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Review

Food Supply Chain Transformation through Technology and Future Research Directions—A Systematic Review

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Abstract: *Background*: Digital and smart supply chains are reforming the food chain to help eliminate waste, improve food safety, and reduce the possibility of a global food catastrophe. The globe currently faces numerous food-related issues, ranging from a lack of biodiversity to excessive waste, and from ill health caused by excessive consumption to widespread food insecurity. It is time to look back at how technology has tackled food supply-chain challenges related to quality, safety, and sustainability over the last decade. Moreover, continuous transformations of the food supply chain into a more sustainable business model with utmost resilience is the need of the hour due to COVID-19 disruptions. *Method*: This study aimed to systematize literature (2010–2021) in the described context and propose a future research direction, with the assistance of a systematic review and bibliometric analysis on the research agenda proposed above. *Results*: The findings reveal that technological Industry 4.0 (IR 4.0) tools face specific barriers due to the scope and objective of the application. *Conclusion*: The Internet of Things has received more attention than any other IR 4.0 tool. More integration between the specialized tools is needed to address this issue. Furthermore, the authors have proposed a food supply chain-based operational framework on technological inclusion to facilitate the roadmap for food supply chain 4.0 for more resilience and food supply chain viability.

Keywords: food supply transformation; supply chain 4.0; food safety; food quality; food sustainability; COVID-19 disruptions; systematic review

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1. Introduction

The need for food is indicated to quadruple over the next ten years, and the only acceptable alternative is to increase supply without jeopardizing our future. According to the most current UN estimate, there are 7.3 billion people today—and we may reach 9.7 billion by 2050. This expansion, together with rising affluence in developing nations (which generate dietary changes such as eating more protein and meat), is pushing increased global food demand. By 2050, food demand is anticipated to increase by 59 percent to 98 percent. This will shape agricultural markets in unprecedented ways. Farmers worldwide will need to enhance crop production, either by increasing crop production on existing agricultural land or by raising crop productivity on existing agricultural lands through fertilizer and irrigation, as well as adopting innovative methods such as precision farming. However, the environmental and social costs of clearing more land for agriculture are often significant, especially in the tropics. Moreover, crop yields (the number of crops gathered per unit of area cultivated) are currently expanding too slowly to satisfy projected food demand [1]. As a result, farmers' adoption of technology is a critical method for improving

agricultural sustainability and production in developing countries [2]. Farm technology, such as remote-controlled harvesting, automated irrigation systems, biometric scanners, drone-based inventory monitoring, and driverless tractors, has made a big difference in recent years. However, the agriculture industry is not as digitally advanced as other industries [3]. Technology can help farmers improve transparency and traceability along their supply chains. Consumers have acquired access to sustainability- and compliance-related information because they are now keen on tracing and tracking the food source they consume [4]. This has further pushed all the stakeholders in the food supply chain (FSC) to create a strong connection between sustainable practices and the food value chain [5].

The Sustainable Development Goals are centered on food systems. The SDGs' broad scope necessitates holistic methodologies that include previously "siloed" food sustainability analyses [6]. All components of food systems must be sustainable, resilient, and efficient in order to provide food and nutrition security for current and future generations. To promote food system sustainability transitions, several measures can be undertaken, including increased efficiency, demand limitation, and food system change. Creating sustainable food systems necessitates shifting from a conventional agriculture-centered policy to a smart food system policy and research paradigm [7]. Sustainability and environmental protection have been in the spotlight. Sustainability is having a significant impact on the global food supply chain, partly because customers desire healthier foods that do not harm the environment [8,9]. Technological tools such as artificial intelligence (AI), Machine Learning (ML), Internet of Things (IoT), Big Data (BD), Digital Twins (DT), Blockchain (BC), and Cyber-Physical Systems (CPS) have leveraged their capabilities greatly to address food supply-chain challenges related to safety, quality, traceability, and sustainability. There is a need to systematize past research endeavors to understand better the trends and future research scope in this context. On that note, this research aimed at conducting an integrated approach of a systematic review and bibliometric analysis that focused on answering the following research questions: What are the current challenges in FSC? What are the technological applications in FSC to overcome those challenges especially during pandemic disruptions? Why is sustainable FSC so important for the future? What are the antecedents of effective relationship management and FSC transformation?

The introduction part of this paper discussed the study's objective, and is followed by the literature review that portrays the trends, applications, and benefits of different technological tools applied in FSC. The keyword selection and article exclusion/inclusion criteria are described in the methodology section, followed by the results section. The dataset was snowballed with systematic and bibliometric analysis to assess the research trend and gaps. Using the insights accumulated from the overall review, the authors have proposed future research directions and barriers in the technological adoption in FSC at the end of this paper before the conclusion.

2. Literature Review

2.1. Rubrics of Food Supply Chain

Food production is divided into four phases. The first stage is locating (local or international) raw materials and verifying their quality and safety standards. Next, after the food is processed, it is sent to the handling and storage stage, where it is cleaned and processed into various end products. The subsequent phase comprises handling and storage, where they are packed according to their specifications before being moved on to distribution and transportation [10]. There are different supply-chain models, such as continuous (cash crops), fast chain (perishable items), efficient (unique products), agile (retail products), flexible (agricultural and meat products) and custom figured (hybrid food items).

Moreover, the global food supply chain is complex and struggles to meet the sustainability and safety benchmark. Therefore, a more robust supply chain structure and market governance are needed to maintain an innovative, sustainable food system. Furthermore, sustainability, availability, financial capital, food safety and security, and traceability are crucial to building a smooth FSC [11].

2.2. Effect of Pandemic Disruptions on Food Supply Chain

The food systems are meeting enormous stress and challenges due to the pandemic disruptions. The world food manufacturers and supply chain providers are now trying to meet that demand by using effective international and domestic trading protocols to stop supply chain resources and bottlenecks [12].

The COVID-19 epidemic has ushered in a new era in the world, with FSC bearing the full brunt. Considering the food supply chain, commercial activities and the supply of various food products have been halted due to a reduction in demand, the closure of food manufacturing facilities, and financial constraints. Farm labor, processing, transportation, and logistics obstacles, as well as significant shifts in demand. The majority of these disruptions are the result of policies implemented to slow the spread of the virus. In the face of these pressures, food supply chains need resilience. Grocery shop shelves are being emptied at a quick pace as stockpiling activity shifts in conjunction with panic buying behavior among customers. Moreover, the greatest threat to food security is not a lack of food, but a lack of consumer access to food [12,13].

Food policymakers are working hard to maintain costs and flows at as minimal a level as possible. The worst-affected section is labor scarcity in food processing and packaging companies, as the industries have been asked to reduce their workforce to stop transmissions. As a result, there are more significant bottlenecks in the FSC [13].

2.3. Conventional Food Supply Chain and Issues

As the world's population grows, so does the need for more food, demanding a more excellent supply of high-quality commodities. On the supply side, however, there is still concern about the industry's ability to fulfill higher product yields and quality improvements as a result of issues such as climate change, droughts, and agricultural productivity. The global agricultural linkages are intricate because they involve numerous actors at various levels, from those who generate and add value to processed goods to those who sell. When there are several distinct food items, each with its own unique and widely fragmented supply chain, the complexity rises. Consumers are increasingly concerned about responsible food sources and food production [14]. FSC management is more difficult in developing countries because they typically involve small-scale farmers with hardly any market governance and outreach. Adverse effects on food availability are generated because of the hurdles faced by FSC, such as substantial intermediation, diminished profitability, decreased quality, food waste, and loss of revenue [15].

Therefore, major players are now motivated to adopt sustainable methods in their supply chains since they can guarantee a consistent food supply and profitability. However, sustainability has a price and workflow to follow. It is one of the major trump cards that can fetch an organization's competitive advantage as per the natural resource-based view. The parameters of successful sustainability directly reduce wastes and improve environmentally green practices (waste reduction), social responsibility (social wellbeing), and economic viability (improved livelihood) [16,17]. It would be interesting to see how technological tools assist in addressing these challenges in FSC.

2.4. Application of Internet of Things (IoT), Big Data & Blockchain in FSC

In underdeveloped countries, only a tiny part of the food supply chain will usually be considered for food ecosystem security audits. The accessibility of the ecosystem, access to the supply chain, and utilization of the food chain are three measurement scales generally used to inspect food and ecosystem security. Food supply networks are complex and interconnected, and IoT-based systems can monitor them to capture details on food materials and protect the ecosystem [18]. The Internet of things (IoT) platform can provide product traceability information in the food supply chain, assisting customers, especially during this pandemic disruption where the information available is so vague. By combining IoT and blockchain technologies, FSC can become more transparent and productive by delivering robust and stable information to clients and related stakeholders [19].

At present, pathogenic and parasitic contaminations can move with frozen food packages, according to scientific evidence, especially in the context of the current COVID-19 situation, where traceability is critical in maintaining food quality and safety. To create a tamperproof audit trail to verify parasites and viruses in packed foods in the FSC, IoT-based, tamperproof data sharing with a centralized architecture and blockchain smart contracts can be used [20]. IoTs can efficiently handle seedling procurement and temperature management in the agriculture industry [21]. Ortañez et al. (2020) [21] built an effective and flexible IoT-based coordinating system for boosting the coordinating mechanism in the agriculture food supply chain during natural outbreaks, to stop the issues caused by fake food. Balamurugan et al. (2021) [22] presented a supplier-based, blockchain hyperledger technology to ensure that FSC data is available and traceable, with an unimpaired substantial computational capacity when implemented within the realms of the IoT [23].

Mondal et al. (2019) [24] presented a distributed ledger technology assisted by IoT architecture, and created a transparent food supply chain using a proof-of-object-based authentication system, similar to cryptocurrency's proof-of-work protocol, coupled with an RFID-connected sensor for real-time data acquisition. As a result, establishing a food traceability supply chain is an effective strategy to address the food safety issue. However, the running costs of a standard food traceability supply chain system are substantial [25]. In an environment where economies are growing more competitive, diversified, and complex, customers have now started to expect high quality and traceability. Blockchain-based software platforms have been advocated to improve traceability by increasing transparency within the FSC [26].

Because of rapid technological advancements, key competitive techniques are rapidly changing. The amount of data globally is continuously increasing; every 12 months, the amount of data in the world doubles [27]. Customers now put too much emphasis on food ingredients and nutritional composition. Even while organic foods are nutritious, they need stringent certification procedures. Big data and blockchain can suffice this issue by providing the necessary certification platform [28].

Li et al. (2017), [29] created a prototype tracking tool that allows the use of sensor data and the creation of data-driven pricing decisions in a variety of operational scenarios and product features. Furthermore, in the same context, Ji et al. (2017), [30] previously introduced a Bayesian network approach for predicting market demand that combines sample data and establishes a cause-and-effect relationship between data, as well as a crisp schematic on how large data can be integrated into Bayesian mathematical network optimization to anticipate demand. Moreover, a service-oriented traceability platform (SOTP) used in the packaged foods supply chain allows real-time dynamic data acquisition and processing of packaged foods information, creating a ubiquitous environment in the packaged foods supply chain. This ensures packaged food's life-cycle visibility and traceability from their production, circulation, and consumption [31]. Additionally, the objective of algorithms for tracing contamination sources and locating potentially contaminated food in markets can be achieved [32].

2.5. Blockchain in FSC

Blockchain is a secure digital ledger that records and validates user transactions that cannot be altered or deleted. These actions are known as blocks, each having its own digital signature and a connection to the previous one. This approach creates a growing list of chronologically arranged encrypted records. Digital currencies or cryptocurrencies are utilized across the supply chain to pay for the quality of assets. Agriculture farmers, distributors, and consumers can pay for selective access, sharing, and authentication of products. The transactions are followed by advanced encryption systems [33,34]. A QR code is placed on food packaging that contains all of the evidence gathered along the supply chain. Consumers may scan the QR code to obtain comprehensive stock traceability, including origin information. Moreover, in global logistics, the distributed ledger technology-based smart contracts (which use the blockchain to execute agreements), and

the smart web (cloud) have all been used to preserve container information so that its partners may receive data on container conditions, such as humidity and temperature [34].

Furthermore, this allows banks to also benefit from the FSC's visibility and lend money to farmers without risk. Buyers will have an easier time verifying whether the seller's statements regarding the food quality are accurate through blockchain smart contracts [35]. This technology makes it easier to decentralize, enhance security, sustain and manipulate supply chains during disruptions [33]. Furthermore, a better cost-control mechanism of the food traceability supply chain-based system is also possible to practice [25,26].

2.6. Artificial Intelligence (AI) and Machine Learning (ML) in FSC

AI offers many benefits to the food-processing supply chains. Supply chain players will invest in AI if they foresee long-term revenue gains and other benefits [36]. AI can improve the industry's performance in many ways and add to the gross domestic value. These ways include technical feasibility, intelligence, data quality, and accessibility [37]. Additionally, the food supply chain uses vast amounts of energy. This use significantly affects the environment all along the chain. AI-based optimization can help reduce energy consumption by sharing information, minimizing energy use, optimizing truck routes, reducing greenhouse gas, and shrinking the carbon footprint which is very essential during this pandemic and post pandemic era [38]. Recently, researchers have focused on using AI to help protect supply chains from the effects of disruption. This research suggests that AI can help to improve forecasts and thus mitigate the outcomes of disruptions, an aspect of supply-chain risk management [38]. In recent years, supply-chain risk management has received a lot of attention, intending to protect supply chains from disruptions by forecasting their occurrence and mitigating their negative consequences. Therefore, AI has prompted researchers to look into machine-learning techniques and their application in supply-chain risk management [39].

Food quality is a significant aspect that food engineers keep in mind whilst designing a food system. In tea production, Núñez-Carmona et al. (2021) [40] calculated the volatilome of several tea varieties using metal oxide gas-sensor data and machine learning to provide a competitive tool that can project predictive analysis based on time, costs, and contamination. Moreover, food traceability and shelf life are directly proportional. ML assists blockchain platforms in building anticounterfeiting solid technology in FSC, overcoming drawbacks of low levels of traceability, scalability, and data accuracy. Shahbazi et al. (2021) [41] suggested a blockchain- and machine-learning-based food traceability system (BMLFTS) that relied on a fuzzy logic approach that improved perishable food shelf-life management. The BC was used to reduce warehouse and shipment times and thereby improve reliability. Alfian et al. (2020) [42] proposed an IoT-based traceability system that utilized RFID and raspberry pi-based sensors. The RFID reader tracks and traces the merchandise while the raspberry pi is used during storage and travel to record temperature and humidity and forecast future temperatures. Sometimes, the food supply chain involves multiple stakeholders and distributors, which always leads to information asymmetry. To counteract, Mao et al. (2018) [5] designed a blockchain-based credit evaluation system to enhance food supply-chain monitoring and management efficiency through intelligent and innovative Long Short-Term Memory Network contracts (LSTM).

2.7. Digital Twins & Cyber-Physical Systems in FSC

The adoption of diverse technologies has aided in the advancement of food processing and logistics. To improve insights and optimize designs and processes, more sophisticated numerical tools and software platforms have emerged. The concept of the digital twin was successfully introduced as a valuable tool in the context of industrial digitization [43,44]. The digital twin is a virtual clone of a real-world process, connected to the environment via Big Data tools to analyze the functions of more physical models. This enables us to model and virtually visualize environments and processes risk-free, which is very apt for

the present COVID-19 conditions [45]. The supply chain-based digital twins provide end-to-end visibility along with demand charts, levels of inventory, and asset management [46].

Furthermore, cyber-physical systems have evolved as intelligent mechanical entities that help in the smart production and packaging of products. Therefore, it can be easily linked with IoT, AI, and ML for better performance [47]. One good example of a digital twin application in FSC is portrayed by [48]. They created a digital fruit twin based on mechanistic modelling mimicking the thermal behavior of food products (fruit) across the cold chain, and quantified the enzymatically driven, temperature-dependent biochemical breakdown processes. This improves supply networks by documenting and predicting where temperature-dependent food-quality loss happens in each supply chain due to extended refrigeration times.

3. Methodology

The selection of keywords and the database were the first steps in this study. The authors used the Scopus database for this study because it enabled them to investigate a broad spectrum of publications. The primary keyword, food supply chain, was entered into a title search option followed by Internet-of-things, Big data, Digital twin, Artificial Intelligence, Machine learning, Cyber-Physical Systems, Blockchain, and Industry 4.0 title-abstract-keyword search option. The time-frame was limited from 2010 to 2021 (current). The authors selected only the articles that were published in English journals and excluded review papers. Conference papers were included because of their novelty, latest findings, and research proposals published in the conference proceedings.

The search code applied was as follows:

(food AND supply AND chain) AND TITLE-ABS-KEY (technological AND advancements) OR TITLE-ABS-KEY (internet AND of AND things) OR TITLE-ABS-KEY (big AND data) OR TITLE-ABS-KEY (digital AND twin) OR TITLE-ABS-KEY (artificial AND intelligence) OR TITLE-ABS-KEY (machine AND learning) OR TITLE-ABS-KEY (cyber AND physical AND systems) OR TITLE-ABS-KEY (block AND chain) OR TITLE-ABS-KEY (industry 4.0)) AND PUBYEAR > 2009 AND (LIMIT-TO (DOCTYPE, “ar”) OR LIMIT-TO (DOCTYPE, “cp”)) AND (LIMIT-TO (LANGUAGE, “english”)) AND (LIMIT-TO (SRCTYPE, “j”) OR LIMIT-TO (SRCTYPE, “p”)) Results.

Initially, 156 documents were obtained. Then, the duplicates were removed, and authors thoroughly read the title and abstract of all the papers to scrutinize and bring down the number to 112 final datasets. A detailed methodology with a schematic is shown in Figure 1.

The dataset was snowballed to obtain results such as publication trends and distribution, source of publication and related technological concepts they primarily focused on, research work that was highly cited in this area along with the current number of citations, FSC properties, and percentage of research work plotted against the respective technological tool inclusion, department-wise categorization, and related research work, and barriers in technological adoption in FSC with future research trends. Insights of systematic analysis assisted in systematizing and structuring the dataset and understanding the current trends and challenges in FSC.

A bibliometric analysis on keyword coupling (food safety, quality, and sustainability) was also performed with the same dataset to interpret the relevance and concentration of research work. The authors wanted to understand different clusters of research work on this area. All indexed keyword coupling was run to retrieve the word cloud and gain an overall idea of the research area targeted over the past decade, and the country-wise link strength and citations were retrieved to understand the research work conducted according to the geographical locations. In addition, the relevance between the publication sources was checked to study how the researchers coauthored and cited other research publications in other journal sources. The main agenda of using both forms of analysis is to reap maximum insights on the topic of study, identify research gaps to answer for the research questions, and to propose future research directions.

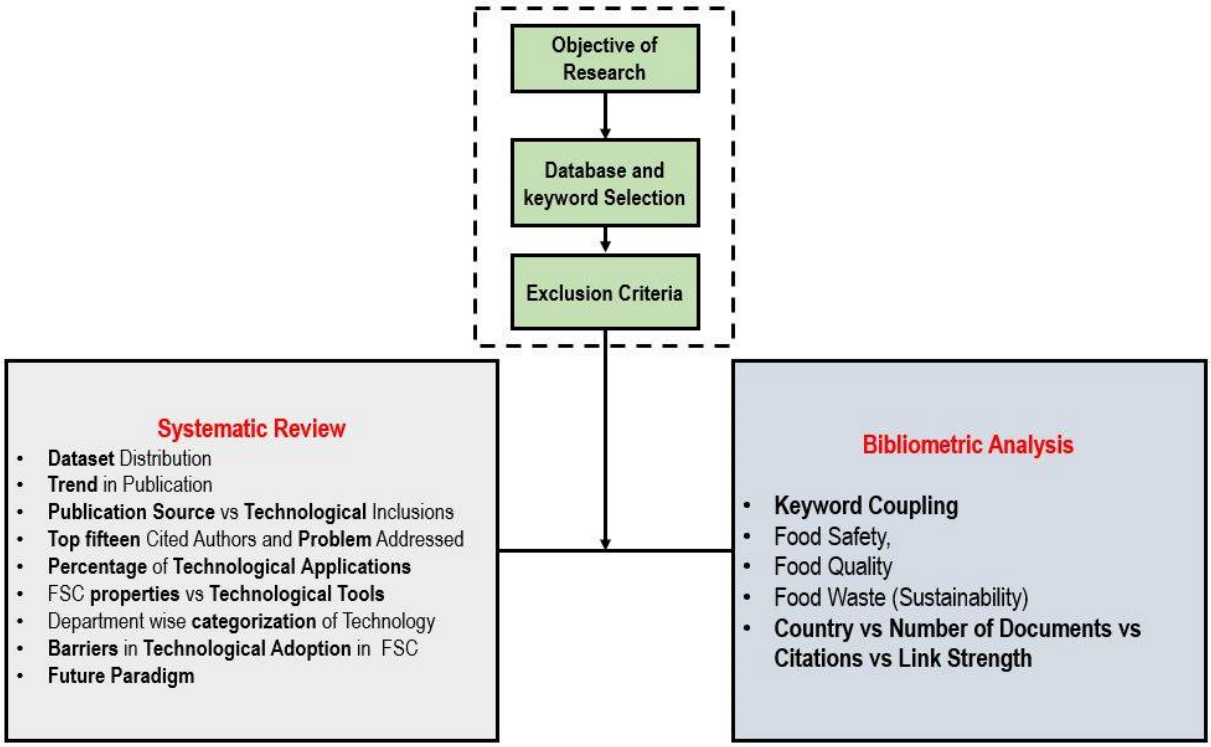


Figure 1. Methodology.

4. Results

The percentage of type of publications and datasets distributed was computed and projected in Figure 2. Conference papers accounted for 31% of the total publications. Figure 3 portrays the trend in publication. There is gradual rise, generating a good number of publications especially in the years 2017 and 2019.

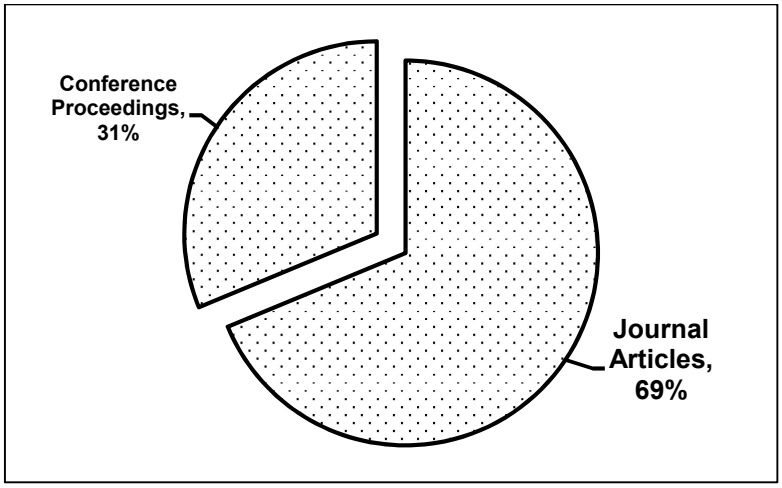


Figure 2. Dataset Distribution.

Table 1 displays the number of publications relating to technological advances in research work over the timeframe. The *International Journal of Production Research* and *Journal of Cleaner Production* have the most publications in the area of AI and blockchain applications in FSC. Furthermore, the top 15 most highly cited research works are tabulated in Table 2. The technological evolution has occurred gradually from applying RFID, IoT, blockchain, and AI.

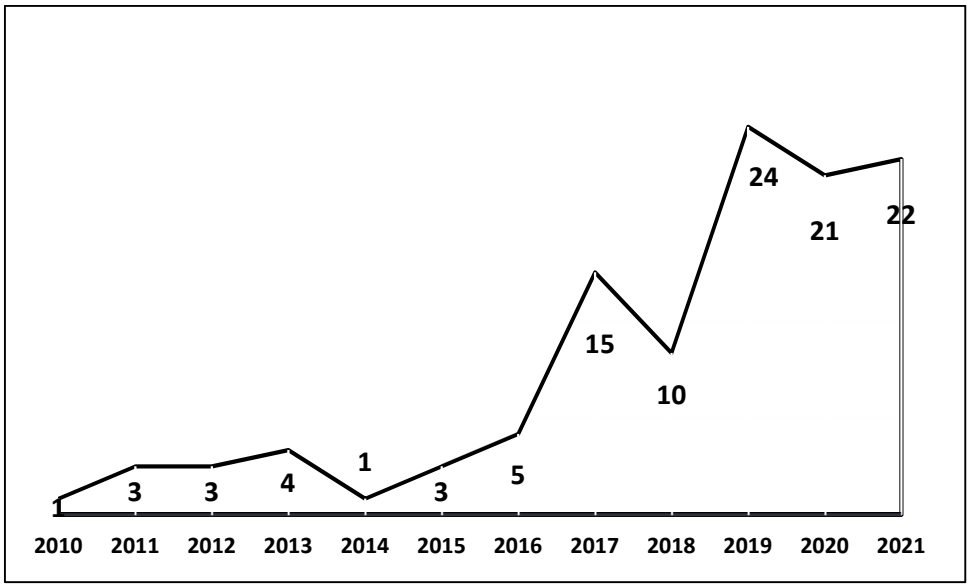


Figure 3. Trend in Publication.

Table 1. Source of Publications vs. Technology (Targeted Research Area).

Publication Source	No	Technology (Research Area)
International Journal of Production Research	5	Artificial Intelligence (Food Supply Chain Configurations), Mixed Integer Nonlinear Programming (Food Perishability), Blockchain (Food Traceability), Decision Support Systems (Arima, Arimax Machine Learning) Dynamic Network Sensors (Pricing Chilled Food Supply Chain).
Journal of Cleaner Production	4	Blockchain (Traceability, Tracking), Big data (Green Agrifood Supply-Chain Investment decisions), Decision-Making Trial Evaluation Lab (Reduce FSC risks)
Industrial Management and Data Systems, Production Planning and Control	3	Data-Driven Problem (FSC problems), Internet of Things (Perishable FSC), IoT (Tracking Prepacked Food Supply Chain), Blockchain (FSC Traceability)
2nd International Conference on Industry 4.0 and Smart Manufacturing, ISM 2020, *International Journal of Environmental, Research and Public Health, Computers in Industry, Food Control, International Journal of Supply Chain Management, Benchmarking, Foods, Sustainability* (Switzerland), *Technological Forecasting and Social Change*, Proceedings of the 5th NA International Conference on Industrial Engineering and Operations Management, IOEM 2020	2	Blockchain (FSC Traceability), Digital QR code (FSC safety), Fuzzy Logic (FSC Information), IoT (FSC Information Integration), Big Data (FSC sustainability, Integrity), Stochastic Modelling (Perishable FSC)

The abstract, title, and full text (only those available) were thoroughly reviewed by the authors to retrieve information on the percentage or volume of technological tools adopted in FSC-based research, which is shown in Figure 4. The inferences show that IoT and big data have been extensively applied; however, AI, ML, cyber-physical systems, digital twin, and blockchain technology still need more attention to discover further implications and benefits for FSC. Later, authors divided FSC based on food quality, safety, and waste and found out the relevant technological adoptions to meet the research objectives which is portrayed in Table 3. The findings reveal that IoT-assisted blockchain technology, RFID integrated with IoT, artificial intelligence, and machine learning were applied to improve food safety and quality.

Table 2. Author (top fifteen) vs. Problem addressed vs. Citations.

Author	Problem Addressed	Number of Citations
[49]	Integrated RFID (Radio-Frequency Identification) and blockchain for an agrifood supply-chain traceability system (production, processing, warehousing, and sales)	465
[50]	Built a food supply-chain traceability system for real-time food tracing based on HACCP (Hazard Analysis and Critical Control Points), blockchain and Internet of Things.	263
[51]	Presented AgriBlockIoT, a fully decentralized, blockchain-based traceability solution for Agrifood supply chain management.	175
[52]	Analyzed the concept of virtual food supply chains from an Internet of Things perspective and proposes an architecture to implement enabling information systems in a Fish Supply Chain.	147
[53]	Proposed a value-centric business–technology joint design framework for acceleration of data processing, self-learning shelf-life prediction and real-time supply-chain replanning.	139
[54]	Proposed big-data analytics-based approach that considers social media (Twitter) data for the identification of supply-chain management issues in food industries.	89
[55]	Proposed a food-safety prewarning system, adopting association rule mining and Internet of Things technology, to timely monitor all the detection data of the whole supply chain and automatically prewarn.	76
[24]	Proposed a blockchain-inspired Internet-of-Things architecture for creating a transparent food supply chain by integrating a radio frequency identification (RFID)-based sensor at the physical layer and blockchain at the cyber layer to build a tamperproof digital database to avoid cyberattacks.	67
[56]	Proposed a supply-chain quality sustainability decision support system (QSDSS), adopting association rule mining and Dempster's rule of combination techniques.	66
[5]	Provided a blockchain-based credit evaluation system to strengthen the effectiveness of supervision and management in the food supply chain.	61
[57]	Identified the various barriers that affect the adoption of IoT in the retail supply chain in the Indian context and also investigates the interdependences between the factors using a two-stage integrated ISM and DEMATEL methodology.	52
[29]	Investigated the potential benefits of the chilled-food chain management innovation through sensor data-driven pricing decisions to predict the remaining shelf life of perishable foods.	48
[58]	Proposed an effective and economical management platform to realize real-time tracking and tracing for prepackaged food supply-chain based on Internet of Things (IoT] technologies, and finally to ensure a benign and safe food consumption environment.	46
[59]	Discussed goals and strategies for the design and building of an IoT architecture aiding the planning, management and control of the Food Supply Chain (FSC) operations using a simulation gaming tool embedded with IoT paradigm for the FSC applications.	40
[60]	Proposed a blended, grey-based Decision-Making Trial and Evaluation Laboratory (DEMATEL) model to assess the relationships among the identified major risks in FSCs.	39

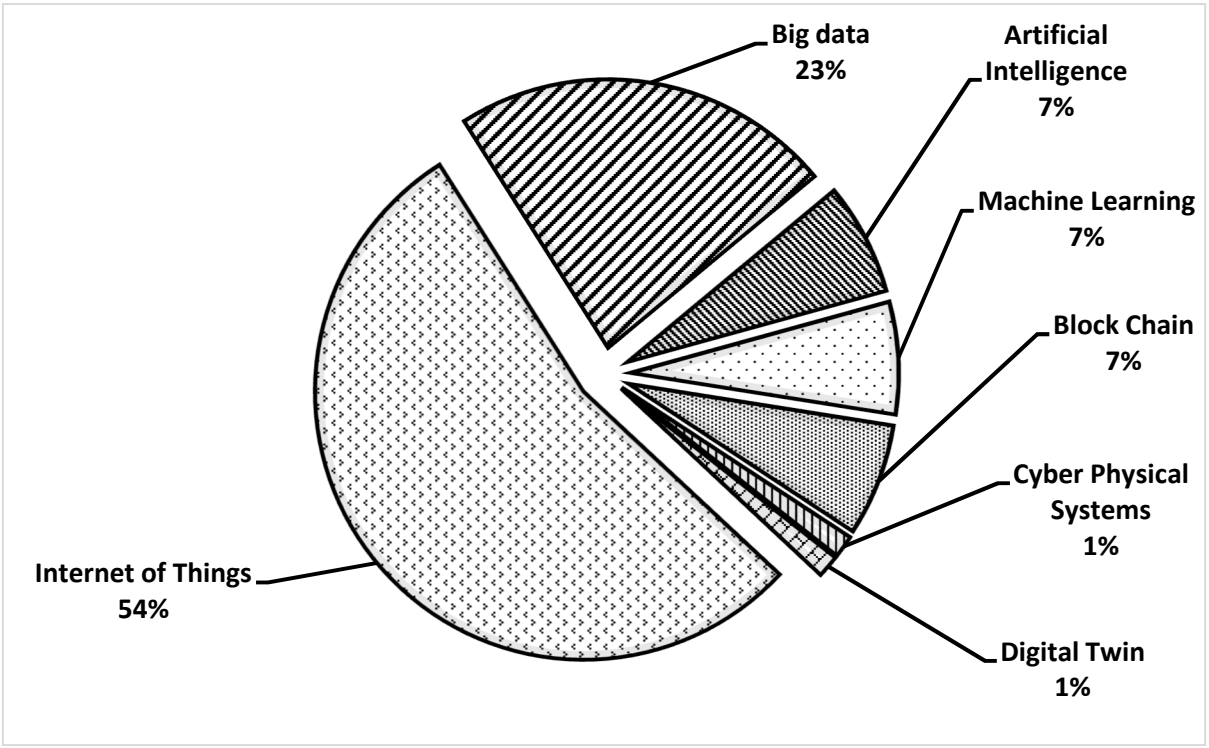


Figure 4. Percentage of Technological Tools.

Table 3. Properties of FSC vs. Proposed Technologies.

Reference	Food Quality	Food Safety	Food Waste	Proposed Technologies
[61]		✓		Cyber-physical network systems (monitor food contamination)
[22]		✓		IoT—blockchain-driven traceability technique for data transparency
[62]			✓	Smart sensing technology to enhance food quality and freshness
[20]	✓			Blockchain- and IoT-based traceability system for food waste
[25]		✓		Cost-of-food traceability using blockchain
[40]			✓	IoT-based inventory network tracing to minimize food waste
[63]		✓		To check for adulteration and foodborne diseases—Traceability using grey Dematel approach
[42]	✓			RFID-coupled, IoT-based food-quality forecasting
[48]			✓	Digital twin-based behavioral modelling
[64]		✓		IoT-based agrifood logistics system architecture
[49]		✓		RFID-integrated blockchain for food traceability
[65]			✓	Food supply-chain monitoring and planning using IoT

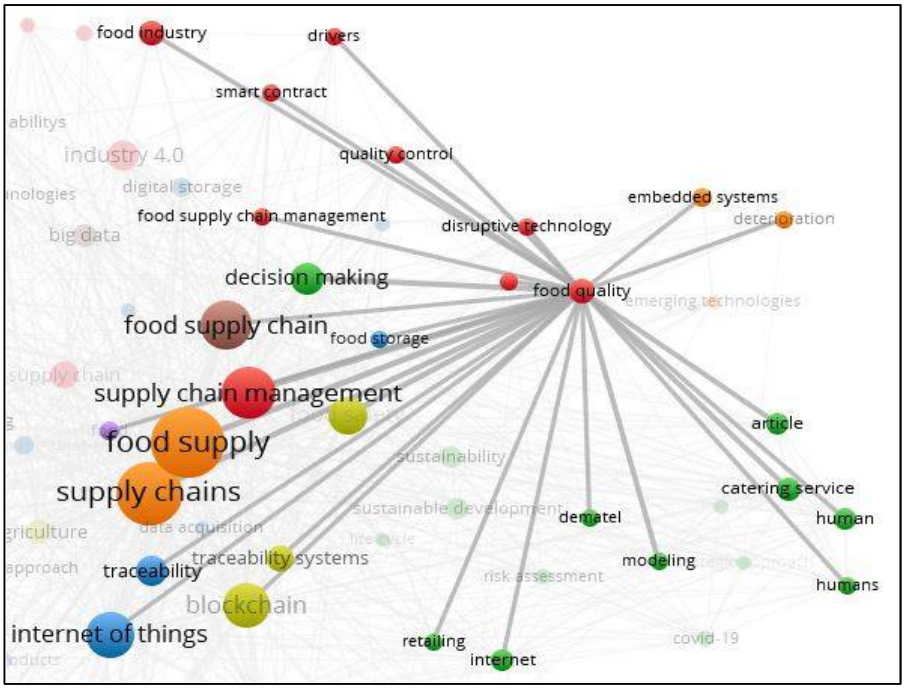
The FSC was classified into Production and Processing, Food Tracking and Traceability, Warehousing and Packaging, Logistics Branding, Marketing & Sales, and the corresponding technology applied. This classification was performed to obtain an in-depth idea of the technological tools and advancements at different stages of the food chain, starting from raw materials and ending with finished goods. This information is tabulated in Table 4. The results show that more research has been conducted on food traceability and tracking in recent years.

Table 4. Department-wise Categorization of Technological Tool Adoption.

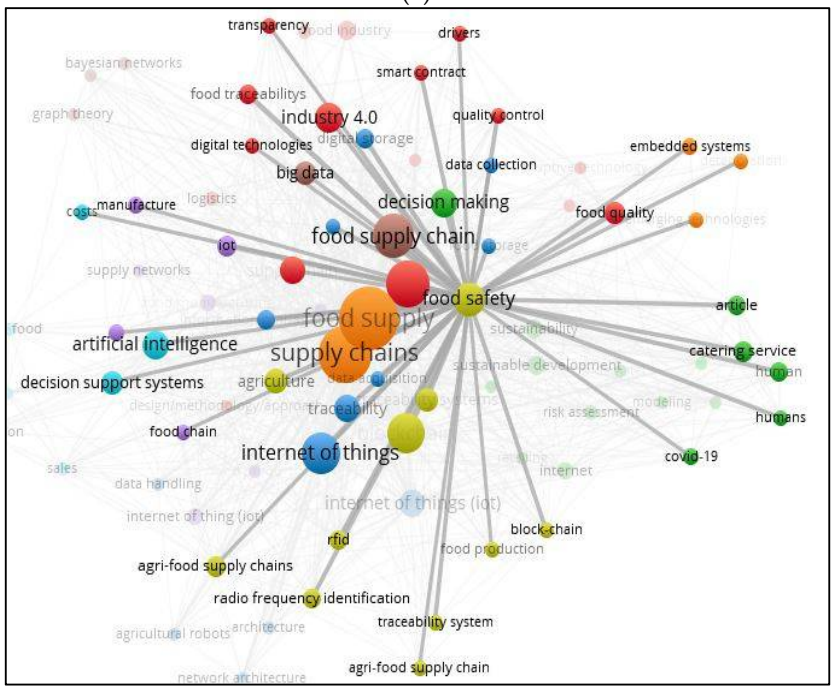
Reference	Food Production and Processing	Food Tracking and Traceability	Warehousing and Packaging	Logistics	Branding, Marketing & Sales	Technological Tool Applied & Purpose	Publication Source
[20]		✓				Blockchain-based food traceability to ensure safety	*Foods*
[66]	✓					Blockchain integrated with QR code and built FoodSQRBlock in food production (scalability and feasibility)	*Sustainability*
[67]			✓	✓		Enhanced naive Bayes approach and IoT integration in warehousing and transportation	*International Journal of Scientific and Technology Research*
[3]	✓					Smart Farming Technology Framework	*Land Use Policy*
[68]	✓					Producer-to-consumer food production and quality-based blockchain ledger	*Quality—Access to success*
[41]		✓				Blockchain machine-learning-based food-traceability system (BMLFTS) to improve food readability, scalability and improve anticounterfeiting	*Electronics*
[69]			✓	✓		IoT-enabled supply-chain parameters and modelling	*Industrial Management and Data Systems*
[37]	✓					AI adoption to address operational efficiency in food production at SMEs	*HSE Economic Journal*
[70]					✓	Decision support systems (Arima, Arimax) for food sales forecasting	*International Journal of Production Research*
[22]		✓				IoT- and blockchain-driven food traceability	*International Journal of Information Technology*
[4]		✓				Blockchain-based diary product supply-chain traceability	*International Journal of Production Research*
[38]				✓		AI-based energy savings in food logistics	*IEEE Industrial Applications of Artificial Intelligence (2020)*
[71]		✓				Bayes classifiers algorithm integrated IoT for food supply-chain traceability	*International Journal of Engineering and Advanced Technology*
[63]		✓				Grey Dematal approach for food traceability	*Information Processing in Agriculture*
[72]				✓		Internet of perishable logistics for food supply-chain networks	*IEEE Access*
[73]					✓	Determinants of food safety level using smart technology	*International Journal of Environmental Research and Public Health*
[74]					✓	Electronic Product Code (EPC)-based Internet of Things for food sales monitoring	*International Journal of RF Technologies*

5. Bibliometric Analysis of Food Safety, Quality, and Sustainability Using Keyword Coupling

A bibliometric keyword coupling was conducted using the Vosviewer software on the dataset with 978 keywords. The number of keyword repetitions was set at three, in which 83 keywords met the criteria. The keyword nodal burst was separately captured from the bigger image and projected as Figure 5a–c to visualize food quality, safety and waste (sustainability). The authors selected the sustainability keyword-based nodal image in the keyword coupling related to food waste, since the waste node was much smaller and meagerly relevant compared with the other bibliometric, full-factorial coupling clusters.

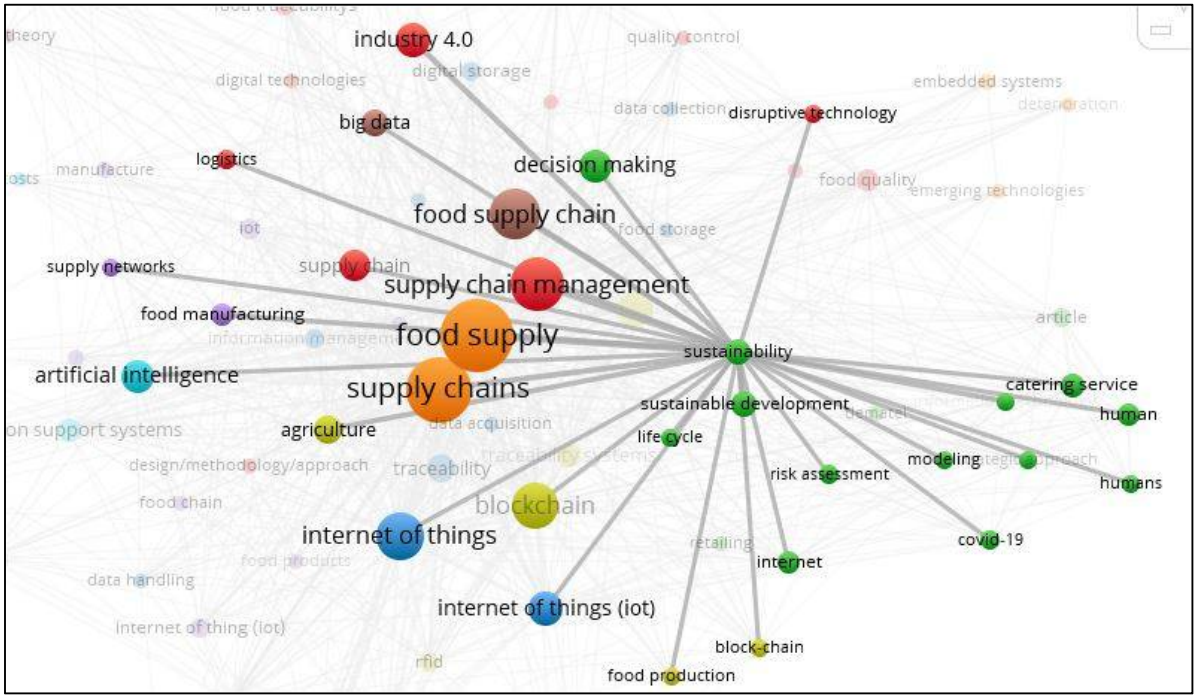


(**a**)



(**b**)

Figure 5. *Cont.*



(**c**)

Figure 5. (**a**) Food Quality, (**b**) Food Safety, (**c**) Food Waste (sustainability).

The keyword bibliometric coupling results show the relevance of the research area (keyword) and the intensity of work done based on the distance between them and the size of the node, respectively [43,75]. Inferences can be retrieved by identifying the gaps and future research work. The results from 5a reveal that smart contracts have been deployed in the food industry to maintain food quality. IoT, embedded systems, and Dematel Fuzzy logic algorithms are the primary tools related to food quality maintenance. Whereas IoT, AI, radio frequency identification device (RFID), embedded systems, and big data have all contributed towards maintaining food safety, as shown in Figure 5b. However, IoT and big data are in different clusters with less relevance. This indicates that more research is needed to understand the challenges and drivers of those technological adoptions in FSC from food safety. The same tools are also assisting in sustainability but are seen even farther apart in the nodal burst. The interpretation of the results from Figure 5c keyword burst shows that food waste or sustainable norms of food production and logistics are still in their infancy.

Indexed Keyword Coupling

Another set of keyword couplings on the indexed keyword set was conducted to visualize the overall keyword cloud. The minimum number of keyword occurrences were three, and 59 met the threshold out of 741 keywords. The indexed keyword coupling based on text mining has been shown in Figure 6. Five clusters have been identified from the word could. Artificial Intelligence, decision support systems, and big data (data mining) are grouped along with the agricultural systems and food traceability. A separate cluster has been generated for food storage and traceability related to food safety. RFID, IoT, blockchain, and agricultural robots are grouped in a separate cluster. Sustainability and strategic decision making for risk assessment seem to be very close and relevant.

The dataset was further reviewed to generate country-wise relevance, number of documents, and total citations per country. A maximum number of research and citations in FSC and technological adoption has been seen in the United Kingdom, followed by India, China, Turkey, and United States. The minimum number of documents and citations per country was fixed as two. A total of 26 countries out of 33 met the criteria as tabulated in Table 5. This

inference is crucial to finding out from which countries researchers and institutions contribute more towards FSC and push other researchers to discover their objectives.

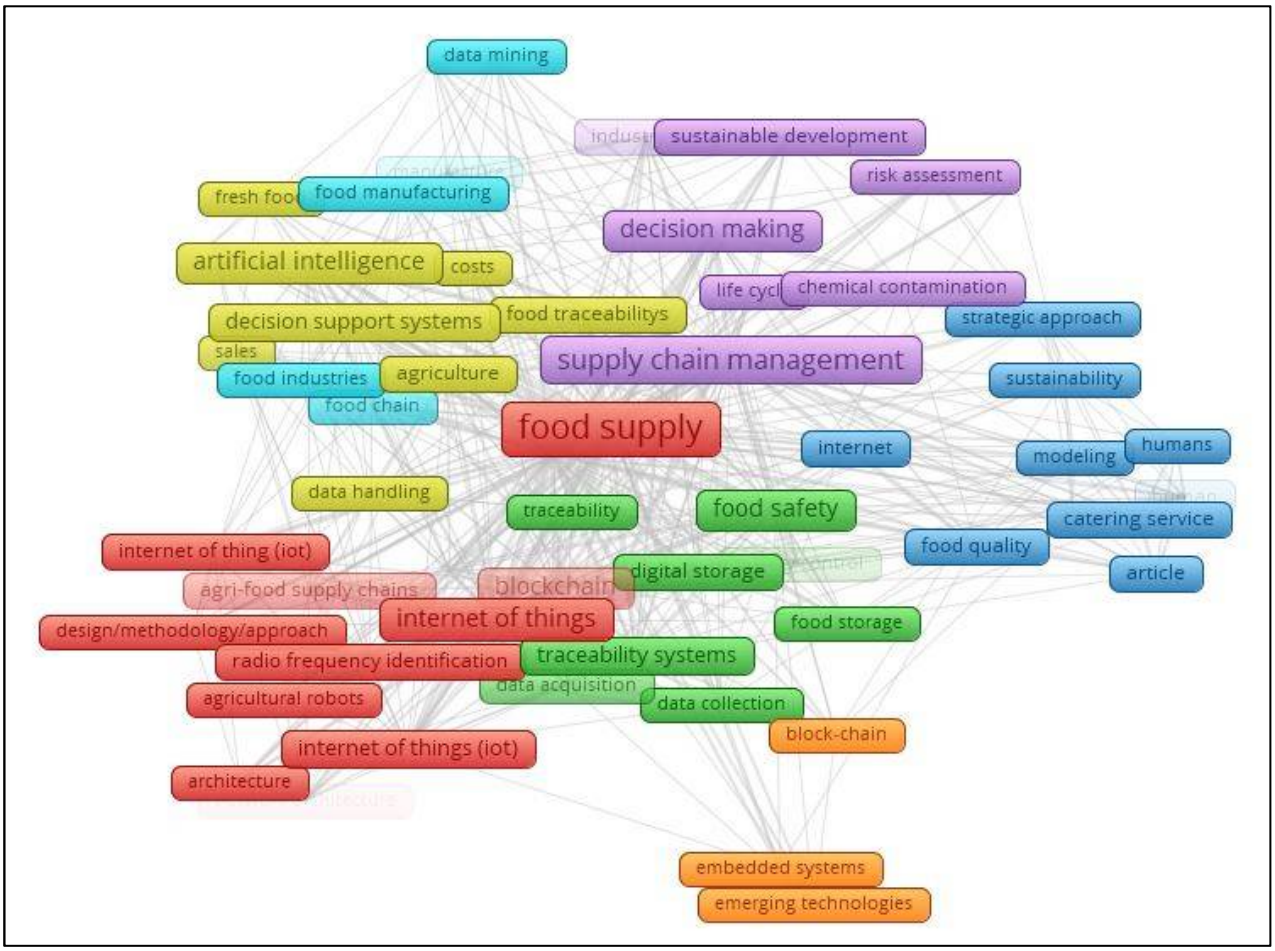


Figure 6. Indexed keyword coupling.

Table 5. Research Link Strength and Citations between Countries.

Country	Documents	Total Citations	Link Strength
United Kingdom	22	276	1943
India	20	131	1686
China	25	481	855
Turkey	3	16	841
United States	9	206	692
Canada	6	53	576
Italy	11	295	340
Netherlands	6	252	337
Indonesia	2	4	273
France	5	73	248

Later, the bibliometric coupling on sources was conducted with one article having a minimum of 10 citations. Out of 90 sources, 29 were the most relevant, which is clearly shown in Figure 7. The larger the nodes, the greater the research volume, and the closer the nodes more relevant the research work. *International Journal of Production Research, Journal of Cleaner Production, Sustainability, Industrial Management and Data Systems*, *Information*

Systems Frontiers, and *Food Control* are the journals that have been extensively published in these areas.

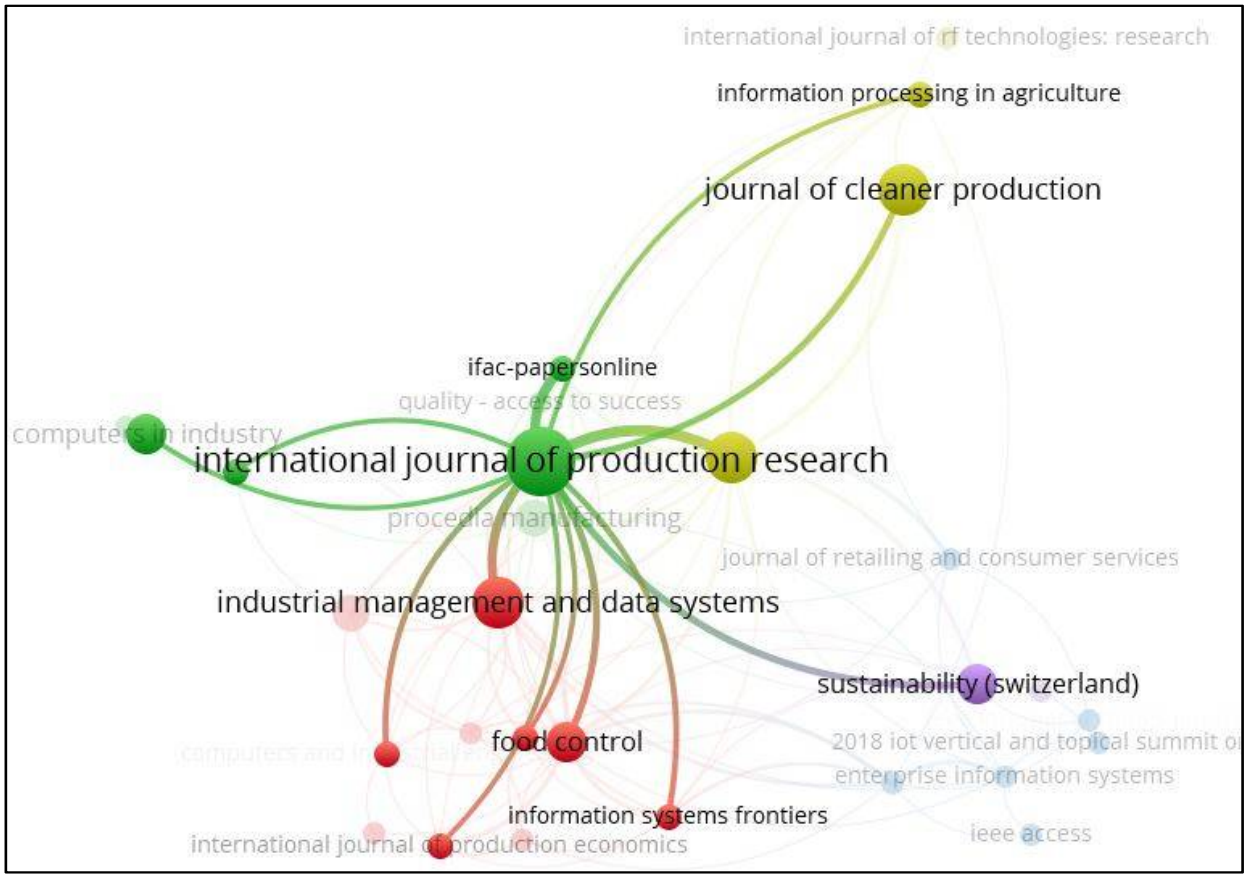


Figure 7. Bibliometric coupling of Journal Sources.

6. Discussion

Global warming, population growth, industrialization, and the need for sophisticated food systems are all being addressed by innovation. Applying technologies in monitoring ecological effects, smart farming, and value addition for future smart value chains has a tremendous and intriguing perspective. For predicting and forecasting crop cultivation, reaping time, and grade, technologies such as AI are employed to find in-time conveyance and optimized market outreach. This systematic review and bibliometric analysis yielded a set of research implications, which the author discusses in depth in the sections below.

6.1. Effect of Current Pandemic on FSC

The COVID-19 outbreak gave birth to a new phase in the food sector and supply chain. The repercussions on humankind, the economy, and food safety are still being worked out. Food scientists and experts face numerous issues, including securing food safety, identifying SARS-CoV-2 locations where food is produced, processed, and distributed, and effectively sanitizing surfaces and working areas. More precautions are required as we progress to the final stages of the supply chain, as more people are involved in the process. Food monitoring and surveillance would become increasingly reliant on the development of effective bioanalytical technologies [76].

The pandemic is responsible for rapid shifts in the foodservice to retail food patterns requiring flexible FSC. Potential long-term changes in the supply chain include greater food supply-chain automation and digitization. In addition, technological investments in online delivery infrastructure have changed retail food landscapes. Nonetheless, the danger of labor scarcity due to worker sickness, self-isolation, or movement constraints has

critical consequences and makes FSC more vulnerable. Significantly, in the meat processing and general food packaging industries, the demand has increased substantially [77].

The working atmosphere experiences a complete transformation where most of the work is from home, depending on digital communication and contactless electronic communications. Therefore, the technological inclusions in the food system that have been incorporated, especially in areas such as quality control, verification, and certification, have improved FSC. However, the physical inspection of food items during the packaging and logistics procedures are still facing challenges due to disruptions in the supply-chain footprints [13,78].

Policy guidelines and operations are being amended continuously. There is a greater need to tap and leverage the full capability of IR 4.0 technological tools and protocols to overcome the challenges due to pandemic disruption. Truck routes can be optimized, warehouse locations can be divided and scattered, we could rely on locally grown crops, implement agile and lean methods in agriculture, and most importantly the supply chain footprints should be planned to create supply-chain viability.

6.2. Technology and Food Sustainability

The current scenario necessitates the convergence of appropriate supply-chain systems with industry 4.0 to maintain sustainability. An intelligent food-production system can effectively address challenges in food safety, security, control, and perishability [17]. One of the biggest reasons for the world's existing sustainability challenges might be attributed to the lack of potential to incorporate technological advancements effectively [79].

Given the perishability of food and the importance of food safety in agricultural goods, a better technology-driven strategy is required at every stage of the food supply chain during processing and manufacturing to avoid waste and assure high-quality end products [17,80]. To bolster these facts, Belaud et al. (2019), [81] developed a big-data integrated food supply-chain design for the bioconversion of lignocellulosic biomass, creating environmental sustainability in the agricultural waste valorization domain. These technologies directly and favorably impact traceability, compliance, and coordination between FSC actors and their adoption-intention decision processes that generate scalable, interoperable, and cost-effective architecture for supply-chain integration and sustainability [82].

6.3. Scope for Circularity in Food Supply Chain and Waste Management

Many research projects are focused on reducing food waste. Product deterioration and decomposition were identified as three main sources of food waste during logistics [83–85]. Food organizations are trying to adopt circular economy strategies to improve supply-chain ecological stability. However, from the perspective of underdeveloped nations, the adoption of circular economy and sustainability elements is more complicated than in rich countries. An excellent sustainable strategy shall rewrite poor government policies, lack of technology and practices, and lack of awareness and education. These are among the main obstacles to a successful circular economy-led sustainable supply-chain integration [86].

Green and sustainable supply-chain management methods have emerged in recent decades to incorporate environmental concerns within organizations by avoiding unexpected negative environmental repercussions due to consumption. Parallel to this, the circular economy concept has gained traction in the literature and in practice in industrial ecology. The circular economy pushes the bounds of environmental sustainability by emphasizing the idea of designing the products so that there are viable linkages between ecological systems and product consumption [87].

6.4. Technological Adoption in FSC and Challenges

Effective management of food safety and security, demand and supply shortages, quality of products, and traceability, can bring economic and social progress in the food sector. Technological tools provide viable and protracted platforms to reduce human intervention and error [88]. Reconceptualizing supply-chain design and operations with

the help of digital technologies helps in overcoming the barriers in FSC [89]. However, very little research has been conducted on the factors that affect these technologies' adoption to attain supply chain 4.0. More research into the perceived drivers and hurdles to implementing supply chain 4.0 in the context of FSC is required. The significant challenges and barriers are supply–demand imbalance, rapidly changing customer expectations, legal ramifications, cost optimization, and lack of organizational collaboration [90].

The introduction of blockchain technology resolves many challenges related to food integrity, traceability, and audit [80]. Casino et al. (2021) [4] stated that upstream and downstream supply-chain players are pushed to store and manage traceability-related data to provide proof of regulatory compliance to government authorities. Tian et al. (2017) [50] developed a food supply-chain traceability system for real-time food tracing based on HACCP (Hazard Analysis and Critical Control Points), backed by blockchain and the Internet of Things, which provided an open, transparent, neutral, reliable, and secure information platform for all supply-chain members in FSC. Chen et al. (2017) [91] introduced a unique, intelligent, predictive food traceability with a cyber-physical system coupled with simulation modelling by combining intuitionistic-based fuzzy case-based reasoning with enterprise architecture and value stream mapping. The CPS-based food traceability system was utilized to identify traceable objects that are reactive to a broader range of intelligent food traceability using a novel approach for traceability performance-prediction behavior.

IoT can give concrete and commercial benefits to FSC, hence improving the efficiency and productivity of operational procedures. However, it is increasingly difficult for retailers to adapt their marketing strategies to shifting consumer behavior as the food retailing industry becomes more complicated and flexible. Internet of Things (IoT) is intended to assist businesses in checking the quality of food products, planning waste management for things beyond their shelf life, managing shop temperatures and other equipment that reduces energy use. As a result, the adoption of IoT is currently in infancy, despite its enormous potential [57]. Cyber-physical systems (CPS) have now been introduced to take care of food traceability from a future internet perspective to display intelligent behavior such as smart predictive business practices in the FSC. Nonetheless, the CPS-based food traceability system faces several new issues, including communication efficiency, heavy capital investment, and system architecture requirements [91].

6.5. Role of Technology in Food Relationship Strategies

Horizontal collaboration and relationship policies between FSC players are the need of the hour, where there are very minimal supply chain footprints and routes, especially during this COVID-19 pandemic. Therefore, proper collaboration and cooperation strategies in food supply chains can improve resource usage and market governance. Furthermore, they can assist in enhancing the FSC resilience and all three different dimensions of sustainability [92,93]. Effective relationship strategies through horizontal and vertical collaborations improve cost and quality in FSC [94,95].

Designing processes to jointly reap the benefits via developing goals and also investing in capabilities and assets are very essential. Technological implementation will ease the planning and goal-sharing setup in FSC. State-conflicting goals should be avoided by framing better relationship strategies. Blockchain-based smart contracts in the food supply chain and IoT-assisted big-data cloud technology can help overcome this challenge by setting up secure contracts between stakeholders and increasing FSC integrity [96].

The blockchain smart contract would have an RFID identifier preinstalled that would retrieve information on the area, state, nation, time related to product packaging, storing, transportation, and product quality. An ID tag is a setup in the RFID label that would be integrated with the blockchain to store permanently immutable information for secured time-stamped transactions. Collaboration and establishing business contracts among the food supply-chain players to incorporate food relationship strategies is eased by this protocol [97].

Furthermore, technological platforms can be shared between competitors to enable an effective downstream horizontal collaboration through mutual trust and benefit sharing [98].

6.6. Food Supply Transformations through Technology

Achieving food-system sustainability is a global concern, especially knowing how in-parallel food supply transformation could be accomplished. The practically feasible role of technology and human engagement with agricultural systems are pondered to streamline this food supply-chain transformation. Food sustainability, integrity, traceability, safety, waste management, and pandemic disruptions are major elements in the FSC to be considered for transformation and more resilience [12,99,100].

Technology adoption in FSC creates transformation both in the quality and safety of food products. Moreover, technology has been adopted to improve resource efficiency and productivity in food systems. This has reduced agricultural raw material inputs to reduce environmental externalities. Many farms across the world are applying big data and data analytics in equipment maintenance, field mapping, and other operational activities to optimize irrigation to improve the productivity of agricultural practices. Additionally, digital-twin technology-based geographical information systems (GIS) are adopted to perform precision agriculture that allows the utilization of sensors to optimize the use of pesticides, fertilizers, and water. Moreover, other decision support systems help farmers to maximize production efficiency while minimizing production costs and the environmental footprint of their operations. These aspects serve as a building block for the transformation of food systems [101].

7. Future Research on Technological Inclusions for Food Supply-Chain Transformation and Innovation

After a systematic literature review and bibliometric analysis, authors have accumulated insights on the future research scope and direction. More research should be focused on innovating agricultural farming, production, and processing with the help of smart supply chains and digital technologies. There are significant research opportunities if artificial intelligence and machine learning are applied to control food transport optimization issues, demand-forecasting, prescriptive shipping technologies for perishable food products, and organizing safety and quality in the food chain. The percentage of customer satisfaction should be kept as a key performance index during the integration of technological tools and FSC. Blockchain-based smart contracts can be built to complete state-of-the-art functional and purpose-driven supply-chain and financial transactions. Moreover, the food supply chain needs to be strengthened more from all three facets (food quality, safety and sustainability) in order to fight the COVID-19 pandemic disruptions. Additionally, IoT-assisted big data can build horizontal collaborations that improve food relationship strategies.

Government policies, approvals, and audits can be digitalized using the blockchain and IoT to increase FSC resilience. Blockchain platforms can also create traceability certificates capturing all the supply chain footprints. Cyber-physical systems can directly help in food processing and packaging in this and next decade, where fewer human interactions are desired due to the pandemic. The quality of the FSC from a micrologistics perspective can be improved using cyber-physical systems and smart robotics in the food processing and packaging area. Blockchain and big-data-driven technology can assist farmers in practicing responsible procurement to maintain sustainability standards, both environmentally and economically. A complete food supply transformation-based operational paradigm is shown in Figure 8. After a detailed review of the dataset, the authors propose related technological interventions that are required at different stages of the FSC. It displays barriers and challenges at the different echelons of FSC and the technology tools that can be applied to overcome them and create scalability for more supply chain 4.0 drivers in FSC.

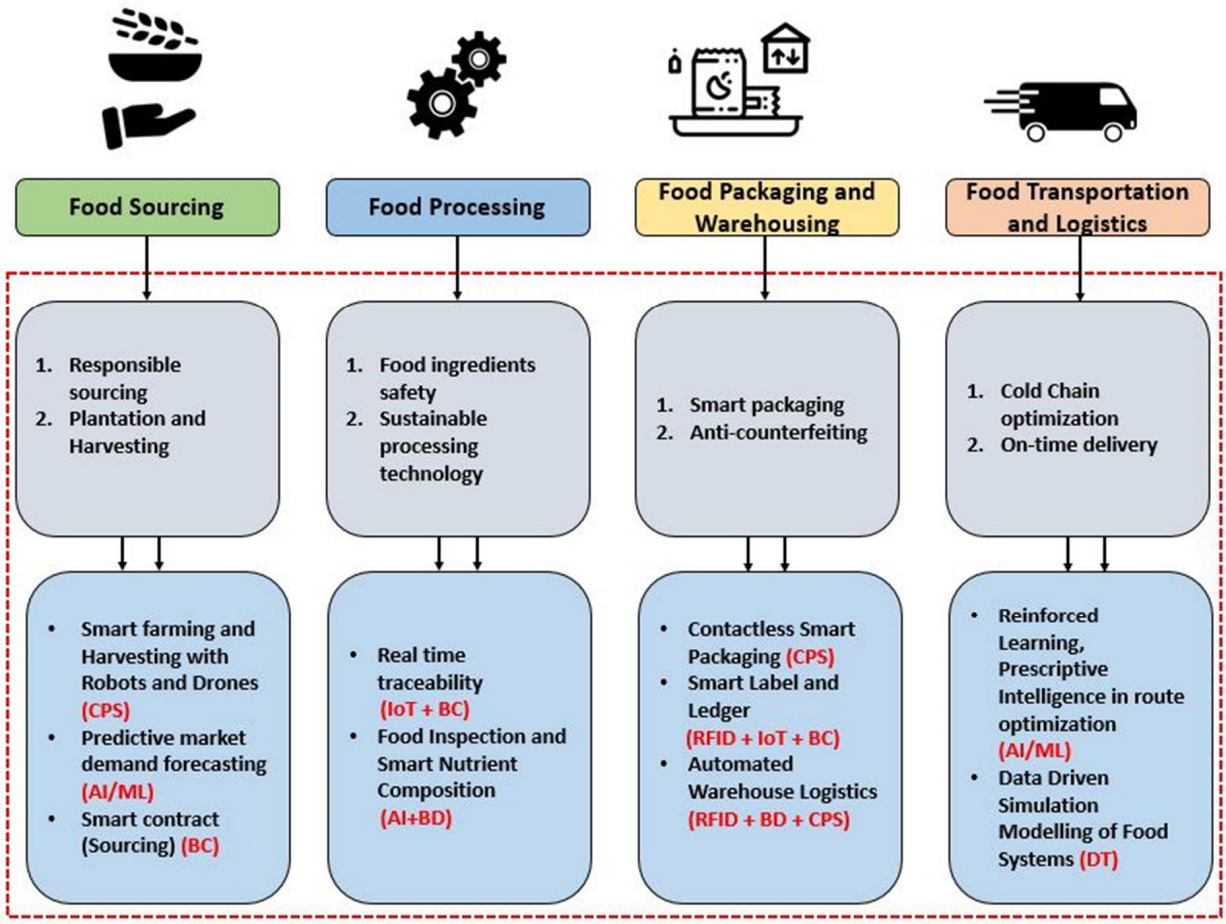


Figure 8. Food Supply Chain 4.0 Operational Paradigm.

The costs associated with FSC such as logistics, freight, energy, fuel, workforce, and capital investment in technology should be kept to a minimum to suppress the bullwhip effect in the chain. IoT-assisted big data can help in this aspect by creating cost patterns in the data warehouse and showing the predictive and prescriptive solutions for better decision making using machine-learning algorithms. In addition, a high level of quality and safety is needed for final food products at all times, both globally and locally. Enhancing the visibility and interaction in the FSC, a business can witness significant gains.

8. Conclusions

This study aimed to systematize the previous literature on FSC and the application of IR. 4.0 tools, and review how the past research has been focused on counteracting the disruptions in FSC. More problems need to be addressed regarding how to effectively integrate one or more tools to reap maximum benefits. Very few studies have applied blockchain (integrity, security), artificial intelligence and machine learning (error-free prescriptive platform), digital twin, or cyber-physical systems within the scope of the study. Additionally, there is a need to build more digital support systems for FSC to improve decision making, especially within pandemic conditions.

More studies must be focused on avoiding food wastage. However, technical failures in the supply chain eventually result in food waste. The cost of monitoring suppliers makes it difficult for retailers to embrace new and innovative suppliers. More modern automation in food systems has piqued the interest of food manufacturers regarding long-term investment. Unquestionably, the impending food catastrophe cannot be cleared overnight. The apparent benefit of digitization is that it helps to reduce waste that could otherwise be avoided. When one out of every three freight journeys is for food, generating

better real-time data to enhance routes and distribution planning is critical. Furthermore, by utilizing digital and automation technologies, food loss may be avoided and costs can be drastically reduced. When real-time data is used with a variety of sustainable indicators, businesses may drastically cut yearly energy utilization.

Future research should be aimed at improving the level of digitalization, marching towards strong traceability systems that can control food advocacy, source, and safety during this pandemic, where counterfeiting and adulteration can more common than usual. Moreover, digitalization offers a complete audit trail of trustworthy information that enables the supplier to enter the supply chain with the capacity to validate the quality of the production and the procedures at all stages, from farm to retailer. More research should be focused on traditional food procurement methods that have spawned both consumer expectations and misconceptions. Consumers should be more informed and educated about food quality and its health consequences. The use of technological instruments reduces waste in FSC, strengthens its resilience, and increases viability. The changing end-to-end business model relies mainly on revolutionary innovation in the food sector. Food safety and advocacy will improve as a result of embracing digitalization, allowing the market to democratize accessibility and experiment. All of this is possible due to the industry's automation, increased efficiency, improved consumer knowledge, and support for important food production and consumption changes.

Furthermore, achieving transformation in the food system would need a significant shift in attitudes, as well as the roles and duties of public sector actors versus corporations in determining food demand. This can be achieved by properly planning horizontal collaboration protocols in FSC. Economic development, human health, and planetary health are all dependent on food systems, and getting all three right is critical. They are intertwined and have a significant impact on one another. Every nation must conceive prospective future possibilities in which everyone consumes adequately, based on food systems that are ecologically, economically, and socially viable. Local and national perspectives on how such food systems would appear in their higher prevalence should guide policy goals intended to achieve long-term transformation.

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