in this critical domain.

1.5. Study Objectives

This comprehensive systematic review was undertaken with the following multifaceted objectives:

- Meticulously chart and synthesize the expansive landscape of scholarly publications concerning sustainability and resilience within the intricate domain of FSCs, meticulously scrutinizing their intricate interplay and repercussions amid the backdrop of the COVID-19 crisis.
- Discern and elucidate the intricate nuances, convergences, and disparities inherent in the multifaceted concepts of sustainability and resilience as they manifest and evolve within the dynamic realm of food supply chains, particularly in the context of their safety and security, pre- and post-COVID-19.
- Categorize and systematize the diverse scholarly contributions based on their thematic emphases, encompassing investigations into the underlying causes for the potential dearth of sustainability and resilience within the food and broader supply chain sectors and their profound implications for public health.
- Additionally, this review aims to illuminate the strategic imperatives and concrete actions needed by these critical sectors in response to their multifaceted challenges while creating a systematic conceptualization for analyzing the intricate fabric of these scholarly works.

2. Materials and Methods

The methodology employed in this systematic review adhered to a rigorous and structured approach as outlined below in the flowchart in Figure 1. In conducting our research, we employed a meticulous and systematic approach guided by Haji et al. [2]. This comprehensive guide was instrumental in shaping the search and selection process,

ensuring that our methodology adhered to established best practices in the field. Utilizing a systematic approach provided a structured framework that aided in identifying, evaluating, and including relevant sources, ultimately enhancing the rigor and reliability of our research.

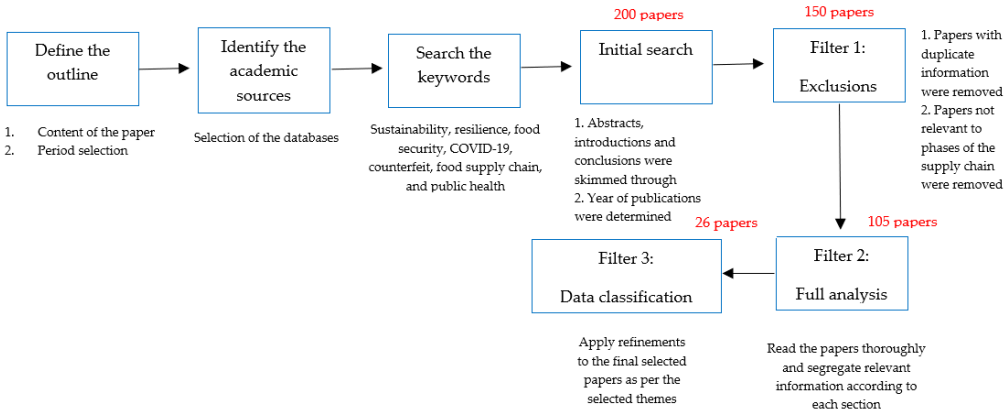

Figure 1. Flowchart for research and selection process.

2.1. Data Sources

A meticulous and systematic search of scholarly literature was conducted utilizing a range of renowned and widely recognized databases, including Scopus, Elsevier, Google Scholar, PubMed, and Springer. The study focused on the period from December 2019 to 2023, corresponding to the emergence and end of the COVID-19 pandemic. This time frame was selected with precision to encapsulate the evolving landscape of food security threats, which have exhibited a pronounced escalation since the onset of the pandemic, exerting a significant influence on public health. Only publications in the English language were considered to ensure uniformity and consistency.

2.1.1. Keywords

The keyword selection for this study was meticulously curated to encompass a comprehensive spectrum of pertinent concepts and dimensions. The identified keywords included sustainability, resilience, food security, COVID-19, food supply chain, and public health, as well as similarities and differences.

2.1.2. Inclusion Criteria

The criteria for inclusion were judiciously established to ascertain the utmost relevance and significance of the selected publications. The following inclusion criteria were applied:

- Papers dedicated to the multifaceted domains of sustainability and resilience within the context of FSC, with a primary objective of ensuring food security.
- Research that analyzed the underlying rationales contributing to the lack of sustainability and resilience within FSC.
- Articles that examined the implications of food security on the overarching dimensions of supply chain sustainability and resilience, which inevitably affect public health.
- Comparative analyses of FSC realms, drawing parallels and distinctions.
- Reports that provided actionable insights and forward-looking perspectives on the development and implementation of sustainable and resilient supply chain strategies to safeguard food security.
- Strict adherence to the English language criterion.
- Inclusion of papers published during and after the emergence of the COVID-19 crisis, encompassing 2019 to 2023.

2.1.3. Exclusion Criteria

To ensure precision and relevance, certain exclusion criteria were rigorously applied:

- Papers discussing sustainability and resilience without directly relating to food security or failing to define their interrelationships were excluded.
- This review omitted editorial pieces and letters.
- All papers not published in English or predating the COVID-19 pandemic, specifically before December 2019, were systematically excluded.

This comprehensive methodology was rigorously applied to select, filter, and analyze the scholarly publications that form the basis of this systematic review, ensuring a meticulous and total synthesis of the most pertinent literature on the subject matter.

2.2. Data Collection

The analysis focused on key aspects of the publications, such as the underlying causes of sustainability and resilience challenges within the realms of food security, their impacts on public health, the proposed strategies and measures to enhance sustainability and resilience for ensuring food security, and a comparative analysis of these factors. Several themes, strategies, and actions under these categories have been extracted using thematic analysis. Table 1 summarizes each theme identified.

Table 1. Key attributes of the included articles.

Category	Focus	Author, Year
Relationship between sustainability and resilience	Developing a practical supply chain model that encompasses three critical perspectives: agility, resilience, and sustainability, while exploring flexible networks that demonstrate legality, resilience in the face of disruptions, and resistance to pandemics.	Ivanov [18]
Actions/Impacts/Strategies	Evaluating the impact of COVID-19 on the triple bottom line (TBL) of sustainability to contribute to the future sustainable development agenda.	Ranjbari et al. [17]
Actions/Strategies	The significance of sustainability in enhancing food supply chains: leveraging blockchain technology for improved security and sustainability.	Park & Li [19]
Strategies	Implementing sustainability measures in the food sectors for enhanced public health by leveraging the Internet of Things (IoT), Radio Frequency Identification (RFID), and blockchain technologies.	Varriale et al. [20]
Impacts/Reasons/Strategies	Understanding the factors behind unsustainable food security, their public health implications, and strategies for creating sustainable food systems.	Bakalis et al. [21]
Impacts/Strategies	COVID-19's influence on food systems and public health: introducing the 'One Health' strategy for sustainable food Systems, future recommendations, and alignment with United Nations SDGs from a 'Planetary Health' perspective.	Mardones et al. [22]
Relationship between sustainability and resilience	Defining the interplay of sustainability and resilience and evaluating their roles in supply chain performance.	Negri et al. [23]
Impacts/Reasons	The involvement of various enterprises in securing food and nutrition during COVID-19: identifying the causes of food security unsustainability.	Nordhagen et al. [24]
Relationship between sustainability and resilience	Exploring the interplay between sustainability and resilience in the food production sector.	Owida et al. [25]
Reasons	Factors contributing to food supply chain unsustainability.	Han et al. [26]
Relationship between sustainability and resilience	Primarily centered on exploring the influence of resilience on the sustainability relationship and its role in upholding the socio-economic performance of the organization.	Rai et al. [27]
Relationship between sustainability and resilience	Examination of definitions and the interconnections between both approaches.	Roostaie et al. [28]
Actions/Strategies	Use of nanotechnology in promoting sustainability in modern agriculture to ensure food safety.	Ur Rahim et al. [29]

Table 1. *Cont.*

Category	Focus	Author, Year
Impacts	Utilization of nanotechnology to enhance sustainability in contemporary agriculture and ensure food safety.	Galanakis et al. [30]
Impacts/Strategies	Adopting a One Health approach for ensuring food safety, security, and sustainable production.	Garcia et al. [31]
Reasons	Susceptibility to food insecurity during the COVID-19 lockdown.	Loopstra [32]
Strategies	Technological innovations and disruptions in the food industry following the COVID-19 outbreak.	Galanakis et al. [30]
Impacts/Reasons	The influence of lockdown measures on food systems in India during the COVID-19 pandemic.	Sukhwani et al. [33]
Strategies	Enhancing food safety, quality, and convenience by promoting awareness of humanitarian food science and technology advancements to bolster food security and resilience.	Bounie et al. [34]
Reasons	Consumer panic buying and hoarding behaviors during the COVID-19 pandemic.	Hall et al. [35]

Thematic analysis is a robust and versatile qualitative research method renowned for distilling rich and complex data into meaningful patterns, themes, and insights. Its usefulness spans various fields, offering valuable contributions to research, academia, and practical applications. A primary strength lies in its flexibility, allowing researchers to explore diverse datasets and unearth latent patterns or recurring concepts. This method empowers researchers to systematically identify, analyze, and interpret qualitative data, enabling a deeper understanding of underlying phenomena or trends within a given context. In addition, it is a potent tool for organizing and structuring data, making it invaluable in synthesizing information from multiple sources. Whether analyzing interviews, focus groups, textual data, or literature reviews, thematic analysis can extract meaningful themes, generating nuanced insights.

Following rigorous reviews, 26 studies met the predefined inclusion criteria out of 105 initially assessed for potential inclusion. Sixty-two papers from the systematic review because they did not meet the inclusion criteria, mainly because they were published before COVID-19 was introduced. Furthermore, six papers were considered in the discussions that followed the systematic review, even though they were not included as illustrated in Figure 2.

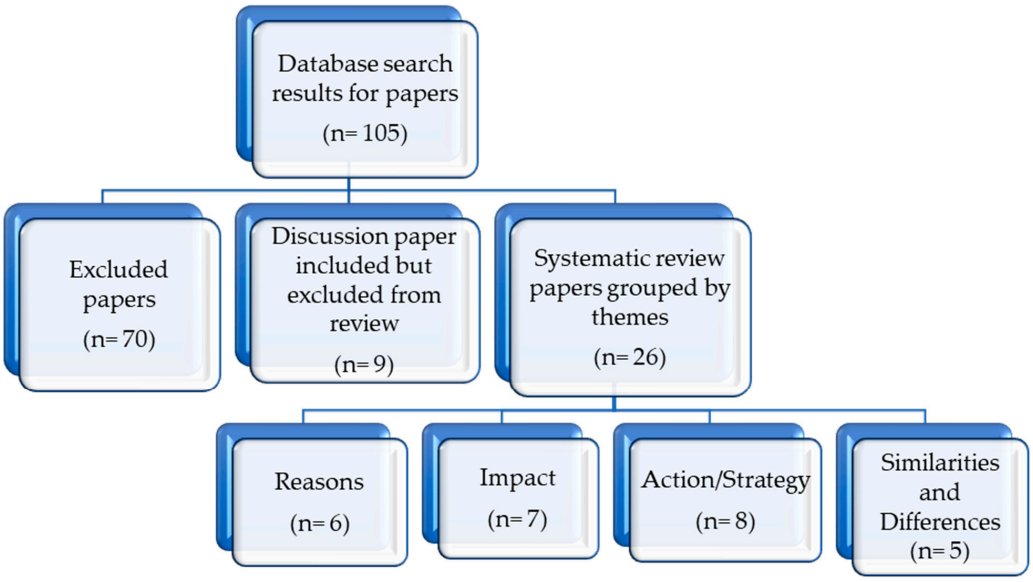

Figure 2. Data classification and themes.

2.3. Data Classification

Twenty-six publications were categorized according to their primary emphasis on various aspects, including the reasons behind the lack of sustainability and resilience, the impacts of these factors on different aspects such as public health, the strategies and actions proposed or discussed in the publications, and the exploration of similarities and differences between the concepts of sustainability and resilience. This categorization provides a structured overview of the key themes and areas of focus within the selected publications, as shown in Table 1.

Following is a brief explanation of each theme as they relate to "reasons, impacts, action/strategy, similarity, and differences" within the context of "Building Resilience in Food Security: Sustainable Strategies Post-COVID-19":

- Reasons: Researching the underlying causes behind challenges within food security and the lack of sustainability and resilience post-COVID-19 within food security is critical. It allows for a deeper understanding of the root factors contributing to vulnerabilities, disruptions, or inefficiencies within the food supply chain, as identified in the analyzed publications.
- Impacts: Examining the effects of these factors on different aspects, such as public health, economies, societies, and the overall food systems, allows for a comprehensive assessment of the repercussions resulting from disruptions or inadequacies in food security post-COVID-19.
- Action/Strategy: Various proposed strategies and measures were extracted from the publications to enhance sustainability and resilience within food security post-pandemic. These actionable insights provide a pathway for future practical implementation.
- Similarities and differences: Examining the interdependence and correlation between sustainability and resilience within the context of food security post-COVID-19 is pivotal. In the thematic analysis, commonalities were identified across different publications regarding challenges, responses, or strategies related to food security post-COVID-19. Identifying these similarities allows unified, scalable solutions to be developed across various contexts. Additionally, differences in challenges, responses, and resources were identified within the analyzed publications. As a result of recognizing these diversities, tailored and context-specific interventions can efficiently address specific needs.

3. Literature Review

This section explores the distinct characteristics associated with the various identified themes that are explored. These themes were meticulously categorized based on their relevance to this study, allowing a better understanding of their unique attributes and implications. Dissecting these characteristics sheds light on their multifaceted nature and discerns how they interplay within the context of our research. Moreover, the repercussions of these themes on public health are closely examined, recognizing their significance in the broader spectrum of our study's objectives. This in-depth examination of theme attributes and their influence on public health is an essential structural foundation for forthcoming discussions and discoveries, enabling a more nuanced and comprehensive understanding of the subject matter.

3.1. Reasons and Factors Underlying Food Security Challenges

Numerous publications within the body of research have extensively documented the intricate web of reasons and factors contributing to the prevailing issue of food security inadequacies. The contributing elements were thoughtfully curated and are presented in Table 2 to enhance clarity and facilitate a more structured understanding of them. This tabulated summary systematically overviews the multifaceted factors and categorizes them into distinct themes. By organizing these reasons into thematic groups, we elucidate their intricate relationships and commonalities, offering a more holistic comprehension of the

complex landscape surrounding food security challenges. This tabular representation is a valuable reference point for our subsequent discussions, offering a concise yet comprehensive framework to explore the various dimensions of food security issues in greater detail.

Table 2. Reasons contributing to food security challenges.

Reasons	Descriptive Terms
Food Production and Logistics Disturbances	Food supply chains and production systems faced significant disruptions primarily due to labor and supply constraints resulting from restricted movement. These disruptions heightened the risk of food counterfeiting and threatened food security considerably [21].
Lockdown measures led to increased food insecurity	Widespread unemployment [21], income loss, and reduced purchasing power [33] caused by the lockdown were among the primary factors contributing to food insecurity and shortages.
Interruptions in access to essential inputs, equipment, and services	It encompasses constraints in facilities, product transportation, and the procurement of inputs, equipment, and skilled technicians, which impacted the food system during and after the pandemic [24].
Food security and agricultural disruptions	The food system typically encompasses various stages, including production, packaging, distribution, and storage, bridging the gap between farm-to-table connections. However, with the onset of the pandemic, all types of food supply chains were significantly impacted, including those for fresh vegetables, fruits, bakery products, perishable goods, and food grains [26].
Food insecurity resulting from economic crises	Food insecurity doubled by the end of 2020 following the economic crises that arose after the onset of COVID-19 [26].
Consumer panic buying behavior	Various incidents of food insecurity have been reported in India after the emergence of the COVID-19 crisis, and these cases have been linked to consumer panic behavior. These instances depend on various socio-economic factors and proximity to the source of the risk [33,35].

3.2. Impact of Insufficient Food Security on Public Health

Numerous publications have delved into the impacts and challenges related to food security. These papers were organized and classified into distinct thematic categories, as outlined in Table 3, offering a comprehensive exploration of these critical topics.

Table 3. Implications of food security shortages.

Impacts	Descriptive Terms
Economic and social sustainability	Approximately 690 million individuals experienced food insecurity, and the repercussions of the COVID-19 pandemic on the global economy pose significant hurdles in attaining resilience and sustainability in food safety and public health, as noted by Ranjbari et al. [17].
Scarcity of food resources	The limited shelf life of perishable food products, coupled with consumer panic buying during the COVID-19 pandemic, has created significant challenges in managing these items and their supply chains to meet demand. Lockdowns and mobility restrictions have exacerbated product shortages, leading to noticeable shifts in consumer purchasing behavior in the post-pandemic era [17,21].
Disrupted FSC and food wastage	Reports of disrupted food chains and food wastage by food producers due to food insecurity were documented [21].
Joblessness and income loss	In various African nations, the closure of numerous informal markets, vital for numerous low-income consumers and farmers, significantly impacted the food supply chain and the essential requirements of consumers [22]. A report highlighted the consequences of pandemic-related lockdowns on food security, resulting in income loss and reduced purchasing power [33].

Table 3. *Cont.*

Impacts	Descriptive Terms
Physical and emotional well-being	Nutrition and food security are pivotal in attaining the Sustainable Development Goals (SDGs) and building resilience against diseases [24]. Inadequate nutrition, food insecurity, and low-quality diets directly impact physical and mental health [22].
Financial setbacks	A survey encompassing 367 food systems across 17 distinct Asian and African nations revealed that most businesses experienced significant challenges, including reduced sales and difficulties procuring necessary inputs, equipment, and services. The survey identified an 80% decline in production volume [24].
Counterfeit food products	Food security and supply chain disruptions have heightened the risks of food counterfeiting. This situation has created a critical challenge in detecting and verifying the authenticity of nutraceuticals and functional foods that offer genuine health benefits, as Galanakis et al. [30] discussed. Counterfeiting has become a more pressing concern in the food industry due to disruptions, making it imperative to ensure the identification and validation of health-enhancing products.
Challenges to the environment, society, and economy	Various threats encompassing environmental concerns such as climate change, marine debris, and resource depletion, along with social issues such as worker rights and consumer awareness, as well as economic challenges related to market goods, services, and competitiveness, were identified [30].
Disruptions in food availability and accessibility	Food security's four primary dimensions, availability, accessibility, utilization, and stability, were significantly impacted [33]. Disruptions in agricultural production, food availability, utilization, and stability caused by disasters like hurricanes, floods, tornadoes, wildfires, blizzards, emerging diseases, and earthquakes directly affect food security and public health [31].
Agricultural catastrophe	A quarter of agricultural trade and production faced disruption due to natural disasters, as shown in a survey conducted by the Food and Agricultural Organization from 2003 to 2013 [31].

3.3. Strategies and Approaches for Integrating Resilience and Sustainability in Food Security

Various research papers have proposed numerous strategies to embrace sustainability and resilience within the food sector, considering their implications for public health. These strategies can be classified into distinct thematic categories outlined in Table 4 to provide a comprehensive summary.

Table 4. Strategies for enhancing resilience and sustainability in food security.

Strategies	Descriptive Terms
SDG 10: Promoting socio-economic sustainability	Socio-economic sustainability, aligned with SDG 10 of the United Nations' 2030 agenda for sustainable development, is pivotal in bolstering healthcare systems and addressing food and nutritional requirements through mechanisms such as debt suspension [17].
Integration of blockchain technology	Blockchain technology, an innovative solution, utilizes distributed and decentralized ledgers to monitor the real-time flow of goods and services, enhancing resilience in the FSC and fostering sustainable development. This technology can improve food safety, health, nutrition, and efficient waste management, as demonstrated by Wal-Mart's successful implementation in its supply chain [19]. Blockchain offers two key advantages: streamlining supply chain management and distinguishing between genuine and counterfeit food products [36].
Integration of blockchain technology with other advanced technologies	Incorporating blockchain technology in conjunction with RFID and IoT offers various economic and environmental advantages, as it enhances traceability and monitoring capabilities [20]. In pursuit of decentralization, autonomy, traceability, transparency, and credibility within FSCs, blockchain technology has been synergized with modern advancements such as AI, cloud computing, big data, wearable devices, IoT, and 5G [37].

Table 4. *Cont.*

Strategies	Descriptive Terms
Incorporating a resilient approach into the FSC	The research confirmed the importance of various factors such as emergency planning, staff training, food supply redundancy, supplier networks, framework, location, service providers, assurance, and continuous learning [21]. It also highlighted the significance of setting short- and long-term goals to address challenges related to labor mobility, transportation, and production, all of which are influenced by human resources, transport limitations, and regional policies [38].
Enhancing food systems through SDGs	Enhancing global food systems requires accelerating and reinforcing support for local production and rural producer communities in low- and middle-income countries. Enhancement involves fostering more profound engagement with producers and consumers, evaluating the consequences of interventions and policies related to food systems, and enhancing food security by adopting risk-based approaches [22].
Utilizing nanotechnology for enhancing food security	Commercializing food products enhanced with nano-additives for advanced monitoring, preservation, and protection can be crucial in ensuring food safety and quality [29]. These nano-additives can potentially revolutionize the food industry by offering improved methods for monitoring, preserving, and safeguarding food products throughout their journey from production to consumption. By integrating nanotechnology into food substances, we can enhance the shelf life of products, minimize food waste, and ensure that consumers receive safe and high-quality food items.
One health approach	The Integrated One Health Strategy involves the interconnected well-being of humans, animals, and the environment. This strategy emphasizes collaborative efforts to enhance public health, animal health, and environmental resources, all of which contribute to ensuring food security. The article delved into food science and technology's significance and profound influence on a sustainable and resilient food system [34].

3.4. Exploring the Similarities, Differences, Connections, and Disparities between Sustainability and Resilience

While various papers have explored the commonalities, distinctions, and interconnections between sustainability and resilience within supply chain systems, none have delved into their integration within the realms of food or their potential enhancements for public health. Table 5 presents an overview of existing publications that have addressed the parallels and disparities between sustainability and resilience and their intricate relationships.

Table 5. Comparisons, contrasts, and interplay of sustainability and resilience.

Similarities/Differences	Descriptive Terms
Common ground between sustainability and resilience	Both sustainability and resilience are indispensable for organizations [23]. They serve as foundational pillars that enable organizations to not only swiftly rebound from crises but also do so without compromising their long-term sustainability and value [27]. While these two concepts share similarities, they can be seamlessly integrated, as supported by various theoretical frameworks [28]. This integration can enhance an organization's overall performance and adaptability in facing unforeseen challenges.
Distinguishing characteristics between sustainability and resilience	Sustainability encompasses several facets, including conceptualization, implementation, performance evaluation, measurement, and future research objectives within a supply chain context. In contrast, resilience includes the capacity to adapt, respond, and recover from disruptions while adjusting to new favorable conditions. It measures a system's ability to endure, adapt, and thrive without impairing its functionality [23]. Resilience is often divided into two primary categories: proactive resilience, which involves preparing for potential disruptions, and reactive resilience, which focuses on recovering from disorders. Sustainability embraces the triple-bottom-line approach, considering environmental, societal, and economic aspects [27].
Interplay and relationship between sustainability and resilience	Resilience and sustainability are interconnected components, each influencing the other in complex ways. Achieving resilience can affect sustainability differently, and their integration can be challenging due to potential conflicts [25].

4. Discussion and Results

Numerous papers have delved into sustainability and resilience over recent years. While some have emphasized the interconnectedness of these terms, others have highlighted their distinct conceptual underpinnings [39]. Several frameworks have been proposed, underscoring their potential alignment benefits for public health and environmental well-being [40]. Given these concepts' parallels and occasional conflicts, this paper systematically conceptualizes their similarities and disparities, focusing on their integration within the food sector. This integration seeks to bolster public health by enhancing the resilience of supply chains, especially in the face of disruptions triggered by COVID-19 or any future similar pandemics.

The confluence of sustainability and resilience within supply chains holds immense potential to enhance overall management and performance [41]. This study's literature review reveals that when aligned with resilient techniques, sustainability practices can pave the way for robust solutions. This study articulates the key sustainability factors and strategies in the food sector. It identifies the potential capacities of key sustainability factors in the food supply chain domain to withstand disruptions. It contributes to safeguarding food security by considering the potential to withstand disruptions amid disasters and crises. Integrated sustainable supply chain resilience potentials are effective once built sustainably and robustly. These potentials become efficient once utilized by practitioners in the field sustainably and reliably. We interpret the term effective as focused on the build-up of potentials, e.g., as in Jomthanachai et al. [42]. In this regard, food security and environmental factors, e.g., climate change, are closely connected [43]. Ultimately, this research aspires to set a path toward resilient and sustainable food systems that deliver economic, social, and environmental benefits to the public.

4.1. Integrating Sustainability and Resilience for Food Security

The emergence of the COVID-19 pandemic starkly exposed the vulnerabilities and deficiencies in our food supply chains, highlighting the pressing need for resilience and sustainability. A systematic conceptualization that integrates these two critical aspects should be developed to address this imperative. Considering the profound impact of food systems on public health and the global economy, this study focused on consolidating food security for populations worldwide to face future pandemics through sustainability and resilience.

Based on the COVID-19 crisis, this study examined the causes and impacts of food insecurity on public health. In addition to enhancing resilience and sustainability in food security, the study discussed the similarities, distinctions, and interconnections between sustainability and resilience within FSC systems. Sustainable strategies and actions were outlined for creating resilient FSCs. The integration of sustainability and resilience plays a pivotal role and is closely intertwined with robust business practices and economic growth, thus enhancing resilience and sustainability. Integrating sustainability and resilience within the food sector offers a multitude of benefits, particularly in ensuring food security and significantly impacting public health. One key advantage lies in the consistent access to nutritious food for populations. Sustainability practices embedded in agriculture and food production ensure the long-term viability of food sources, maintaining their abundance and diversity. This resilience within the food system acts as a safety net during crises or disruptions, mitigating the risk of food scarcity and addressing a fundamental aspect of public health: access to adequate nutrition. Moreover, integrating resilience strategies strengthens the food sector's ability to withstand shocks and disruptions. Whether facing climate-related events, supply chain disturbances, or global pandemics like COVID-19, a resilient food system adapts and functions efficiently. This adaptability ensures a steady food supply, effectively curbing food insecurities that can significantly impact public health outcomes.

Another critical benefit is the enhancement of food safety and quality. Sustainable practices inherently prioritize food safety and quality standards. When coupled with resilience

strategies, these practices fortify the system against potential contamination or compromised quality during crises. Safeguarding food quality minimizes health hazards associated with unsafe or poor-quality food, promoting better public health outcomes. Furthermore, a sustainable and resilient food sector often fosters local production and distribution networks. This localization bolsters local economies and contributes to community health by ensuring access to fresh, locally sourced produce. Additionally, it creates economic stability within these communities, providing continued livelihoods and strengthening community resilience. The fusion of sustainability and resilience also promotes environmental harmony and healthier communities. Sustainability practices mitigate environmental degradation and reduce negative health impacts linked to pollutants or unsustainable farming methods. When integrated, resilience strategies ensure that these ecological benefits persist even during challenging times, ultimately contributing to improved public health outcomes and overall community well-being.

Nanotechnology presents an innovative avenue to fortify sustainability and resilience within the food industry, contributing significantly to the pursuit of food security. Its application offers multiple advantages, primarily enhancing food preservation, safety, and resource utilization. Nanomaterials, such as nano-enzymes and innovative packaging, bolster food systems' resilience against various challenges. One key benefit lies in their ability to extend the shelf life of perishable foods. Nano-based packaging materials create barriers that minimize oxygen exposure, moisture, and microbial growth, thus preserving food freshness for extended periods. This elongated shelf life reduces food waste and ensures a more resilient food supply chain, minimizing losses during transportation and storage. Moreover, nanotechnology aids in fortifying food safety measures. Nano-sized particles possess antimicrobial properties, enabling them to combat pathogens and reduce contamination risks. By incorporating these particles into packaging materials or food surfaces, nanotechnology actively safeguards against spoilage and foodborne illnesses, enhancing overall food safety and resilience against potential health hazards.

Additionally, nanotechnology promotes resource efficiency in food production. Nano-based delivery systems for nutrients, pesticides, or fertilizers enable precise and targeted application, reducing resource wastage and environmental impact. This technology contributes to sustainable agricultural practices by optimizing resource utilization, ensuring a more resilient and environmentally conscious food production system. Furthermore, nanotechnology offers novel methods for detecting contaminants or adulterants in food, enhancing traceability and quality control. These advanced detection mechanisms contribute to increased transparency and trust within the food supply chain, augmenting resilience against fraudulent practices and bolstering overall food security. Patidar et al. [44] drew attention to issues such as poor product traceability, disrupted product flow, food counterfeiting or contamination, and adverse public health effects. They underscored the necessity for further research to gain a deeper understanding of these concerns and devise practical solutions. In this context, blockchain technology emerges as a formidable sustainable approach, providing social, economic, and environmental sustainability and thus fortifying FSCs against disruptions. Its applications span from farm to consumer, ensuring the authenticity and legality of food products and bolstering resilience by curbing cybercrime and counterfeiting. Blockchain technology applied in food traceability is a game-changer in advancing sustainability and resilience for ensuring food security. This implementation revolutionizes supply chain transparency by establishing an unchangeable ledger, enabling food traceability from origin to consumption. This transparency minimizes risks like fraud or contamination, ensuring authenticity and accountability throughout the supply chain. By swiftly identifying and addressing issues, blockchain enhances resilience against disruptions such as illnesses or supply chain issues, ensuring food safety. Furthermore, this transparency empowers consumers to favor ethical and sustainable products, encouraging responsible choices. Integrating blockchain with IoT and RFID technologies further strengthens traceability, enhancing transparency, mitigating risks, and promoting sustainability. This comprehensive approach is crucial in fortifying food systems' sustainability,

resilience, and overall security, significantly impacting global food security initiatives. The literature reveals that post-COVID-19 food insecurity was primarily driven by hunger, malnutrition, and insufficient institutional capacities. These challenges directly impacted public health and necessitated a sustainable humanitarian response. In this regard, food science and technology shine as a sustainable approach that facilitates resilient food systems and is pivotal in enhancing sustainability and achieving food security. Advanced scientific techniques aid in developing resilient crops, enhancing agricultural practices, and mitigating environmental risks. Biotechnology, for instance, facilitates the development of genetically modified crops more resistant to pests, diseases, and harsh climatic conditions, ensuring better yields and food availability. Precision agriculture, another technological advancement, optimizes resource usage by employing sensors, drones, and data analytics to manage water, fertilizer, and pesticides precisely, reducing waste and environmental impact while enhancing productivity. Moreover, advancements in food processing technologies help preserve food, reduce spoilage, and extend shelf life, thereby reducing food losses and contributing to food security. These technological interventions enhance sustainability by reducing resource usage and environmental impact and bolster resilience by creating more robust and adaptable food systems capable of withstanding various challenges, ultimately contributing to global food security. This technology aids long-term sustainability and resilience by promoting economic feasibility and fostering stakeholder collaboration. Haji et al. [45] have highlighted the significance of food science and technology in humanitarian responses and emphasized consumers' preference for local food systems. By implementing these technologies, we can enhance food security, stimulate employment, and invigorate local economies, ultimately contributing to resilient and sustainable food systems.

Another sustainable strategy for fortifying food systems involves life cycle assessment (LCA), which is crucial in bolstering sustainability and resilience and ultimately achieving food security. This strategy entails adopting short- and long-term sustainable strategies, including ensuring labor movement, evaluating policies relevant to resilience, and reinforcing survivability in inventory management, manufacturing, and transportation. The interconnected support of human resources, transportation logistics, and regional policies plays a pivotal role in overcoming shortages and enhancing resilience. LCA evaluates the environmental impacts of food production systems throughout their entire life cycle, from raw material extraction to processing, distribution, consumption, and waste disposal. This assessment enables stakeholders to identify and mitigate environmental hotspots, optimize resource utilization, and minimize waste generation at each stage of food production. By quantifying the environmental footprint of food production, LCA helps make informed decisions to enhance sustainability, such as selecting more eco-friendly production methods, reducing greenhouse gas emissions, and minimizing water usage. Moreover, by identifying vulnerabilities within the food supply chain, LCA contributes to enhancing resilience against disruptions by enabling the development of strategies to mitigate risks and build more robust and adaptable food systems. This comprehensive analysis fosters a more sustainable and resilient food production landscape, which is crucial for achieving long-term food security goals. Additionally, we recognize the affirmative impact of SDGs and a holistic One Health approach to public health. The latter fosters a holistic connection between human, animal, and environmental health, requiring concerted efforts to improve public health, animal health, and environmental resources to ensure food security. The One Health approach champions resilient food systems by preventing diseases, ensuring food security, and safeguarding environmental quality.

We have successfully constructed a systematic conceptualization by thoroughly examining and elaborating on these factors under the overarching theme of Strategies and Approaches for Integrating Resilience and Sustainability in Food Security. This framework significantly contributes to delineating the necessary requisites for establishing sustainability and resilience within food systems, enabling a comprehensive understanding of the essential elements required to fortify these critical dimensions. Figure 3 offers a systematic conceptualization illustrating the integration of critical sustainability factors, thus paving

the way for resilient food security. This structure serves as a guiding compass, illustrating the role and impact of sustainable strategies in fortifying food systems, ultimately ensuring food security and enhancing public health.

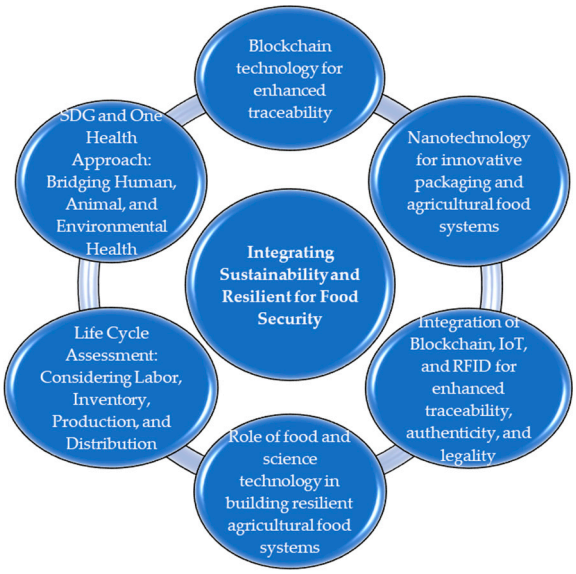

Figure 3. Integrating sustainability and resilience for food security.

4.2. Future Research Directions

The future research directions discussed in this section can help advance the understanding of how integrating sustainability and resilience can lead to more robust and secure food systems, ultimately benefiting public health and the environment. Researchers and stakeholders should work collaboratively to address these critical topics and contribute to developing resilient food security strategies for the future. Here are some potential future research directions for Integrating Sustainability and Resilience Food Security:

- Analyze the long-term impact of sustainability and resilience on food systems, particularly their effectiveness in maintaining food security during prolonged crises or disasters.
- Investigate the socio-economic implications of sustainability integrating and resilience approaches in food systems, including their economic feasibility and effects on employment and local economies.
- Utilize emerging technologies, such as advanced data analytics, artificial intelligence, and automation, to further enhance the integration of sustainability and resilience in FSCs.
- Analyze cross-sectoral impacts of integrating sustainability and resilience into food systems on other sectors like healthcare, environmental conservation, and social welfare, as well as synergies in these areas.
- Assess how policies, regulations, and governance structures affect the implementation of sustainability and resilience strategies in the food sectors.
- Identify consumer behavior and preferences in response to resilient food systems and how consumer choices affect the development of sustainable and resilient food systems.
- Examine the implications of integrated sustainability and resilience approaches on global health and food security, considering their effects on vulnerable populations and developing countries.
- Assess the effectiveness of sustainability and resilience integration in diverse food system contexts and identify best practices by conducting comparative studies across different regions or countries.

- Explore the role of multi-stakeholder collaborations, public–private partnerships, and community engagement in promoting sustainable and resilient food systems.
- Develop quantitative metrics and indicators to assess and compare the success and impact of sustainability and resilience integration in food security.
- Research how climate change adaptation strategies can be integrated with sustainability and resilience efforts in food systems to address rising climate-related challenges.
- Conduct case studies of specific regions or organizations that have successfully integrated sustainability and resilience into their food systems and highlight key strategies and lessons learned.
- Focus on interdisciplinary approaches that combine expertise from food science, environment science, public health, economics, and technology to solve complex problems.

5. Conclusions

The study highlights the deficiencies in sustainability and resilience within the FSCs brought to light by the COVID-19 pandemic. It emphasizes the necessity of a food system consistently delivering optimal outcomes while maintaining the resilience to cope with disruptions. This research addresses a gap in the existing literature by exploring the harmonization of sustainability and resilience within the food sectors. By conducting a systematic literature review and thematic analysis, this study extracts essential insights into integrating these concepts, emphasizing their importance in fortifying sustainable supply chains. The themes are reasons, impacts, actions/strategies, similarity, differences, and integrations. Subfactors are associated with each of these key attributes. Integrating sustainability and resilience principles is crucial to achieving high-quality food systems. Leveraging modern mechanisms and technological advancements, particularly digitalization and visualization techniques, can significantly bolster food security, fortifying the resilience of these critical systems. The study advocates for a deeper exploration of the relationship between sustainability and resilience in vital sectors like food, offering valuable insights to enhance readiness in confronting future pandemics.

This study delves into the interconnectedness of sustainability and resilience, focusing on integrating these concepts within the food sector to enhance supply chain resilience, especially in the wake of unexpected events like the COVID-19 pandemic. By examining the causes and impacts of the pandemic on food security, this research aims to create resilient and sustainable food systems that offer economic, social, and environmental benefits. It utilizes advanced technological interventions such as nanotechnology, blockchain, IoT, RFID, and life cycle assessment to enhance critical aspects of sustainability and resilience, ensuring better public health outcomes. The systematic conceptualization derived from these interventions outlines essential requirements to establish resilient food security and improved public health.

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