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Key Food Supply Chain Challenges: A Review of the Literature and Research Gaps

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ABSTRACT

The large volume and diversity of research sources related to the challenges affecting the efficient operations of FSCs demand a systematic literature review to explore the tools employed to address such challenges and to identify research gaps for future research. Our review of the FSC literature covered 141 articles published over the period 2010-2021. It was found that advanced technologies and optimization models were the most predominant tools for addressing FSC challenges with 40% of the articles embracing IOT-based technological frameworks and 56% of the reviewed papers deploying mathematical and computational optimization methods. The study also revealed that 73% of the reviewed articles primarily focused on addressing challenges related to sustainability, safety and quality, and traceability and transparency. In addition, about 92% of the research contributions originated from European, North American, and Asian geographic countries. Finally, 39% and about 46% of the articles were exploratory by nature and focused on addressing challenges within generic food chains, respectively. Based on a content analysis of the reviewed papers, potential research directions were suggested to fill the identified gaps. The dearth of research focusing on addressing food loss and waste, coordination, globalization, resilience, and robustness, and food-security challenges is one of the identified research gaps. Additionally, the deficiency of empirical studies validating the models/frameworks developed and the meagreness of research focus on unique types of food chains can be addressed as potential research venues.

Keywords: *challenges, food supply chains, literature review, research gaps, tools*

1. INTRODUCTION

A food supply chain (FSC) comprises a complex network of farms and processing facilities, distributors, and stores/retailers that spans the entire 'farm to fork' chain (Deep and Dani, 2010). FSCs have evolved from a single player who produced the goods for self-consumption to a network of players that span across the globe to serve the evolving needs of consumers. Each FSC is characterized by a unique network of facilities based on the types of food (i.e., fruits, vegetables, dairy, staple foods, meat, etc.) and forms of food (i.e., fresh, frozen, dried, canned, processed, etc.). As safe and fresh food intake is vital to human life, food supply chains are of prominent importance to every individual. However, FSCs are constantly facing various challenges that impede the delivery of affordable, safe, and nutritious food to consumers, in addition to the economic and environmental challenges.

In recent years, a growing number of research works have investigated the impact of different challenges on the efficient and effective operations of FSCs. The most common and key challenges that have been discussed in the FSC literature are food loss and waste (FLW), traceability, transparency, safety and quality, coordination, globalization, technology advancements, resilience and robustness, sustainability, volatility in demand and supply, and food security.

According to the Food and Agriculture Organization (FAO)'s report on global FLW, about 33.33% of the global food produced for human consumption gets lost or wasted globally. Food gets wasted throughout a FSC from production to consumption. However, 40% of the food losses within the developing countries occur at post-harvest and processing stages, whereas 40% of the food losses within developed nations occur at retailer and customer levels (FAO, 2011). Further, the amount of global food loss accounts for about 1.3 billion tons of food approximating to an amount equivalent to 990 billion US dollars (Shashi *et al.*, 2018). Such enormous amounts of food losses across the globe might result in vital challenges towards feeding the growing population across the world. Food losses and wastes not only impact economic and food security but also contribute towards wastage of natural resources employed to grow, process, package, and transport food. Food wastage can be reduced by increasing the awareness levels at the downstream end of the FSC. However, the reduction of food losses mainly depends on the efficiency and performance of the production/processing, storage, and distribution activities within the food chain.

Traceability is the ability to capture, store, and provide essential information related to activities within the supply chain. It is essential within a food supply chain as it aids in assuring the quality and safety of foods produced and distributed (Marmiroli *et al.*, 2011; Bhatt *et al.*, 2013). It also provides customers with an opportunity to become knowledgeable about food production steps and ingredients used towards assuring food quality, provenance, safety, and sustainability (Scholten *et al.*, 2016). On the other hand, transparency is also vital as FSCs need to abide by stringent government regulations/audits and fulfils the information requirements of health-conscious and knowledgeable consumers. In addition, transparency enables collaboration between players, reduces costs, and sparks innovation (Astill *et al.*, 2019).

As food takes up a long path from farms to consumer consumption, it is highly vulnerable to contamination at any stage of the supply chain resulting in diseases and infections at the consumer end. So, stringent care, hygiene, and adherence to norms/regulations for packing, transportation, and storage are to be maintained to ensure the quality and safety of the produce (Han *et al.*, 2019). The need for technology adaptation, such as the usage of sensors, temperature controllers, and cloud-based solutions for data is on the rise to ensure the freshness and quality of the output and to avoid spoilage/waste.

Coordination among supply chain partners is another key challenge for the efficient operation of FSCs. It is essential as it enables communication, information sharing, optimal decision making, and effective utilization of core competencies to co-create value through sharing of knowledge resources across the supply chain (Dania *et al.*, 2018; Handayati *et al.*, 2015).

The recent increase in food miles provides a clear picture of the globalization of food chains and the challenges associated with increased food trade among nations (Dani, 2015a). The cross-border movement of foods ensures the availability and diversity of food choices for people across the globe. However, such movements increase food safety and quality risks necessitating international collaboration and continuous monitoring of foods across the global food chains. In addition, globalization challenge within FSCs is the result of changes in size and nature of demand, governance requirements at national and international levels, and volatility in production levels resulting from adverse climatic conditions, competition for key resources, and changing customer perceptions.

As one of the critical challenges for FSCs, resilience enables supply chains to prepare, resist and rebound from disruptions/disturbances and facilitates quick recovery to its original or better situation (Ali *et al.*, 2018). On the other hand, robustness facilitates capability development within supply chains to become insensitive to disturbances (Vlajic *et al.*, 2013). Improved resilience aids food chains to face large-scale disruptions due to unexpected events such as the current Covid-19 pandemic (Marusak *et al.*, 2021).

Sustainability is the ability to avoid practices that violate environmental, social, and economic responsibilities. It embraces environmentally friendly practices to reduce food waste and to optimize production/distribution systems within supply chains (Validi *et al.*, 2014). The sustainability principles/practices enable supply chains to gain a competitive edge in the market through the satisfaction of increasing demand for food in an environmentally friendly fashion. Implementation of these principles/practices within food supply chains is the need of the hour to assure food security for future generations (Li *et al.*, 2014).

Food Security is the ability to ensure consistent and regular availability of food. It is a multidimensional performance indicator to assess the capability of a country or a region to consistently provide physical, economic, and timely access to food for all its people. According to the Food and Agriculture Organization (FAO) report, food security relies on four pillars: availability, access, utilization, and stability. Availability is the amount of available food in a country or region through all forms of domestic production, imports, food stocks, and food aid. Food access (including physical, social, and economic access) is the ease with which the population can acquire food. Food utilization refers to safe and nutritious food meeting dietary needs. Food stability always reflects the presence of the other three pillars. Therefore, a more formal and comprehensive definition for food security is the situation when all people always have access to sufficient, safe, and nutritious food necessary to lead active and healthy lifestyles (FAO, 1996).

Several papers have recently reviewed the FSC literature within different contexts in relation to FSC challenges. Some of the reviews conducted to date addressed challenges within a specific type of FSC such as perishable food chains (Lemma *et al.*, 2014), fresh fruit supply chains (Negi and Anand, 2015; Soto-Silva *et al.*, 2016), agri-fresh food supply chains (Dania *et al.*, 2018; Handayati *et al.*, 2015; Siddh *et al.*, 2017; and Feng *et al.*, 2020), and cold chains (Chaudhuri *et al.*, 2018; Mercier *et al.*, 2017; Ndraha *et al.*, 2018; Shashi *et al.*, 2018). Other review papers focused on addressing a specific challenge faced by food chains such as FLW (De Oliveira *et al.*, 2021; Kafa and Jaegler, 2021; Lemma *et al.*, 2014; Soto-Silva *et al.*, 2016), transparency (Wognum *et al.*, 2011), quality (Chaudhuri *et al.*, 2018; Mercier *et al.*, 2017; Ndraha *et al.*, 2018; Siddh *et al.*, 2017), collaboration/coordination (Dania *et al.*, 2018; Handayati *et al.*, 2015), and sustainability (Akkerman *et al.*, 2010; Wognum *et al.*, 2011).

Our extensive review brings in three main contributions to FSC literature. Firstly, in contrast to the above cited review papers, our paper presents an up-to-date review related to multiple key FSC challenges within a single article. Secondly, it identifies tools (methods, frameworks, models, techniques, and technologies) addressing specific challenges within specific FSCs. Thirdly, it illuminates limitations in existing FSC research works and proposes prospects for the future based on the identified research gaps.

The remainder of this review paper is structured as follows. Section 2 presents the research methodology adopted for conducting the literature review. Section 3 highlights the research findings identified from the reviewed literature. Finally, Section 4 provides conclusions and future research recommendations.

2. RESEARCH METHODOLOGY

A systematic literature review process serves to handle the diversity of sources of knowledge within a specific research domain. It aids the researcher in mapping and assessing the key scientific contributions within the area of interest. It also fosters the quality of the review process through a comprehensive and unbiased search process and thorough synthesis of the fragmented literature within the study domain in a systematic, transparent, and reproducible manner (Tranfield *et al.*, 2003). The review process adopted in our study follows the next three stages.

1. Searching/Exploring
2. Screening/Filtering

3. Synthesis/Deductive Reasoning

2.1 Searching/Exploring

The search aimed at identifying all the possible sources of publications related to the key identified challenges and the tools employed within the FSC literature to address them. The search was executed by identifying a list of initial keywords from the related previous literature review papers. The initial list of keywords was further fine-tuned through pilot searches to match the theme of the study. The final list of keywords was then used to construct the following query string.

((“*Cold Supply Chain*” OR “*Cold Products*” OR “*Food Supply Chain*” OR “*Perishable Food*”) AND (“Sustainability” OR “Quality” OR “Safety” OR “Traceability” OR “Transparency” OR “Globali*” OR “Resilien*” OR “Security” OR “Loss” OR “Waste”))

The search was executed in the title, abstract, and keywords in the papers from the Scopus database as it is one of the largest index and citation databases with a wide coverage of high-quality scientific journals, conference proceedings, and books (Baas *et al.*, 2020). The publication time for the search was limited to the 2010-2021 period. Only relevant works from 2010 were included in the review since the oldest review paper related to FSC challenges was published in 2010. The search was carried out in the “engineering”, “business, management, and accounting”, “environmental sciences”, “computer sciences”, “decision sciences”, “energy”, “economics, econometrics, and finance”, and “mathematics” subject areas of Scopus database.

2.2 Screening/Filtering

The search process retrieved a total of 2350 documents matching the search criteria. As the keyword combinations can result in duplicate articles, the search results were initially screened to eliminate duplicate records. The elimination of duplicates resulted in a total of 2330 documents for further screening. The list of articles was further scrutinized by reviewing the titles and abstracts to eliminate articles that do not align with the inclusion and exclusion criteria listed in **Table 1** below. Further, irrelevant articles were filtered out after complete scanning of their contents. Finally, the references within the selected papers were also scanned to select relevant articles for the review not identified by the search process. The systematic search and screening process aided in selecting a total of 141 articles for comprehensive analysis. The article selection and screening process are summarized in **Figure 1** below.

Table 1 Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
• Articles addressing key FSC challenges discussed above. • Articles addressing different food chain categories. • Articles providing technological solutions to the challenges under consideration. • Articles providing technical and methodological solutions to the challenges under consideration. • Articles providing mathematical models, and solutions to the challenges under consideration. • Articles presenting systematic literature reviews, quantitative/qualitative studies, empirical studies, and conceptual frameworks related to FSC challenges.	• Articles addressing challenges within other types of supply chains. • Review of literature concentrating on theoretical definitions. • Articles concentrating on a single firm or business entity within the food chain. • Articles concentrating on production and processing within food chains. • Articles concentrating on microbiological aspects of food.

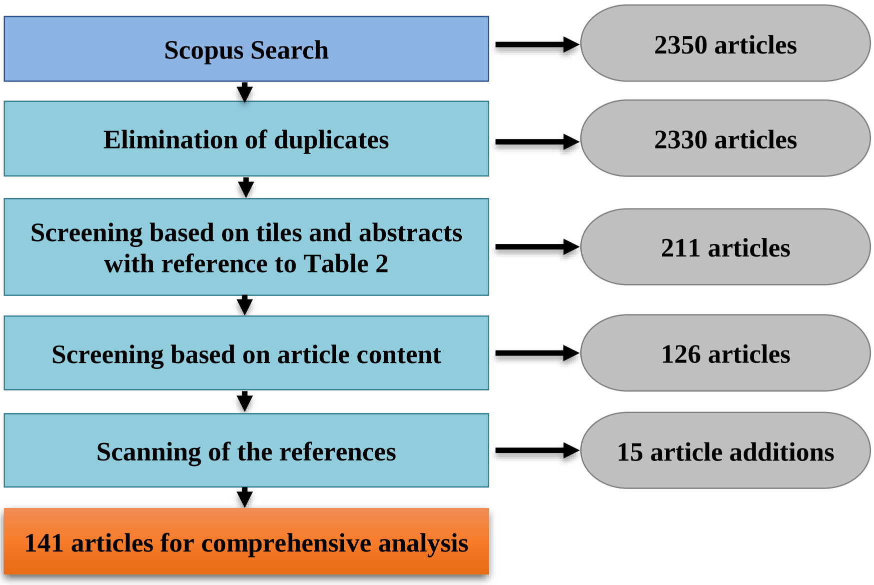


Figure 1 Article Selection and Screening Process

2.3 Synthesis/Deductive Reasoning

The selected articles were analyzed and synthesized comprehensively based on the framework listed below:

1. Distribution of article's by the year of publication and geographic origin/region of publication
2. Research methodologies adopted
3. Types of food supply chain considered
4. Challenges addressed
5. Technologies employed
6. Models/frameworks adopted

2.3.1 Distribution/Grouping of Articles

The interest in understanding and managing challenges within food chains motivated many researchers to conduct various studies related to the challenges under consideration. The progressive acceleration in the publication of scientific papers is reflected in **Figure 2** below depicting the distribution of articles by the year of publication. The figure shows that about 70% of the reviewed articles were published during the period 2017-2021. Indeed, the recent numerous challenges about the growing human population and demand for food items, consumers' preference for food quality and safety, emergent consumers' concerns about sustainability, food security, and traceability issues led practitioners and researchers to look for new tools, techniques, and methodologies to efficiently operate FSCs chain, which reveals the recent prominent role of research within FSCs to address the highlighted challenges.

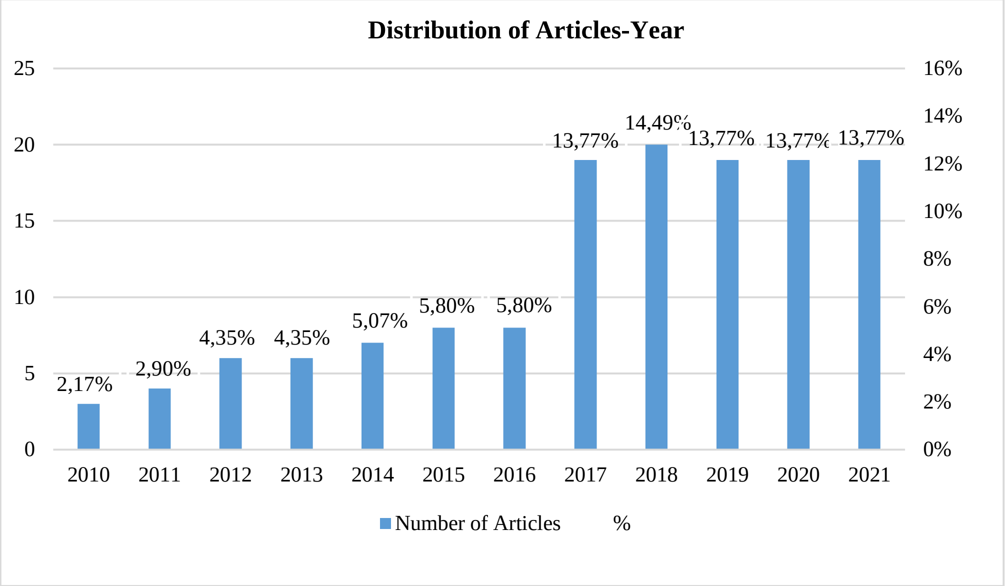
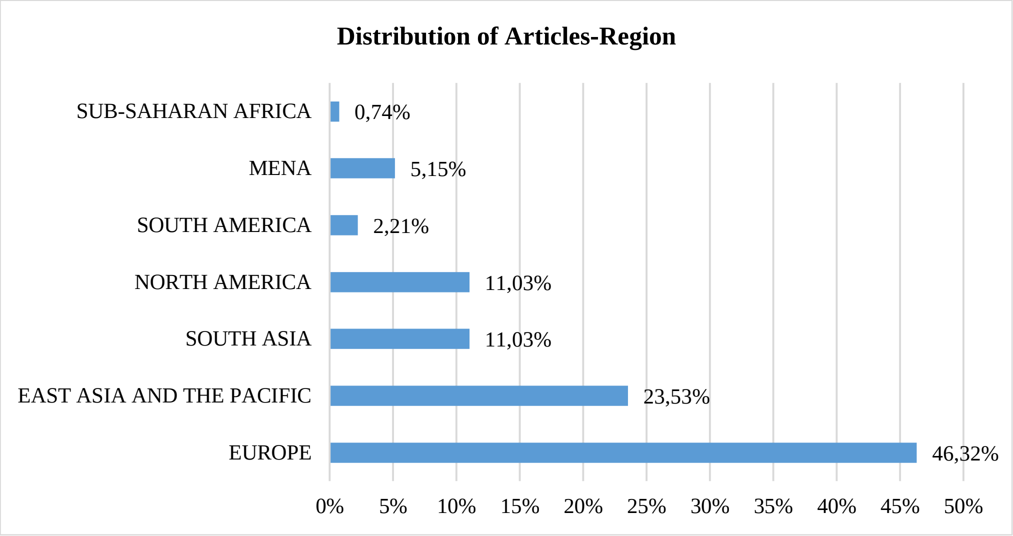


Figure 2 Distribution of Articles by the Year of Publication

Figure 3 shows the distribution of articles by geographical region. It is based on the country in which the majority of the authors currently reside. Based on the geographic distribution, Europe has the highest number of author publications with about 46% of the reviewed papers. It can also be observed that there exists a significant shortage of research contributions from the Middle East, South American, and African regions, where most of the FSC challenges such as food security, quality, and safety are prevailing.



EUROPE (Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Norway, Portugal, Serbia, Spain, Sweden, the Netherlands, and the UK)

EAST ASIA AND THE PACIFIC (Australia, China, Hong Kong, Indonesia, Malaysia, New Zealand, Singapore, South Korea, Taiwan, and Vietnam)

SOUTH ASIA (India)

NORTH AMERICA (Canada and USA)

SOUTH AMERICA (Brazil and Colombia)

MIDDLE EAST AND NORTH AFRICA-MENA (UAE and Qatar)

SUB-SAHARAN AFRICA (South Africa)

Figure 3 Distribution of Articles by Geographical Origin

2.3.2 Research Methodologies Adopted/Employed

Table 2 illustrates the different research methodologies adopted for analyzing FSC's challenges. It can be noticed from this table that 39% of the articles adopted the exploratory methodology to identify characteristics, factors, conditions, and criteria needed to formulate models and frameworks to address challenges within FSCs. On the other hand, about 8% of the studies adopted empirical research indicating a gap in driving knowledge from experience rather than from theory. The low percentage of empirical research methods could be attributed to the lack of enough data to conduct such research. However, with recent developments within the field of data science, more research studies can be expected in this direction.

Table 2 Article Distribution by Adopted Research Methodologies

Category	% dist.
Applied	14.12%
Correlational	4.71%
Descriptive	28.24%
Empirical	8.24%
Experimental	5.29%
Exploratory	39.41%

2.3.3 Types of Supply Chains Considered

Table 3 provides insight into article classification based on the types of supply chains considered in the reviewed papers. The classification indicates lower contributions from agri-food chains. Most of the reviewed papers (about 46%) did not specify the types of FSC under study.

Table 3 Articles Distribution by Type of Food Supply Chain

Category	% dist.
Agri-Food	9.72%
Cold Chains	21.53%
Fresh Food/Local	9.72%
Generic	45.83%
Perishable	13.19%

2.3.4 Challenges Addressed/Targeted

Table 4 reports the distribution of the articles by the identified FSC challenges. Around 73% of the articles concentrated on addressing sustainability, safety and quality, and traceability and transparency challenges within the FSCs. Such articles' distribution indicates a gap/shortage of studies focusing on coordination, globalization, resilience and robustness, and food security-related FSC challenges.

Table 4 Article Listing by Challenges Addressed/Targeted

Category	% dist.
FLW	5.41%
Traceability and Transparency	19.59%
Safety and Quality	25%
Coordination/Collaboration	4.73%
Globalization	3.38%
Resilience and Robustness	6.08%
Sustainability	29.05%
Food-Security	6.76%

2.3.5 Technologies Employed

Table 5 illustrates different technologies employed for enhancing transparency, traceability, quality, safety, and sustainability within FSCs. Applications of Internet-of-Things (IOT) were predominantly used to address traceability and transparency issues within FSCs. This indicates a gap in the utilization of other available technologies to foster comprehensive solutions for addressing quality, sustainability, safety, coordination, and resilience/robustness challenges in a holistic pursuit.

Table 5 Article Listing by Technology Adaptations

Category	% dist.
Artificial Intelligence (AI)	10.64%
Augmented Reality	2.13%
Big Data Analytics	2.13%
Blockchain	14.89%
Cloud Computing	4.26%

Table 5 Article Listing by Technology Adaptations (Con't)

Geographic Information Systems (GIS)	2.13%
Industry 4.0	4.26%
Internet of Things (IOT)	40.43%
Radio-Frequency Identification (RFID)	10.64%
Smart/Intelligent Packing	8.51%

2.3.6 *Models/Frameworks Adopted*

Table 6 categorizes the reviewed articles based on the types of models/frameworks adopted for analysis. Around 56% of the articles focused on the usage of mathematical and computational optimization to reduce costs, wastes, energy usage, and carbon emissions. Furthermore, the optimization models aimed at enhancing sustainability, total profits, pricing, and delivery routes subject to environmental conditions for food storage and distribution. However, the models developed for specific environments and scenarios need to be validated using longitudinal studies and empirical case studies within different geographical settings.

Table 6 Article Listing by Models/Frameworks Adopted

Category	% dist.
Conceptual Models/Frameworks	20.55%
Decision-Making Models	13.70%
Mathematical and Computational Optimization (Mathematical/Statistical/Simulation/Heuristics)	56.16%
Structural Models	9.59%

3. SIGNIFICANT FINDINGS FROM THE LITERATURE

Based on the reviewed articles, it is observed that FSC management has emerged as a predominant area of interest to academics, researchers, and practitioners. Although the studies mainly focused on addressing quality and sustainability challenges within FSCs, only a few of them concentrated on simultaneously addressing multiple challenges. The sub-sections below provide a review of the main findings concerning each of the challenges addressed within FSCs. The tools deployed to address each of the identified challenges are also outlined. Further, it should be mentioned that the technology advancement challenge is addressed in sub-sections discussing traceability and quality/safety challenges. Likewise, the volatility in demand and supply of food challenges are discussed in the sub-section related to globalization, resilience/robustness, and food security challenges.

3.1 *Food Loss and Waste*

Tromp *et al.* (2016) formulated a discrete event simulation model to study the impact of prevention actions i.e., marketing strategies to impact customer demand for the items, logistical actions to reduce storage time of the items on the shelves, and technical interventions to extend the shelf-life of the products to reduce chilled food wastes within a perishable food chain. Mathias and Sadananda (2017) employed analytical methods to determine postharvest losses in terms of quantity and value for selected vegetables. Liegeard and Manning, (2020) focused on FLW reduction at the customer end through the deployment of intelligent packaging and smart kitchens enabled with IoT sensors. Williams *et al.* (2020) employed a multi-step method involving questionaries, food waste diaries, and in-depth interviews. They applied their method to 37 Swedish households in order to determine the role and functionality of packaging in reducing food waste across multiple food categories.

Vieira and Matzembacher (2020) emphasized the importance of digital business platforms (DBPs) to reduce food waste and losses within the food chains. According to the authors, DBPs can contribute to food waste solutions by serving as alternate coordination mechanisms within FSCs to help identify opportunities and design strategies to reduce food losses and waste across the chain.

De Oliveira *et al.* (2021) highlighted the importance of a circular economy in terms of reduction, reuse, and recycling to reduce FLW. Omolayo *et al.* (2021) emphasized the importance of Life Cycle Analysis (LCA) studies to address FLW. Dora *et al.* (2021) proposed a conceptual framework to mitigate and prevent FLW within agri-food chains through a systems approach and employing circular economy concepts. Bhattacharya and Fayezi (2021) underlined the importance of multi-stakeholder collaboration within FSCs to reduce FLW. The authors proposed a conceptual framework to enhance collaborative relationships within FSCs through the alignment of vertical and horizontal stakeholder orientations. Magalhães *et al.* (2021) identified inadequate transportation systems, inadequate/defective packaging, lack of storage facilities, poor handling/operational performance, and lack of coordination/information sharing as five main causes for FLW within a fruit and vegetable supply chain through interpretive structural modeling. Based on the above, **Table 7** reports the list of methods, models/frameworks, and technologies employed to curtail FLW within FSCs.

Table 7 Tools Proposed to Address FLW

Methods	Circular economy concepts, LCA, and stakeholder collaboration.
Models/frameworks	Collaboration frameworks, discrete event simulations, and interpretive structural modelling.
Technologies	Intelligent packaging and smart kitchens enabled with IOT sensors, DBP.

3.2 *Traceability and Transparency*

Bhatt *et al.* (2013) highlighted the importance of the development of frameworks based on critical tracking events and key data elements for the successful implementation of traceability systems within FSCs. Gautam *et al.* (2017) studied the impact of the accuracy of traceability systems on reducing liability costs (costs incurred from quality losses) through early detection. The authors formulated a multi-objective integer non-linear programming model to strike a balance between the cost reduction targets for transportation and RFID implementations and liabilities incurred from quality losses within a perishable chain. Haleem *et al.* (2019) listed food quality and safety (1), legislation (2), agroterrorism threats (3), certifications (4), competitive advantage (5), sustainability (6), animal welfare (7), tracking of goods (8), information quality (9), ICT systems (10), information sharing (11), and production scheduling/optimization (12) as key influential drivers for traceability implementation. They found that keys (1-4) were influencing drivers while keys (5-12) influenced drivers. Further, the authors mentioned that the identification of such relationships requires the development of frameworks and policies for the successful implementation of traceability systems within the FSCs.

Through a study on the usage of Radio-Frequency Identification (RFID) systems for traceability enhancements within FSCs, Grunow, and Piramuthu (2013) indicated that the additional costs incurred for RFID implementations are economically justified. Galvez *et al.* (2018) and Kim *et al.* (2018) pointed out that RFID, IoT, smart contracts, and barcode-based BC systems support digital tracking of food flows and acquisition of data on storage temperatures, expiration dates, shipping details, origination farm details, and batch numbers. Galvez *et al.* (2018) and Köhler and Pizzol (2020) conducted studies on the adaptation of BC systems for traceability enhancements within FSCs and identified that BC implementations aid with saving time, reducing costs/risks, and enhancing trust by providing immutable data. Moreover, Feng *et al.* (2020) conducted an extensive review on the BC applications within the agri-food chains to deploy the full potential of BC systems for traceability enhancements. The authors proposed an operational framework for a blockchain-based food traceability system to improve agri-food traceability.

Varghese George *et al.* (2019) formulated a food quality index (FQI) algorithm that uses the data generated through BC systems from various stakeholders across the food supply chain. The authors analyzed and segregated the data to generate an FQI value for judging the food quality requirements based on standard storage and handling regulations specified for food safety. Bhatt *et al.* (2013); Galvez *et al.* (2018); Kim *et al.* (2018) and Köhler and Pizzol (2020) agreed that changing customer preferences, conflicting regulatory/policy requirements, implementation costs, confidentiality requirements, lack of coordination/trust between stakeholders, implementation costs, lack of standardization of data, and siloed legacy information systems within supply chains act as roadblocks towards successful implementation of BC and traceability systems.

Zhou *et al.* (2021) developed a conceptual framework to explore the impact of traceability practices (input, process, and output) on sustainability performance. According to the authors, input traceability relates to the practices of acquisition and tracing of information from upstream supply chain partners. Process traceability refers to the practices of processing, reviewing, evaluating, and updating the product data promptly as the product flows across the chain. Finally, output traceability pertains to the practices of tracing and acquiring information related to customer requirements for the origin and grade of the products. Such traceability practices promote continuous learning leading to improved dynamic sensing capabilities.

Chen (2015) developed an autonomous agent-based tracing system using IOT architecture, fuzzy cognitive maps, and fuzzy rule methods for product usage life cycles. Further, agent-based systems were employed as soft computing tools to link food chain stakeholders with elements of fuzzy logic towards modeling and simulating casual relationships between causes and responsibilities. Verdouw *et al.* (2016) developed a virtual information system architecture, using generic technology enablers such as IoT and cloud computing capabilities to track and trace the location of objects, identical to traceability systems built on IoT platforms. Zhang *et al.* (2017) designed a conceptual model adopting IOT technology and the theory of supply hubs in industrial parks. The authors employed the conceptual model to meet the industrial operational requirements of perishable foods and to quickly respond to market changes with real-time information sharing. Accorsi *et al.* (2017) developed a simulation gaming tool embedding the IoT paradigm. According to the authors, the gaming tool provided a comprehensive architectural framework depicting entities, physical objects, physical and informative flows, stages, and processes to be sensed, tracked, controlled, and interconnected.

Todorovi *et al.* (2019) emphasized the adaptation of mobile augmented reality technologies within food packaging systems to enhance traceability through bridging the gap between consumers, products, and product contents. Kalpana *et al.* (2019) and Chen *et al.* (2020) emphasized the importance of adopting smart, innovative, and intelligent packaging utilizing emerging technologies, wireless communications, intelligent tools, sensors, RFID tags, and cloud data solutions to enhance product traceability, food quality and safety improvements, and food waste reductions. Óskarsdóttir and Oddsson (2019) designed a decision support framework consisting of a table listing the available traceability technologies such as paper records, barcodes, RFID, and wireless sensor networks along with their capabilities. The authors further developed a decision tree model to identify the user needs and facilitate the selection of a suitable traceability technology for the product under consideration. Vo *et al.* (2020) proposed an automatic grading solution for traceability enhancement encompassing convolution neural networks (CNN) and computer vision technologies. The deep learning abilities of CNN are employed to grade lobsters into different categories based on image attributes. Singh and Jenamani (2021) designed a not only structured query language (NoSQL) Cassandra-based data repository system to handle huge volumes and high frequency of real-time RFID and sensor data generated within food chains.

Wognum *et al.* (2011) highlighted four transparency approaches: namely environmental reporting (ER), LCA, traceability, and labeling. According to the authors, such transparency approaches help towards enhancing vertical transparency (VT), horizontal transparency (HT), environmental sustainability (ES), and social sustainability (SS) within food chains. The authors showed that ER directly enables HT and ES but indirectly fosters VT and SS. They also indicated that LCA directly enables HT and ES but limitedly supports VT and indirectly improves SS. Trienekens *et al.* (2012) and Astill *et al.* (2019) listed data acquisition technologies (Sensor/Barcodes), IoT, BC, and big data technology solutions as enablers that enhance transparency within food supply chains. However, Trienekens *et al.* (2012); Ndraha et.al (2018); Astill *et* *al.* (2019), and Köhler and Pizzol (2020) highlighted that food chains face multiple roadblocks concerning the realization of the expected benefits from the technological solutions due to issues related to connectivity, data privacy and security, technology implementation, interoperability, additional costs of training, government requirements and regulations, and customer acceptance. In this context, Hu *et al.* (2021) proposed a framework to enhance trust within an Agri-Food supply chain by leveraging the immutability of the Blockchains distributed ledger technologies and paradigm of edge computing to overcome the cost and efficiency problems related to the deployment of blockchain technologies among geographically dispersed agri-farms in remote areas.

Nilsson *et al.* (2019) emphasized the importance of time-temperature integrators (TTI's), IoT, Bio-Sensors, and Blockchain technologies towards enhancing transparency within the food chains. The authors stated that projects implementing such technologies in an integrative fashion within the logistics and packaging systems can further enhance the transparency within the food chains and reduce food losses through the determination of the dynamic shelf-life of foods. Further, James (2019) indicated that a consortium of IoT, cloud computing technologies, and innovative internet technologies enhance the transparency and visibility of products within the global food chains. **Table 8** below summarizes the tools deployed to address traceability and transparency challenges within FSCs.

Table 8 Tools Proposed to Address Traceability and Transparency Challenges

Methods	Environmental reporting, food quality index algorithm, fuzzy rule methods and fuzzy cognitive mapping, and LCA.
Models/frameworks	Blockchain operational framework, critical tracking event-based framework, decision support systems, structural equation modeling, supply hubs conceptual model, and PPO algorithm.
Technologies	Bio-sensors, blockchains, computer vision technologies, data acquisition technologies, IOT architectures, IOT based simulation gaming, mobile augmented reality technologies, NoSQL Cassandra based data repository system, RFID, smart and innovative packaging systems, smart contracts, consortium of IOT/cloud computing/internet technologies, and virtual information systems.

3.3 Safety and Quality

According to Marmiroli *et al.* (2011) and Aung and Chang (2014a), traceability acts as a promising tool for assuring food safety and quality and instilling customer confidence. Wang and Li (2012) highlighted the importance of technological developments and the application of food traceability systems to enhance supply chain visibility and accuracy of shelf-life information for dynamic product quality assessments. Liu *et al.* (2010) and Liu (2015) proposed the development of food safety supply chain traceability management systems to enhance food safety and security for the customers. Their proposed systems are based on artificial neural networks, IoT, and RFID technologies.

Hafliðason *et al.* (2012) developed a conceptual framework for mapping and exploring actual temperature conditions within a chilled fish supply chain using wireless sensor networks. Tianzhong (2016) configured an IoT-based food quality tracking system using intelligent database technologies, RFID technologies, food safety technologies, multimedia, network technologies, wired and wireless network technologies, and other practical high-tech techniques to serve as an integrated monitoring and management information system for food safety detection and quality management. Chaudhuri *et al.* (2018) emphasized the utilization of a three-layered technological infrastructure embedded with RFID systems and IOT sensors for continuous monitoring of temperature, humidity, and vibration to aid with decisions related to quality, shelf-life determination, and risk management within cold chains.

Li (2017) developed an economic IoT-based tracking platform configured with QR codes and RFID systems. The author employed extensible mark-up language within the tracking platform to foster safety and quality enhancements within pre-packaged foods. Tsang *et al.* (2018) proposed an IoT-based route planning system (IRPS) integrating the internet of things, Taguchi experimental design, and genetic algorithms to minimize food spoilage rates and maximize order fulfilment rates.

As quality assurance and control necessitate the development of mathematical models to predict and assess food quality parameters, several studies were undertaken to formulate models for quality prediction and assessment. In this regard, Rong *et al.* (2011) formulated a mixed-integer linear programming model to determine the storage and transportation temperatures throughout food chains, along with the production quantities and delivery paths for the foods. Aung and Chang (2014b) employed a K-means clustering algorithm to classify the items into a set of clusters with different but manageable temperature zones. Kim *et al.* (2015) suggested the usage of center-of-gravity models accompanied by genetic algorithms to determine optimal conditions (temperature and humidity levels) for storage in multi-commodity environments. Li *et al.* (2020) formulated a mixed-integer nonlinear programming model to minimize the system-wide total supply chain costs taking into account the perishability of the products in terms of both food loss and quality deterioration.

Hsiao *et al.* (2018) developed a last-mile vehicle routing problem (VRP) model for a cold chain with high-quality concerns. The authors employed genetic algorithms to determine the fleet sizes, vehicle routing sequences, and shipment quality levels for the distribution of fresh fruits and vegetables. Wang *et al.* (2019) formulated a VRP model incorporating food safety risks emerging from microbial growths within perishable foods. Han *et al.* (2019) proposed a novel hidden Markov model employing grey relational analysis methods to dynamically assess the food quality and safety risks based on highly complex and temporal food characteristics. In order to enhance quality and service levels to customers, Chen *et al.* (2019) formulated a multi-compartment vehicle routing problem with practical constraints such as time-windows constraints, temperature requirements, and fuel consumption. Liang *et al.* (2020) formulated a VRP variation that optimizes route plans and environmental conditions for cold products subject to quality levels at all times. The authors solved the optimization problem through the employment of a branch-and-price algorithm and an adaptive large neighborhood search heuristic. Xu *et al.* (2020) established a data-driven quality degradation prediction model within a stochastic environment based on the key quality indicators and environmental factors for perishable products. The authors utilized the degradation model as an input to a planning model i.e., the VRP model to dynamically optimize the routing, inventory levels, and environmental controls throughout the transportation process in order to safeguard the quality of the products.

Banerjee *et al.* (2016) emphasized the usage of intelligent food packaging to enable real-time monitoring of residual oxygen levels within pre-packaged foods fostering non-destructive assessment of the quality and safety of the foods. James (2019) highlighted the importance of studying the impact of mechanical damage during transportation on the quality of foods. They proposed simulation models to correlate vibrational levels to the shelf-life of the products. Mercier *et al.* (2017) highlighted the importance of measurement, analysis, and management of time-temperature conditions at each critical stage of the cold chain to ensure the safety and quality of food. Similarly, Ndraha *et al.* (2018) provided recommendations for enhancing food safety and quality through continuous and real-time temperature monitoring and tracking using wireless sensor networks, RFID tags, TTI's, and smart logistic modules equipped with GPS systems connected to cloud platforms with 3G networks. Stergiou (2018) promoted the use of intelligent packaging integrated with biological, polymerized, diffusion-based, electrochemical, and photochemical TTI's to enable tracking of temperatures within cold chains. According to the author, the employment of intelligent packaging within cold chains reduces food spoilage and wastage and enhances food safety.

Based on a Delphi study conducted with a team of 106 global food safety experts, Kendall *et al.* (2018) identified demographic changes, economic conditions, resource shortages, environmental conditions, increased complexities within food chains, water security issues, and malevolent activities as key drivers for existing and emerging safety risks within FSCs. Furthermore, a Fuzzy Analytical Hierarchy Process (AHP) study carried out by Sharma *et al.* (2018a) revealed packaging and government policies as the most significant factors for improving safety, security, and sustainability within FSCs. Goransson *et al.* (2018) conducted experimental studies involving temperature monitoring for the shelf-life management of smoked ham and fresh cold chains. Additionally, Lorentzena *et al.* (2020) carried out cold storage experiments within a fish cold chain. The authors employed total volatile basic nitrogen within fish as characteristics for the quality assessment.

Rizou *et al.* (2020) and Galankis (2020) listed a set of safety measures to avoid the transmission of the Covid-19 virus through the food system. The list of measures included frequent washing of hands, continual disinfection of touch surfaces and work environments, pre-cleaning of food distribution vehicles before usage, and strict adherence to social distancing at all times. Manning *et al.* (2021) underlined the importance of knowledge retention policies within FSCs to avoid unintentional organizational memory loss at the individual, organizational, and inter-organizational levels to ensure food safety governance across the entire chain. As the food safety monitoring for hazard identification within a food chain is limited in application due to costly analytical methods and inefficient sampling strategies, Wang *et al.* (2021) developed a simulation and optimization-based modeling approach to determine cost-effective monitoring schemes to effectively identify contaminated sample within a food chain through the determination of optimal sampling strategies, sampling numbers, and pooling rates. Zupaniec *et al.* (2021) conducted a case study on mycotoxin contamination of agricultural commodities to identify the critical factors for food safety in global commodity flows. They found that food safety measures, such as quality management and sampling that are not adapted to the logistics sector are the major food safety challenges. Zupaniek *et al.* (2022) developed a conceptual framework based on a qualitative text analysis of multidisciplinary literature and used agricultural bulk commodities as an example to investigate the impact of global commodity flows on food safety.

Table 9 below provides a summary of the tools identified within the literature to address safety and quality challenges within FSCs.

Table 9 Tools Proposed to Address Safety and Quality Challenges

Methods	Cold storage experiments, Covid-safety protocols and measures, Delphi method, fuzzy AHP, grey-relational analysis, k-means clustering, knowledge retention policies, safety hazard monitoring schemes, Taguchi experimental design.
Models/frameworks	Centre-of –gravity models, frameworks for mapping and exploring temperature conditions, genetic algorithms, hidden-Markov models, quality degradation prediction models, simulation and optimization models.
Technologies	3G networks, artificial neural networks, GPS systems, Intelligent food packaging systems, IOT based route planning system, IOT based food quality tracking systems or platforms, IOT sensors, layered technological infrastructures, QR codes, RFID systems, safety and traceability management systems, smart logistic modules, TTI's, and wireless sensor networks.

3.4 Coordination/Collaboration/Integration

Manzini and Accorsi. (2013) proposed a conceptual framework to facilitate the integration of competencies, problems, issues, and decisions across the food chain to assess and control safety, quality, and sustainability aspects within different stages of FSC. Handayati *et al.* (2015) discussed coordination mechanisms within agri-food supply chains, which are built on interdependencies (ID) and quality requirements (QR). Interdependencies refer to intensity levels of interaction and communication within the supply chain partners. On the other hand, quality requirements refer to a level of difficulties in achieving the desired customer requirements. The authors found that market mechanisms and basic information result in efficient coordination with a low level of ID and QR. Similarly, they identified that basic contracts (oral or written) and collective learning with counseling and training fosters efficient coordination with a low level of ID and a high level of QR. They also highlighted that joint decision-making enhances efficient coordination with a high level of ID and a low level of QR. Finally, they showed that high specific contracts and data integration and information sharing improve efficient coordination with a high level of ID and a high level of QR.

Yan *et al.* (2017) used a revenue-sharing contract to enhance coordination within a three-level supply chain comprising a manufacturer, distributor, and retailer under an IoT environment. According to the authors, such contracts facilitate intelligent production/cultivation, control of cold chain logistics in transit, and management of quality and safety. Stellingwerf *et al.* (2018a) demonstrated that logistics cooperation through vendor-managed inventories (VMI) and joint route planning within temperature-controlled supply chains realizes both economic and environmental savings. Dania *et al.* (2018) studied and enumerated a list of ten behavioral factors (joint efforts, sharing activities, collaboration value, adaptation, trust, commitment, power, continuous improvement, coordination, and stability) to enhance collaborative behavior within the supply chain partners.

Badraoui *et al.* (2020) developed a conceptual model for horizontal logistics cooperation within agri-food chains by linking operational collaboration factors (dedicated investments, information sharing, joint relationship efforts, and resource sharing) to the collaboration outcomes (satisfaction with the collaboration, relationships, and results) through the mediation of relational constructs (dependence, commitment, and trust). Additionally, the authors empirically validated the developed model by employing confirmatory factor analysis and structural equation modeling.

They concluded that collaboration enhances trust and commitment within a relationship leading to enhanced satisfaction. Yang *et al.* (2020) demonstrated the role of cooperation in enhancing collaboration within a fresh food supply chain in Vietnam. Beaz *et al.* (2020) conducted a literature review on the local and organic food distribution systems. They recommended the design of a short food distribution system that closely connects consumers and farmers of local and organic food.

Zhao *et al.* (2021) formulated a comprehensive model to investigate the impact of internal integration (II), supplier integration (SI), and customer integration (CI) on product quality (PQ) and financial performance (FP) within agri-food supply chains. The authors empirically validated their model using inputs from the Chinese Agri-food business entities. They concluded that II and SI are critical to the improvement of PQ. They further showed that PQ mediates and acts as an indirect link between SI, II, and FP. **Table 10** below presents the different tools adopted to address the coordination challenges within FSCs.

Table 10 Tools Proposed to Address Coordination Challenges

Methods	Basic contracts (oral or written), collective learning, data integration/information sharing, joint decision-making, joint route planning, revenue-sharing contracts, vendor-managed inventories, and voluntary or contract-based coordination.
Models/frameworks	Behavioural models, conceptual frameworks to facilitate the integration of competencies, problems, issues, and decisions, and conceptual models for horizontal logistics cooperation.
Technologies	IoT environments.

3.5 Globalization/Internationalization

According to Dani (2015a), the globalization challenge can be addressed by enhancing trust between supply chain partners to foster long-term relationships for betterment in communication, information sharing, and agility within the supply chains. Additionally, Dani (2015a) and Walton (2021) indicated that such challenges can also be addressed through the adaptation of safety standards such as ISO22000 which emphasize global food safety standards, regulations, legislations, etc.

Diabat *et al.* (2012) adopted interpretive structural modeling to model and analyze the risks (macro-level, demand management, supply management, product/service management, and information management) within FSCs. Additionally, they developed two interpretive matrices to analyze the driver and dependence powers of the risks in order to formulate the right mitigation strategies for addressing them.

In order to enhance governance mechanisms within FSCs, Brunori *et al.* (2016) proposed six food chain characteristics (geographical configuration, product identity, spatial distance, size of operations, governance, and technologies) to help measure the “localness” and *“globalness”* of food chains. They formulated a composite matrix for sustainability assessment with health and ethics as two additional pillars to identify best practices, benchmarks, critical points, and errors within the local and global chains for reflexive governance.

Enyinda and Mbah (2017) identified eight major risks encountered by global FSCs resulting from factors such as policy/institutional, political, logistical/infrastructural, demand/supply, weather/natural disasters, biology/environmental, management/operational, and green mandate. They employed AHP as a decision-making tool to identify appropriate risk management strategies for a firm with global food operations. In addition, they identified risk reduction as the most preferred strategy for risk treatment followed by risk avoidance, risk acceptance, and risk transfer within global operations. **Table 11** below provides an overview of the tools proposed to address globalization challenges within the FSCs.

Table 11 Tools Proposed to Address Globalization Challenges

Methods	AHP, localness and globalness gauge, and trust/safety standards (ISO22000),
Models/frameworks	Interpretive structural models.

3.6 *Resilience and Robustness*

Vlajic *et al.* (2012) developed an integrated framework to enhance robustness within a food chain that identifies sources of disturbances and supply chain vulnerabilities. The framework is based on the identification of re-design principles and strategies to prevent future occurrences of the disturbances. The authors applied the integrated framework within the meat industry in the Netherlands. They discovered that sources of vulnerability within a food chain can result from multiple re-design principles ranging from operational and tactical changes to strategic changes. Vlajic *et al.* (2013) demonstrated the usage of the vulnerability assessment method for formulating re-design strategies to improve robustness within FSCs through discrete event simulations within a meat supply chain.

As building resilience starts with reducing vulnerabilities, Stone *et al.* (2015) proposed a resilience framework that balances external (financial, market, legal, infrastructural, societal, and environmental) and internal (physical resources, logistics control, information systems, and intra-organizational structures) vulnerabilities and capabilities (concentration, adaptability, redundancy, efficiency, awareness, anticipation, market recognition, security, and financial readiness) specific to FSCs. The framework can be adopted by FSCs to enhance their capabilities for vulnerability control and resilience enhancement. Bottani *et al.* (2019a) formulated a bi-objective non-linear optimization problem for a multi-product FSC to enhance resilient behavior against disruptions resulting from raw material supply/demand variability. Ali *et al.* (2018) proposed a resilience model depicting the interrelationships between cold chain logistics risks, resilience, and performance. They empirically validated the proposed model using structural equation modeling to demonstrate the moderator's effect of resilience with regard to the negative impacts of logistics risks on cold chain performance.

The resilience approach towards addressing food safety shocks (disturbances) is slightly different from the conventional food risk management approach as it needs to concentrate on only developing the ability to adapt to the food safety shocks instead of developing an ability to resist or eliminate them. In this regard, Mu *et al.* (2021) developed a procedure for building a resilient FSC to food safety shocks (FSS) through synthesizing resilience aspects from various fields such as supply chain management, infrastructure management, etc. The procedure developed mainly concentrates on defining a resilience context towards the identification of resilience factors.

According to Marusak *et al.* (2021), FSCs can improve and build resilience through embracing logistic best practices such as vehicle selection, efficient vehicle utilization, on-time and frequent deliveries, outsourced transportation, horizontal collaboration (clustering of logistic activities and assets within the supply chain networks), facility locations, inventory management, and improved supplier reliability to face large-scale disruptions like the COVID-19 pandemic. Kumar and Singh (2021) employed the best-worst method to rate the impacts of the Covid-19 pandemic on agri-food supply chains. They used quality function deployment to correlate the impacts with strategies to enhance resilience when facing future pandemic situations similar to Covid-19. The tools proposed to address resilience and robustness challenges within FSCs are summarized in **Table 12** below.

Table 12 Tools Proposed to Address Resilience and Robustness Challenges

Methods	Best-worst method, logistic best practices, procedures for resilience enhancement against food safety shocks, and vulnerability assessment methods.
Models/frameworks	Integrated identification frameworks of vulnerabilities, optimization models, resilience balancing frameworks of external/internal vulnerabilities and capabilities, and resilience models.
Methods	Best-worst method, logistic best practices, procedures for resilience enhancement against food safety shocks, and vulnerability assessment methods.
Models/frameworks	Integrated identification frameworks of vulnerabilities, optimization models, resilience balancing frameworks of external/internal vulnerabilities and capabilities, and resilience models.

3.7 *Sustainability*

Food chains can be termed sustainable if they employ environmentally friendly practices, behave in a socially responsible manner, and are economically viable. Several mathematical models have been formulated to enhance sustainable performance within FSCs. According to Zanoni and Zavanella (2012), energy usage within a cold chain is a critical measure for quality and economic dimensions as practically similar products flow through different cold chains with varying energy, processing, and storage requirements. The authors devised an analytical model through consideration of temperatures, storage times, and their impacts on product quality, supply chain costs, and sustainability. Bosona *et al.* (2013) used geographic information system (GIS) tools and location analysis techniques for route optimization within a local food supply chain to reduce the emissions emanating from vehicles.

Govindan *et al.* (2014) developed a multi-objective hybrid optimization model to solve the two-echelon location–routing problems with time windows for sustainable perishable food supply chain network designs. In addition, Bozorgi *et al.* (2014) formulated an inventory model to minimize the costs and carbon emissions resulting from the transportation and storage of temperature-controlled products. Bortolini *et al.* (2016) designed an innovative expert system based on a three-objective linear programming model for the tactical planning of multi-modal food distribution networks. The system is developed considering the perishability of foods (shelf-life and quality loss function), multi-modal shipment modes, multi-level distribution networks, and a mix of food products to simultaneously reduce operational costs, carbon emissions, and delivery times.

Gallo *et al.* (2017) formulated a mixed-integer linear programming model through the estimation of energy consumption and the refrigeration power required for the distribution of fresh food through long-range cold chains. The model was developed within different network scenarios to meet the regulatory, infrastructural, and quality requirements imposed to minimize the total energy consumption within perishable cold chains. Chandrasekaran and Rajesh (2017) employed genetic algorithms to solve a supply chain configuration model for an agricultural supply chain in India to reduce post-harvest losses and CO2 emissions. Rahimi *et al.* (2017) developed an inventory routing model with additional objectives focusing on service levels and GHG emission levels within perishable products distribution. Hiassat *et al.* (2017) proposed a location-inventory-routing model for perishable products. The authors employed a genetic algorithm to solve the model for the number and location of warehouses, retailer inventory levels, and vehicle routes. Yakavenka *et al.* (2017) formulated a multi-objective mixed-integer linear programming model to generate optimal network designs for a perishable fruits supply chain. Hariga *et al.* (2017) designed a hybrid operational and carbon emission mathematical model to optimize lot sizing and dispatching decisions within an integrated supply chain comprised of a plant/warehouse, a distribution center, and a retailer handling cold products.

Stellingwerf *et al.* (2018b) formulated a load-dependent vehicle routing problem model accounting for fuel consumption and emissions related to the load of the vehicle within a temperature-controlled road transportation system. The authors further validated the model through application within frozen food transportation in the Netherlands. Meneghetti and Ceschia (2019) formulated and solved a multi-period refrigerated routing problem using constraint programming. The problem was formulated to select the route with minimal fuel consumption for both traction and refrigeration. Bottani *et al.* (2019b) proposed an evaluation model considering product collection, backroom storage, product delivery, and reverse logistics processes. The authors employed the model to assist food cold chain managers in identifying the inefficiencies within specific processes in order to optimize the sustainability of the entire chain.

Chen and Hsu (2019) designed a multi-temperature joint distribution system to optimize delivery schedules accounting for operations and emissions costs influenced by carbon tax within multi-temperature logistics. As'ad *et al.* (2020) developed a multi-period mixed-integer linear programming model along with solution algorithms yielding optimal ordering strategies for temperature-sensitive products with a limited shelf life. The model was developed considering the environmental constraints via the carbon cap regulatory policies. Based on a sensitivity analysis study, they revealed that adjustments within lot sizes act as a viable alternative toward reducing carbon emissions as compared to making substantial investments in costly energy-efficient technologies.

Levi *et al.* (2011) carried out a comparative LCA analysis of disposable corrugated cardboard boxes (CCB) and reusable packaging systems (RPCs). Based on the study, the authors found CCBs to be more environmentally friendly than RPCs concerning packaging sizes and RPCs to be more environmentally friendly than CCBs for travel distances less than 1200 km. Folinas *et al.* (2013) emphasized the incorporation of lean techniques, such as value-stream mapping, to help identify and eliminate waste through the measurement of carbon emissions within the defined organization boundaries. Koskela *et al.* (2014) conducted LCA experiments to compare the environmental impacts of using a recyclable corrugated cardboard box system and reusable high-density polyethylene (HDPE) plastic crate system for the transportation of toast bread. Based on the experimental results, the authors proved that a recyclable corrugated cardboard box system stands out as an environmentally friendly option to the HDPE plastic crate system. Accorsi *et al.* (2014) designed an integrated framework using LCA and life cycle costing (LCC) for economic and environmental assessment of the adoption of a reusable plastic container packaging system within a food catering supply chain. Using the framework, the authors showed that reusable plastic container adoption leads to reduced environmental impacts (reduced CO2 emissions) with an overall negative economic return.

Sgarboss and Russo (2017) transformed a traditional meat supply chain into a closed-loop supply chain (CLSC) by introducing an additional loop to avoid the disposal of waste (organic waste and animal fat) into landfills. The authors additionally used profitability, payback time, total energy self-sufficiency, and social evaluation (creation of new job opportunities) as indicators to assess the sustainability of the closed-loop system. Bortolini *et al.* (2018) developed a bi-objective mixed-integer linear programming model for the strategic design of a multi-packaging fruit and vegetable fresh food FSC. The model was developed to minimize the costs and carbon emissions. Guillard *et al.* (2018) proposed sustainable packaging solutions with microbial biodegradable polymers built from agro-food waste residues. According to the authors, the packing solutions reduced plastic waste and realized the closure of circular bio-economy loops enabling nutrient flows into the soil. Fan *et al.* (2019) formulated inventory models to reduce the shrinkage of reusable container inventory within a closed-loop food chain. The authors highlighted the importance of retailers' efforts toward reducing shrinkage and maximizing sustainability within the food chains. Zhang *et al.* (2019) developed a mixed-integer linear programming model for profit maximization within a CLSC that coordinates the flows of fresh food products and returnable containers over a finite planning horizon.

Dellino *et al.* (2017) configured a decision support system (DSS) with the integration of demand forecasting, order planning, and delivery optimization. According to the authors, the DSS aids decision-makers with the development of optimal operational plans to enhance the freshness of products and reduce waste, shortages, and residual stocks. Singh *et al.* (2018) identified important criteria such as transportation and warehousing costs, logistic infrastructure and warehousing facilities, customer service and reliability, and network management in the selection of a third-party logistics (3PL) provider for a cold chain. Sharma *et al.* (2018b) adopted the best and worst multi-criteria decision-making method within an Indian dairy supply chain to determine the best and worst challenges towards the successful implementation of sustainability practices. The authors identified environmental factors as the best challenge and government certifications as the worst challenge. Raut *et al.* (2019) designed a cold 3PL providers selection framework with five main criteria (knowledge and information technology management (KITM), budget and government approvals (BGA), safety, security, comfort, convenience, and aesthetics view (SSCA), maintenance management (MAM), refrigerator and loading capacity (RELC)) and thirty sub-criteria. Additionally, the authors used Fuzzy decision-making trial and evaluation laboratory (DEMATEL) and Fuzzy AHP methods to conclude that KITM and RELC stand as the most predominant criteria for 3PL selection. Siddh *et al.* (2021) developed a conceptual model by linking quality practices within agri-food chains to the three sustainability pillars through the mediation of the relational construct of agri-food supply chain quality (AFSCQ). Additionally, the authors empirically validated the developed model employing structural equation modeling and concluded that AFSCQ considerably impacts sustainability through quality practices within agri-food chains.

Tamimi *et al.* (2010) highlighted the importance of switching over to chlorofluorocarbons-free equipment for cold storage and transportation. Additionally, the authors emphasized regular de-frosting and continuous monitoring of temperatures within the cold chains to preserve the value of products and enhance the sustainable performance of cold chains. Hülsmann *et al.* (2010) introduced intelligent containers to reduce the network's CO2 emissions within a fruit supply chain. Haass *et al.* (2015) presented a simulation study to investigate the potential of intelligent containers capable of autonomous controls, alerts, feedback mechanisms, and additional processing. Adekomaya *et al.* (2016) emphasized the need and urgency to redesign food transport systems for optimal energy savings within cold chains as 40% of all foods require refrigeration and 15% of world fossil fuel energy is used in food transport refrigeration.

Ghadge *et al.* (2017) conducted a study to identify the key drivers and barriers to the successful implementation of sustainability practices within Greek dairy supply chains. Based on the study, the authors identified six drivers, namely internal (organizational performance, investors, and suppliers) and external (government, consumers, and competitors) that foster sustainable performance. Further, they identified five barriers, namely market structures, environmental legislation, logistics networks, returns management, and distribution process that hinder sustainable performance. León-Bravo *et al.* (2019) carried out a comprehensive study on sustainability practices related to environment natural resources conservation, green processing/packaging/transportation, waste management, health and safety, work/human rights, community, sustainable sourcing, and supplier development/support that are implemented within multiple stages of FSCs. They identified that different practices implemented at different stages based on the regulatory, normative, and/or mimetic pressures result in different performance enhancements (quality, efficiency, flexibility, and responsiveness) and different sustainability reputation levels (environmental and social). They further reported that vertical integration between stages enhances sustainability across the whole supply chain.

Li *et al.* (2014) discussed the significance of governance, cooperation, technology adaptation, intelligent packaging, life cycle analysis, and food journey management in the implementation of sustainability practices within FSCs. According to the authors, such practices enable the achievement of triple bottom line benefits and supply chain survival within dynamic markets. Dani (2015b) highlighted the importance of voluntarily embedding sustainability into the supply chain design and operations to track ecological footprints, carbon emissions, carbon footprints, food miles, and eco-labeling at each stage of the supply chain (sourcing, production, processing, logistics, and retail). **Table 13** below lists the tools used to handle the sustainability challenges within FSCs.

Table 13 Tools Proposed to Address Sustainability Challenges

Methods	3PL, best-worst method, carbon regulatory policies, comparative LCA analysis, coordination, decision-support systems, food journey management, fuzzy AHP, fuzzy DEMATEL, governance, location analysis techniques, LCA, lean techniques, multi-temperature joint distribution systems, reusable packaging, and value-stream mapping.
Models/frameworks	Analytical models, conceptual models linking AFSCQ and sustainability outcomes, frameworks for 3PL selection, genetic algorithms, hybrid operational and carbon emission models, inefficiency evaluation models, innovative expert systems, integrated frameworks employing LCA and LCC, inventory and VRP models, multi-objective hybrid optimization models, and simulation studies.
Technologies	Artificial intelligence, GIS, intelligent containers, and intelligent packaging, chlorofluorocarbons-free equipments, packaging with microbial biodegradable polymers

3.8 Food Security

Dani (2015c) highlighted the importance of utilization of existing knowledge, and advanced technologies to reduce waste and enhance governance within food systems. According to the author, such developments aid with improving the food productivity levels that help reduce the shortages resulting from volatility of future demand and supply of food in the world.

Namany *et al.* (2019) highlighted that domestic and international food supplies face emerging risks from unexpected supply chain disruptions, uncertain trade transactions, resource scarcities, fluctuating commodity prices, and unexpected disruptions from weather conditions. As a solution, the authors formulated an agent-based model that mimics real-life systems in a dynamic fashion and aids with future performance predictions for risk mitigation, deficit avoidance, and sustainable performance of food systems. Further, the authors used the model to simulate the performance of a tomato market in the state of Qatar within various economic and environmental scenarios. Béné (2020) identified a series of lessons from the covid-19 crisis related to resilience measurements and responses from different actors as policy decisions towards enhancing food systems resilience and food security within the local food systems to combat other shocks and stressors beyond covid-19. Additionally, Galankis (2020) strongly recommended the implementation of Industry 4.0 tools (i.e., information and communication technologies (ICTs), apps, Internet of Things (IoT) platforms, BIG Data, and artificial technologies) within all stages of the food systems to reduce losses and wastes, and, consequently, shortages of food during future pandemic situations similar to Covid-19. Haque *et al.* (2021) proposed the deployment of IoT-based sensors to enhance food security by transforming a traditional inactive scarecrow into a smart versatile scarecrow to protect the farmlands from wild animals and weather conditions. Song *et al.* (2021) employed a systems dynamic approach to simulate hypothetical pandemic scenarios to identify the main causes for food security vulnerabilities within an urban fresh food supply chain. Based on the study, the authors indicated that food security during a pandemic or catastrophic situations can be enhanced through the implementation of strategies and policies focusing on the reduction of customer hoarding behaviors.

Joshi and Sharma (2021) explored the literature to identify fourteen critical success factors (social sustainability performance, economic sustainability performance, environmental sustainability performance, transparency, traceability, technical training/skills up-gradation of stakeholders, e-governance, digital logistics/technology infrastructures, sustainable food security decisions, trust/ collaboration, operational effectiveness/scalability, standardization of sustainable practices, digital security and smart farming) that impact the digital technology (DT) deployments within agri-food supply chains. Additionally, the authors employed a Fuzzy Delphi method to validate the factors and a fuzzy DEMATEL method to divide the factors into cause and effect groups to analyze the interrelationships between the factors. According to the authors, the interrelationships between the factors aid with DT adoptions within the agri-food chains, fostering resilience behaviors and facilitating food security enhancements. **Table 14** below provides an overview of the tools availed to address food security challenges within FSCs.

Table 14 Tools Proposed to Address Food-Security Challenges

Methods	Benchmarking of food security policies, Delphi method, DEMATEL, and knowledge management practices.
Models/frameworks	Agent-based models, and scenario simulations
Technologies	Food productivity-enhancing technologies, digital technologies, Industry 4.0 tools (ICT's, apps, IOT platforms, big data, and artificial technologies) and IOT based security systems.

4. CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

This study presented a systematic review of FSCs literature highlighting the multitude of challenges hindering the delivery of healthy food to everyone across the world. To the best of the authors' knowledge, this is the first review covering most of the practical challenges faced by FSCs in one paper. It has outlined the methods, models/frameworks, and technologies developed toward addressing specific challenges within specific FSCs. The descriptive analysis results highlighted that about 38% and 75% of the reviewed papers appeared in management science journals and were published over the last six years, respectively. It also revealed that the majority of the contributions originated from Europe (about 46%) and that majority of the studies employed exploratory methods (39%). Additionally, most of the reviewed papers focused on generic food chains (46%) and on addressing sustainability, safety/quality, and traceability/transparency challenges within FSCs (73%).

The systematic review allowed the identification of several gaps within the FSC literature for which more focused research is warranted. In the remainder of this section, potential future directions are presented to fill the identified research gaps.

One of the review findings is the scarcity of research on FSC challenges in the Middle East, South America, and Africa regions. Therefore, studies to effectively address these challenges are of prominent importance to these regions. Future research can also be directed toward food loss prevention and food quality management considering the high temperatures prevailing within these regions. The adoption of IoT-based solutions to monitor food traceability, safety and quality is another future research direction.

Table 3 above shows that the distribution of the reviewed articles is predominated by articles focusing on generic food chains (46%). The table also indicates a dearth of research on agri-food chains (about 10%) and fresh food chains (about 10%). Therefore, there is a dire need to focus future research on addressing the discussed challenges within these two types of FSCs. In particular, there exists a need to conduct in-depth studies across nations towards developing standardized constructs for enhancing the quality and safety of agri-products. There is also a need to study how agri-chains within developing and developed nations address the challenges resulting from pandemic situations like Covid-19.

Based on the descriptive results, it was found that a substantial bulk of the research studies (73%) focused on addressing sustainability, quality, traceability, and safety challenges within FSCs. Therefore, studies extending research focus on other challenges such as FLW, coordination, globalization, resilience, security, transparency, and robustness within FSCs are needed. In this regard, future research can be directed towards designing behavioral models for assessing collaboration performance within FSCs.

The descriptive results also revealed that the majority of studies employing technological solutions (40%) adopted IoT systems mainly for transparency and traceability enhancements within food chains. However, enhanced research employing hybrid systems built with advanced technologies such as big-data analytics, cloud computing, and IoT systems is needed to facilitate data-driven decision-making within food chains. Additionally, the ability to capture real-time data related to food and its surroundings fosters comprehensive solutions for addressing quality, sustainability, safety, coordination, and resilience/robustness challenges in a holistic pursuit.

Furthermore, there lies a need to undertake longitudinal studies toward successfully implementing technology configurations within different forms of food chains (fresh produce, meat, dairy, frozen, processed, perishable, etc.). In addition, longitudinal studies are also needful to provide cost justifications through the realization of complete benefits from technology adaptations and implementations.

The adoption of intelligent packaging embedded with sensor technologies aids with decision-making to enhance the traceability of foods and safeguard their quality and safety. However, full-scale implementation of such technologies within food chains requires additional studies towards justifying their return on investments through empirical testing. Also, additional research is warranted towards developing blockchain-based traceable intelligent packaging systems for supervising the foods and providing the customer with reliable traceability information.

The analysis of the reviewed papers revealed that about 56% of the articles employing models/frameworks to realize economic, environmental, or hybrid benefits. Additionally, about 21% of them designed conceptual models/frameworks to enhance specific capabilities within FSCs in addressing specific challenges. However, only 8% of the studies empirically validated the models/frameworks developed to evaluate their accuracy through experimentation and systematic observation within different environments and geographic settings. Therefore, there exists room for validation of the models/frameworks developed for different environments using longitudinal studies to generalize their results. Further, empirical validation is also essential to justify the proposed changes within the FSC configurations to achieve triple bottom line benefits. Similarly, frameworks developed for FSC performance measurement and resilience enhancement need to be empirically validated with real-time data using industrial interviews, surveys, and focus groups.

Moreover, the descriptive analysis revealed that about 80% of the developed mathematical/computational optimization models focused only on addressing sustainability, safety, and quality challenges within the FSCs. Thus, there exists a significant gap in studies focusing on the formulation of optimization models to address other critical FSC challenges such as coordination, globalization, security, transparency, and robustness.

It was mentioned earlier that global food losses prior to consumption are around 33.33%. However, the review indicates that only 2% of the optimization-based papers investigated food loss reduction. Hence, there lies a need to extend the application of optimization methods to minimize food losses within food supply chains.

Within the circular economy area, there are possible research venues to further analyze situations wherein the amounts of waste recovered from closed-loop FSCs are economically justifiable. Indeed, the development of additional analytical models to design optimal closed-loop FSC configurations is needed. In the same line of research, few of the studies focused on employing reusable packages to achieve sustainability targets. Accordingly, studies are needed to assess the economic and environmental benefits of returnable packages.

The review also demonstrated that 77% of the mathematical/computational optimization models developed to address sustainability concentrated on achieving both economic and environmental objectives, and 14% concentrated on achieving only economic objectives. Thus, indicating a shortage of research on the development of integrated FSC optimization models incorporating the three sustainability pillars. In addition, research can be also initiated to develop optimization models for strategic FSC decisions. However, as such mathematical models are computationally complex to be solved exactly, there is a need to develop efficient heuristic and/or metaheuristic algorithms capable of finding near-optimal food supply chain configurations.

Finally, sustainable FSC models developed in the literature can be extended in several directions including multiple products, multi-compartment trucks, multi-transportation modes, multidisciplinary metrics of performance, different carbon reduction policies, different forms of carbon tax depending on the amount of carbon emitted, returnable and disposable containers, multi-echelon supply chain structures, stochastic demands, and multi-period demand structures. It has also been noticed that there exists a huge gap in the development of integrated models to simultaneously address quality and sustainability challenges within multi-product food chains considering product interaction and storage compatibility.

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