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Article

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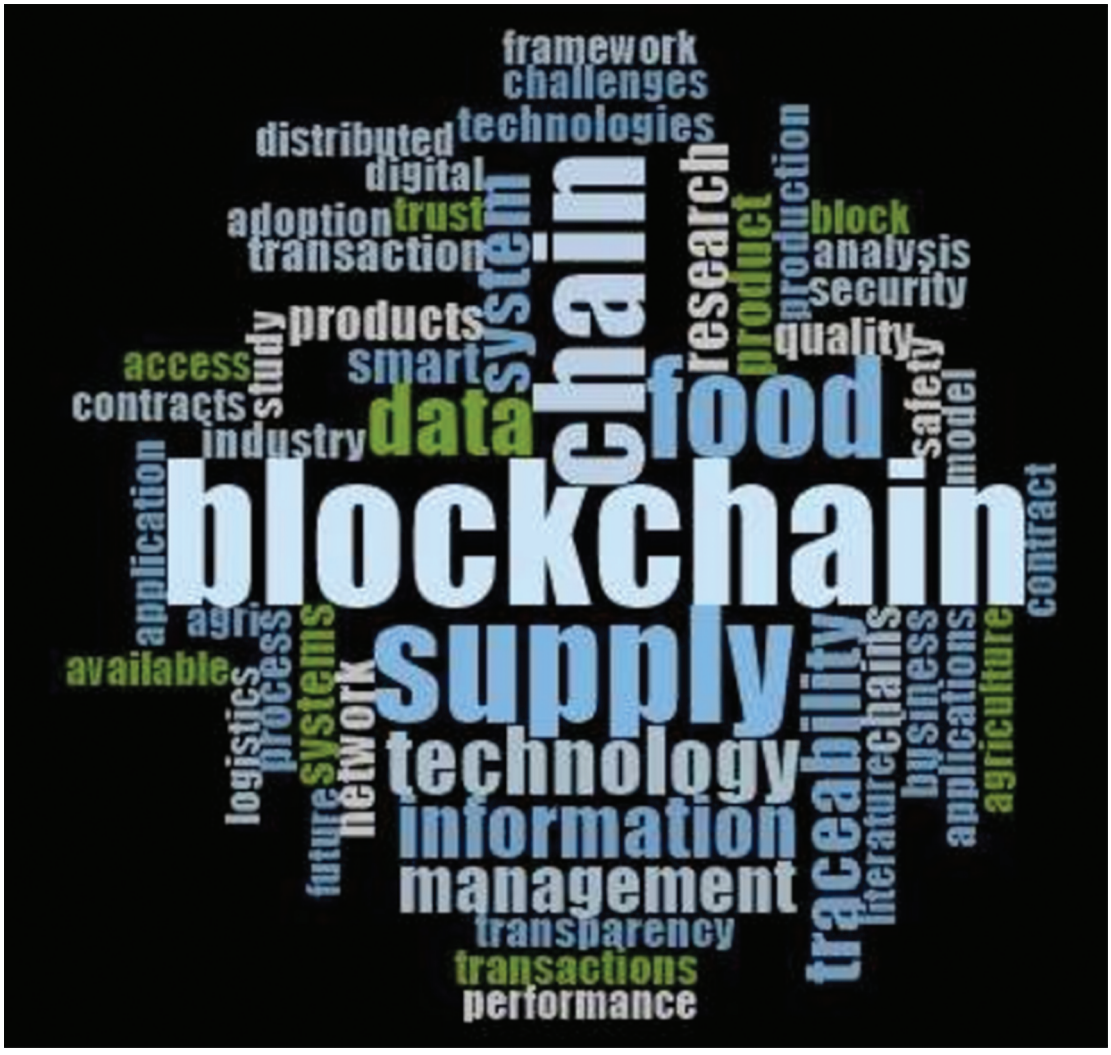

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OPERATIONS, INFORMATION & TECHNOLOGY | REVIEW ARTICLE

How might blockchain technology be used in the food supply chain? A systematic literature review

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Abstract: The complexity of the food supply chain necessitates the implementation of traceability systems. The traceability system optimized the food supply chain management. Blockchain technology promises a new distributed ledger, which provides various uses by solving several traceability issues. Unfortunately, the present study does not completely address the use, opportunities, and challenges of blockchain technology in the food supply chain. Therefore, this study investigates the general knowledge regarding blockchain technology (the concept, features, and type of blockchain) and its use in the food supply chain. The findings of this study assist in gaining a better understanding and information regarding how to strengthen the traceability system in the food supply chain by optimizing the use of blockchain technology. The findings confirmed that the use of blockchain technology in the food supply chain was primarily for traceability, with public/private blockchain assisting as a popular platform. The transaction data is about the product origin information, transaction information, and product label information. The use of blockchain in the food supply chain has the benefit of enhancing food supply chain traceability and transparency. The challenges are the need for significant financial, human resources, and infrastructure investment, limited technical knowledge of stakeholders, significant product changes, the rapid development of the global supply chain, the potential for data manipulation, and policy change.

Subjects: Supply Chain Management; Industrial Engineering & Manufacturing; Information Technology

Keywords: blockchain; food supply chain; technology adoption; traceability; transparency

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JEL classification: Operation Management; Information & Technology Management

1. Introduction

The world is coming together to fulfill similar requirements and improve mutual objectives. Furthermore, ensuring the privacy, safety, validity, reliability, and integrity of each entity and process is essential (Tiwari, 2020). The food supply chain is so complex that traceability systems should be developed. The term traceability is not far from transparency. Traceability and transparency strengthen the food supply chain management, enhance consumer connections, increase efficiency, and minimize the risk and cost of product returns, product loss, and fraud in the food supply chain (Astill et al., 2019; Chan et al., 2019; Galvez et al., 2018). Many technological providers offer traceability system platforms, such as Artificial Intelligence, barcodes, Big Data, Cloud, Internet of Things (IoT), Machine learning, Radio Frequency Identification (RFID), Quick Response (QR) codes, wireless sensor networks (WSNs), and blockchain. Blockchain technology has generated a variety of exposure to optimize supply chain management (Kouhizadeh et al., 2021). Blockchain was initially created by Nakamoto (2009) as a platform for permissionless electronic transactions. The platform includes a network of peer-to-peer that uses proof-of-work to maintain an open record of transactions that assume genuine nodes control the majority of computational resources, rapidly becoming very difficult for an attacker to alter. Blockchain demonstrates how distributed systems can be used to access publicly available information. It provides security with certain features, such as decentralization, immutability, security, and smart contracts to decrease counterparties. Blockchain has been the subject of extensive research. It creates secure information platforms to address issues in the economy and business, society, and politics. Moreover, this platform has been widely adopted by several sectors, such as trade (Yoon et al., 2020), banking (Hassani et al., 2018), healthcare (Attaran, 2022), and logistics and transportation (Koh et al., 2020).

There have been many studies on how blockchain technology could be used in the supply chain (Bai & Sarkis, 2020; Chang et al., 2020; Kouhizadeh et al., 2021; Mahyuni et al., 2020; Saberi et al., 2019). The blockchain in the food supply chain involves all parties. Food traceability is at the forefront of current food safety issues, given recent developments in blockchain technology (Tiwari, 2020). The traceability of food is identical to perishable food. Through traceability, detailed information about food products can be obtained from upstream to downstream. Traceability has become a critical system for maintaining product quality throughout the food supply chain. The traditional framework for tracing systems is time-consuming and more susceptible to hacking, privacy breaches, data manipulation, and fraud (Westerlund et al., 2021). Blockchain is an innovative distributed ledger technology with many potential applications, particularly in supply chain management (Sunny et al., 2020). Therefore, blockchain improved the traditional system by solving several traceability issues.

Since blockchain is recognized as a potential advanced technology, there are significant research gaps due to a lack of studies on its development and implementation in the food supply chain. There is a lack of information about how blockchain technology may be utilized to optimize the traceability system in the food supply chain. Therefore, as a result, the objective of this study is to address these substantial research gaps by answering the following key questions:

What is the fundamental concept of blockchain technology (definition, features, and platform type)?

What are the differences in how blockchain technology is used according to the recently developed model, sector, platform type, and transaction data?

What are the opportunities and challenges of using blockchain technology in the food supply chain?

Therefore, this study explores the blockchain technology fundamental concepts, identifies the use of the blockchain in the food supply chain, and highlights the opportunities and challenges of adopting blockchain-based traceability systems. This study assists practitioners and academics by providing information on the use of blockchain technology along with key factors in developing and implementing the technology to enhance the performance of the food supply chain.

The paper has the following structure. Section 2 outlines the research methodology, and Section 2.2.3 includes a literature review of the fundamental concept of blockchain technology. Section 2.2.4 presents an analysis of the use of blockchain technology based on the recently developed model, sector, platform type, and transaction data, along with the opportunities and challenges in developing the technologies. Section 5 includes conclusions and future research opportunities.

2. Methodology

This study undertakes a comprehensive systematic literature review to investigate the development and use of blockchain technology in the food supply chain. This systematic literature review was carried out using Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) reporting guidance. This study follows numerous phases outlined (Cagigas et al., 2021; Handayani et al., 2018; Liberati et al., 2009; Tamara & Tahapary, 2020; Tan & Taeihagh, 2020): 1) setting eligibility criteria; 2) search strategy; 3) study selection; 4) data collection; and 5) coding. Figure 1 demonstrates the procedures involved in conducting a systematic literature review.

2.1. Eligibility criteria

The following criteria for inclusion are original and review articles written in English; subjects concerning traceability systems in food supply chains; basic information about blockchain (definition, features, and platform type); studies on using blockchain technology and their integration with other traceability system platforms, opportunities, and challenges to implementing the technology.

Exclusion criteria include scientific studies that did not specifically cover blockchain technology. Non-conference or journal-published articles/papers include master and doctoral dissertations, books, blogs, and other informal literature assessments. Other than English-language publications, none of the articles were selected.

2.2. Searching method

A systematic search for scientific information from the literature was employed to categorize all published articles on the study's relevant topic. The primary terminology's synonyms, acronyms, and alternative words are listed. The keywords and synonyms were collected from the current literature on blockchain and food supply chains. The main keywords and their synonyms were synthesized using the "OR" and "AND" operators to generate the search strings relevant to the primary studies.

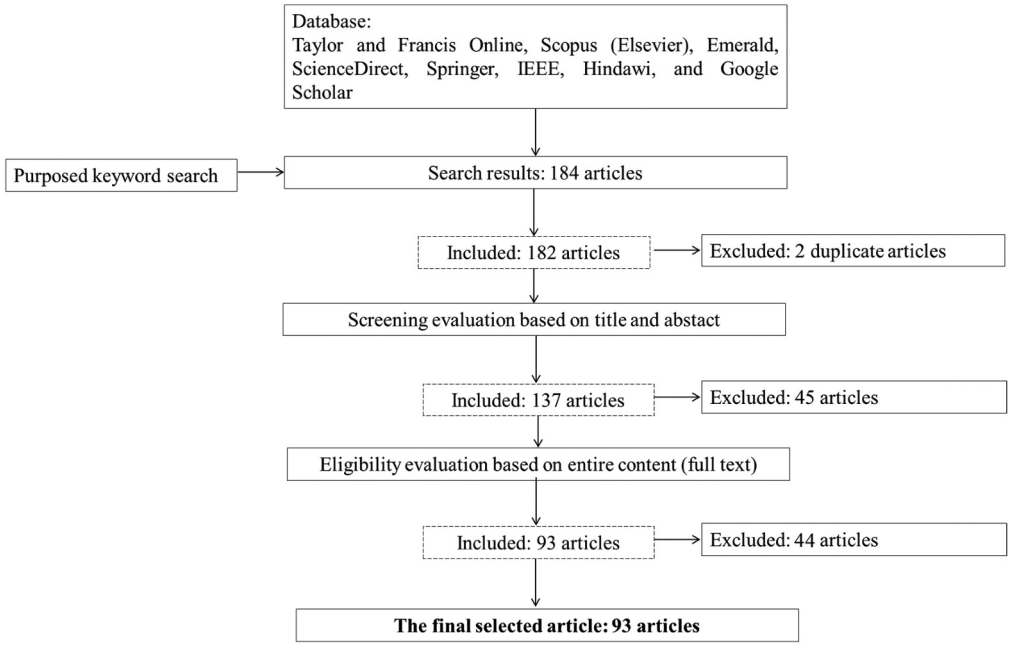
The following is the list of keyword searches or search strings:

1. Traceability system in the food supply chain

Traceability" (including terms such as "Traceability" OR "traceability system" OR "tracing system) AND "food supply chain. ("food supply chain" OR "agri-food supply chain" OR "food and agriculture supply chain" OR "agriculture and food supply chain" OR "agricultural food supply chain" OR "product supply chain")

2. Blockchain

Figure 1. Study selection procedure.



The fundamental concepts of blockchain consist of definitions, features, and types of platforms, therefore the keyword search related to:

(A) Definition: "Blockchain" (including terms such as "Blockchain" OR "blockchain technology")

(B) Blockchain features: "Blockchain" (including terms such as "Blockchain" OR "blockchain technology") AND "feature"(including terms such as "feature" OR "features" OR "characteristics" OR "attributes" OR "elements")

(C) Blockchain platform: "Blockchain" (including terms such as "Blockchain" OR "blockchain technology") AND "platform" (including terms such as "platform" OR "platforms" OR "network" OR "networks" OR "architecture" OR "architectures")

3. The use of blockchain in the food supply chain

The use of blockchain" (including terms such as "The use of blockchain" OR "the use blockchain technology" OR "blockchain adoption" OR "blockchain technology adoption" OR "adoption of blockchain" OR "adoption of blockchain technology" OR "blockchain implementation" "blockchain technology implementation" OR "implementation of blockchain" OR "implementation of blockchain technology" OR "blockchain application" OR "blockchain technology application" OR "application of blockchain" OR "application of blockchain technology") AND "food supply chain. ("food supply chain" OR "agri-food supply chain" OR "food and agriculture supply chain" OR "agriculture and food supply chain" OR "agricultural food supply chain" OR "product supply chain")

4. Opportunities-challenges of blockchain use in the food supply chain

The key driver in developing and implementing blockchain in the food supply chain consists of opportunities and challenges, therefore the keyword search related to:

(A) Opportunities: "opportunities" (including terms such as "opportunities" OR "benefits" OR "advantages" OR "utilization") AND "The use of blockchain" (including terms such as "The use of blockchain" OR "the use blockchain technology" OR "blockchain adoption" OR "blockchain technology adoption" OR "adoption of blockchain" OR "adoption of blockchain

technology" OR "blockchain implementation" "blockchain technology implementation" OR "implementation of blockchain" OR "implementation of blockchain technology" OR "blockchain application" OR "blockchain technology application" OR "application of blockchain" OR "application of blockchain technology") AND "food supply chain" ("food supply chain" OR "agri-food supply chain" OR "food and agriculture supply chain" OR "agriculture and food supply chain" OR "agricultural food supply chain" OR "product supply chain").

(B) Challenges: "challenges" (including terms such as "challenges" OR "difficulties" OR "disadvantages" OR "obstacles") AND "The use of blockchain" (including terms such as "The use of blockchain" OR "the use blockchain technology" OR "blockchain adoption" OR "blockchain technology adoption" OR "adoption of blockchain" OR "adoption of blockchain technology" OR "blockchain implementation" "blockchain technology implementation" OR "implementation of blockchain" OR "implementation of blockchain technology" OR "blockchain application" OR "blockchain technology application" OR "application of blockchain" OR "application of blockchain technology") AND "food supply chain" ("food supply chain" OR "agri-food supply chain" OR "food and agriculture supply chain" OR "agriculture and food supply chain" OR "agricultural food supply chain" OR "product supply chain").

Researchers should determine to what extent the article is up to date. An article based on a search that is more than 5 years will most likely be out of date (Lund et al., 2021). Therefore, the literature is selected based on the most recent, compatible, relevant, and related works published between 2018 and 2022. The history of blockchain can be explored in one exceptional article about the blockchain's origins that was published in 2009. The article collection was mainly concentrated on online resources with substantial repositories of scholarly works, including Taylor and Francis Online, Scopus (Elsevier), Emerald, ScienceDirect, Springer, IEEE, Hindawi, and Google Scholar.

2.3. Study selection

The initial search was conducted using the search strings, and all studies were gathered in Mendeley. First, duplicates were eliminated; two duplicate articles were discovered. As a result, the screening process is divided into two stages: screening evaluation and eligibility evaluation. Using the criteria for what to include and what to leave out, the titles and abstracts of the remaining studies were looked at to see if they were relevant. This method resulted in the collection of 137 articles. The eligibility evaluation was performed based on the entire text of all articles that fulfilled all of the inclusion and exclusion criteria. The final selected article was collected at 93 after the substance of these articles was further evaluated to assess their compliance with the criteria of this study. The study selection procedure is presented in Figure 1.

2.4. Data synthesis process

The NVivo 12 software was employed in this study to produce a systematic literature review. NVivo 12 simplifies information extraction and data synthesis (Cagigas et al., 2021). NVivo data synthesis consists of data, conceptual coding, themes, and dimensions (Meneguel et al., 2022). Researchers can incorporate classification criteria in NVivo based on existing field knowledge, such as word counting, cluster analysis, and other relational tools. A word cloud was employed in this study to quantify the most relevant concepts in the literature. A world cloud is presented to interpret the word frequency of the selected articles. To further organize the data synthesis process, various classifications were also developed.

The first step in categorizing each article was to list its general details, such as the title, author, publishing type, and year. The next step was developing coding systems to identify general information about the food supply chain, traceability, and traceability systems in the food supply chain. The fundamental ideas of the blockchain (definition, features, and platform types), followed by the opportunities-challenges of blockchain use in the food supply chain. The word cloud generated by NVivo 12 for the systematic literature review is shown in Figure 2. The words are

Figure 2. Word cloud.

the most commonly cited word, then we eliminated the irrelevant word and limited the number of words to 25. “Blockchain”, “food supply chain”, and “technology” is the top three cited words.

3. Results and discussion

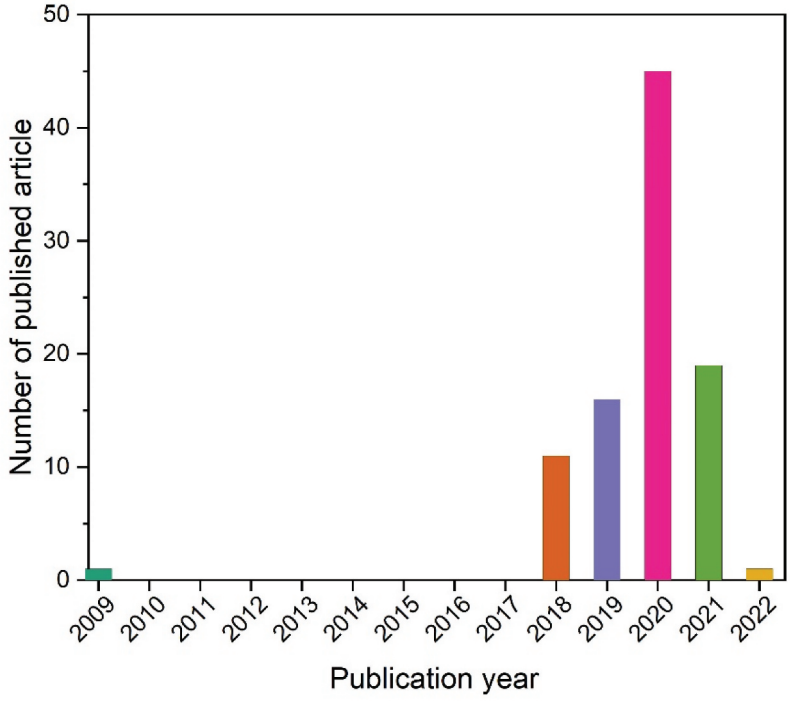
3.1. Study characteristics

The study characteristics describe the demographic information of 93 selected articles. The identification is based on the distribution of literature sources by year, type of study, type of article, and sources of selected studies. Figure 3 shows the distribution of literature sources by year in this study. The results of this study show that if articles are dominated by publications in 2020, this indicates the topic relevant to the application of blockchain technology inside the food supply chain emerging global interest during that year.

Figure 4 displays the distribution of articles according to the type of study. The type of study is classified into two groups: literature reviews and framework models & case studies. The result shows that the literature review dominated the selected article. Figure 5 shows the distribution based on the type of article. The sources of selected studies are shown in Table 1. The type of article is classified into three groups: journal, proceedings, and a book chapter. Figure 5 and Table 1 show that most international journals incorporate studies of the use of blockchain technology in the food supply chain. This study involves 86 journals, 3 proceedings, 3 book chapters, and 1 thesis. The detailed database records can be seen in Table 1.

The conception of a traceability system in a food supply chain is identified in this initial review. This section describes the current state of the food supply chain, which is rapidly demanding a traceability system, which is discussed first, then an overview of the traceability system in the food supply chain.

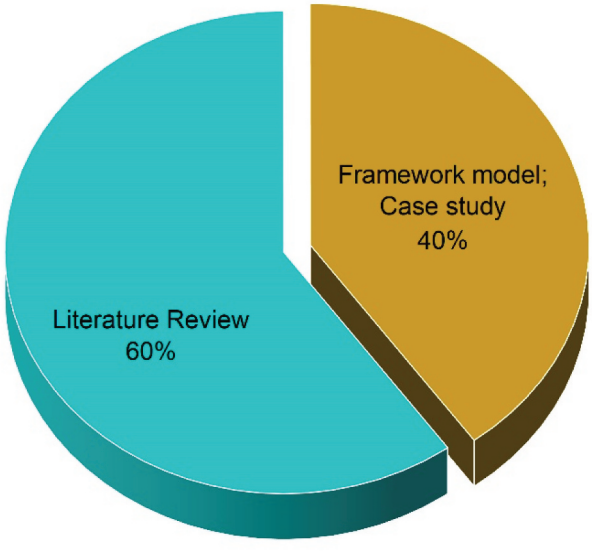
Figure 3. Literature source distribution.



3.2. Food supply chain

Due to the wide range of geographical inconsistencies, product diversification, and business strategy variations, the supply chain has become increasingly complex (Yadav & Singh, 2020), especially the food supply chain (Haji et al., 2020). The rapidly increasing demand for food supply caused complexity (Abdullah et al., 2021). Food supply chains are a complicated framework that includes all agricultural upstream and downstream sectors, with many suppliers, companies, distributors, retailers, and customers (Casino et al., 2020; Fortuna & Risso, 2019). Due to perishability, the food supply chain is more complicated (Yadav et al., 2020). Each food product requires a different supply chain (Duan et al., 2020). Products and information flows must be handled in terms of schedule, quantity, quality, and other factors depending on several processes involving

Figure 4. Type of study distribution.



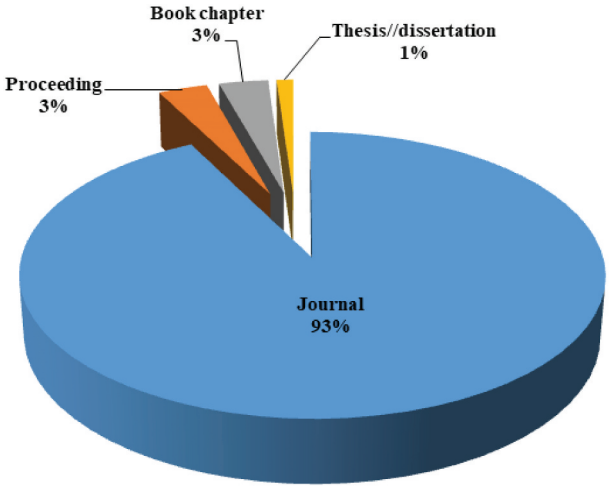


Figure 5. Type of article distribution.

one or more different companies at each level (Kramer et al., 2021; Rejeb, 2018b). Simultaneously, traceability systems provide numerous benefits as the high demand for safe and quality food increases (Demestichas et al., 2020). Moreover, this system is greatly required by suppliers, companies, stakeholders, and consumers (Kasten, 2018; Khan et al., 2020).

Traceability displays information about a food's total life cycle (Shahbazi & Byun, 2021). As a consequence, incorporating a traceability system into the food supply chain is of the utmost importance. Because of their distinct requirements, several firms along the food supply chain are frequently unwilling to share traceability information with others (Behnke & Janssen, 2020; Gao et al., 2020). On the other side, transparency and traceability help to improve food supply chain management (Chan et al., 2019). Transparency improves foodborne illness detection, risk management, mitigating contamination sources, and maintaining consumer demand in the global food supply chain (Astill et al., 2019; Galvez et al., 2018). Traceability and transparency also improve consumer interactions, increase efficiency, and reduce the risk and cost of product returns, fraud, and product loss for food supply chain stakeholders (Bumblauskas et al., 2020).

3.3. Traceability

3.3.1. Definition

Traceability is an important technique for collecting information about all supply chain member's backgrounds, positions, and operations (Agrawal et al., 2018; Astill et al., 2019). Traceability relates to tracking and tracing (Sunny et al., 2020; van Hilten et al., 2020). Data transparency, fraud, and vulnerable information sharing are all limitations of traditional traceability systems. Current traceability systems follow one of two systems, i.e., centralized or decentralized (Lin et al., 2019). A centralized traceability system is handled and operated by a trusted third party; it is prone to a single network hack and is more vulnerable to data manipulation and information leakage. A decentralized traceability system can assist in creating and distributing transparent data sets (Gao et al., 2020; Lin et al., 2019; Sunny et al., 2020).

The security systems sector manages traceability-related information to ensure safety, regulatory compliance, a better understanding of a product's life cycle, and sustainable consumption; one example is the food supply chain (Casino et al., 2019, 2020; Westerlund et al., 2021). The characteristics and conditions of food keep changing during the food circulation process in the food supply chain (Gao et al., 2020). The food supply chain traceability system players are suppliers, companies, distributors, retailers, customers, and governments (Casino et al., 2020; Lin

Table 1. Sources of selected studies

Type of article	Database of records	N
Proceeding	2019 IEEE 30th Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC)	1
	2019 IEEE Intl Conf on Dependable, Autonomic and Secure Computing, Intl Conf on Pervasive Intelligence and Computing, Intl Conf on Cloud and Big Data Computing, Intl Conf on Cyber Science and Technology Congress	1
	IFAC PapersOnLine	1
Journal	Acta Scientiarum Polonorum. Oeconomia	1
	Acta Technica Jaurinensis	2
	Applied Sciences	1
	Asian Journal of Economics, Business and Accounting	1
	Blockchain and Supply Chain Management	1
	Britain International of Exact Sciences (BIoEx) Journal	1
	British Food Journal	1
	Cluster Computing	1
	Cogent Business & Management	1
	Computer Aided Chemical Engineering	1
	Computers & Industrial Engineering	2
	Computers and Electronics in Agriculture	1
	Decision Sciences	1
	Electronics	1
	Expert Systems with Applications	1
	Food Control	1
	Foods	1
	Frontiers in Blockchain	1
	Future Generation Computer Systems	1
	IEEE Access	5
	IEEE Internet of Things Journal	2
	Information	1
	Information Systems and e-Business Management	1
	International Food and Agribusiness Management Review	1
	International Journal of Advanced Computer Science and Applications	1
	International Journal of Applied Evolutionary Computation	1

(*Continued*)

Type of article	Database of records	N
	International Journal of Blockchains and Cryptocurrencies	1
	International Journal of Computational Science and Engineering	1
	International Journal of e-Collaboration	1
	International journal of environmental research and public health	2
	International Journal of Healthcare Management	1
	International Journal of Information Management	3
	International Journal of Logistics Research and Applications	2
	International Journal of Machine Learning and Cybernetics	1
	International Journal of Management Studies	1
	International Journal of Production Economics	1
	International Journal of Production Research	6
	International Journal of Productivity and Quality Management	1
	Journal of Business Research	1
	Journal of Cleaner Production	4
	Journal of Enterprise Information Management	2
	Journal of Food Quality	1
	Journal of Information Security and Applications	1
	Journal of Management Analytics	1
	Journal of the Science of Food and Agriculture	1
	Logistics	1
	Operations Management Research	1
	Production Planning & Control	2
	Robotics and Computer-Integrated Manufacturing	1
	Sensors	1
	SSRN Electronic Journal	2
	Supply Chain Management: An International Journal	2
	Sustainability	4
	Symphonya. Emerging Issues in Management	1
	Technology Innovation Management Review	1

(*Continued*)

Table 1. (*Continued*)

Type of article	Database of records	N
	The Journal of the British Blockchain Association	1
	TrAC Trends in Analytical Chemistry	1
	Transportation Research Part E: Logistics and Transportation Review	2
	Trends in Food Science & Technology	1
	The Journal of the British Blockchain Association	1
Book chapter	SMART Supply Network	1
	Artifical Intelligence for Fashion Indusry in the Big Data Era	1
	Bitcoin: A peer-to-peer electronic cash system	1
Thesis/dissertation	Master's thesis	1
	Total	**93**

et al., 2019). The food supply chain traceability system's key characteristics include identifying all items and material units/batches, tracking when and if they are transported and transformed, and connecting all data (Casino et al., 2019; Ling & Wahab, 2020). An efficient food supply chain traceability system comprises quantitative and qualitative information regarding the material and end product to provide safe and superior products, hence enhancing brand reputation and customer trust (Demestichas et al., 2020; Gao et al., 2020; Kamble et al., 2020). Temperature, power, storage, and light are the most commonly measured parameters in traceability, particularly for real-time product tracking in food supply chains (Zhang et al., 2019).

3.3.2. Traceability system in the food supply chain

Given the present food supply chain's complexity, traceability promotes transparency and safety (Demestichas et al., 2020). Such real-time, robust, and comprehensive data sources support traceability, which increases food supply chain transparency, extends shelf life, reduces environmental impact, and increases customer trust and loyalty (Gao et al., 2020; Westerlund et al., 2021). Several technologies have this feature, i.e., Artificial Intelligence, barcodes, Big Data, Cloud, Internet of Things (IoT), Machine learning, QR codes, Radio Frequency Identification (RFID), wireless sensor networks (WSNs), and Blockchain (Demestichas et al., 2020; DiVaio et al., 2020; Helo & Shamsuzzoha, 2020). However, the widely used technologies are Big Data, the Internet of Things (IoT), Machine learning, Radio Frequency Identification (RFID), and Blockchain. These technologies help protect customers and maintain the quality of the food supply chain (DiVaio et al., 2020; Haji et al., 2020).

Big Data is able to display information from data that humans might otherwise miss. Big Data has the potential to strengthen food supply chains in a variety of ways. For example, A foodborne sickness's early stages may be detectable using Big Data, allowing for early intervention to stop the spread of the illness (Astill et al., 2019). In addition, Big Data helps companies obtain accurate and timely demand information within the food supply chain management (Liu et al., 2020).

Machine Learning (ML) focuses on developing and applying computer algorithms that "learn" through experience. ML is recognized for researching ways to learn directly from data and figure out how to use computers to solve issues. ML can resolve issues and reveal potential relationships between a supply chain's complexity and the likelihood of potential disruptions (Ni et al., 2020). ML is utilized to appropriately and effectively use a variety of data sources obtained at various supply

chain stages (Saurabh & Dey, 2021). The majority of ML approaches have been used to assess the system's prediction. A valid and accurate prediction model is a crucial aspect of decision-making and analysis. As a result, ML models were used, and all processed datasets were saved in a cloud database for time stamping and traceability identification (Shahbazi & Byun, 2021).

With thousands of connected computers and networks, cloud computing is a potent computing technology that transfers computational activities to a distant data center to distribute resources. Cloud computing has become the subject of information sharing in food supply chain systems in information security and protection. The cloud computing platform made it possible to get access to valuable information on-demand for purchasing, managing retail shelves, sales, and management tasks (Zhang et al., 2019).

IoT is widely considered one of the most significant future technology areas, and it is getting considerable attention from a range of sectors. The food supply chain is at the forefront of IoT adoption in tracking shipments and re-route products in real-time (Helo & Shamsuzzoha, 2020; Yadav et al., 2020). IoT also assists in connecting devices and sensors attached to delivery items (Helo & Shamsuzzoha, 2020). IoT and sensor technologies support data collection by providing consistent and efficient solutions (Khan et al., 2020; Misra et al., 2020). Furthermore, IoT is also used for technology of product identification, material inspection, shipment, and storage. Data acquisition throughout this system integration is among these techniques (Demestichas et al., 2020). Traceability would be improved as a result of the integration of the Internet of Things (IoT) with supply chains, particularly in the food and cold chain industries (Zhang et al., 2019).

Among supply chains, RFID is the most widely used and well-known technology (Demestichas et al., 2020). RFID transmits data or information in real-time (Mondal et al., 2019). RFID technology collects data from different sensors attached to delivering goods. RFID technology tracks supply and transport products and establishes real-time shipment status information (Helo & Shamsuzzoha, 2020). RFID tags are attached to products or shipping containers along the supply chain to collect tracking information (Dong et al., 2020). RFID has previously been used to ensure food safety and increase traceability in the food supply chain because of its low cost and small size. Temperature sensor tags based on RFID are widely used in cold food supply chains. Tags equipped with sensors monitor the temperature of food items in storage or transit, allowing for an accurate assessment of their remaining freshness at any given moment (Mondal et al., 2019). The technical overview of the blockchain includes fundamental concepts: definition, features, and type of platforms. It is crucial to comprehend the fundamentals of blockchain technology before concentrating on its use in the food supply chain.

3.4. Blockchain technology

Nakamoto (2009) developed blockchain technology, which was publicized through a peer-to-peer Bitcoin cryptocurrency program (van Hilten et al., 2020). A blockchain is a shared database/ledger of encoded information/digital events accessible by many people. Data is gathered safely, and the authenticity is verified at any point (Astill et al., 2019). Blockchain allows for secure data storage with privacy and control built-in. The primary blockchain principle shows that publicly available information is accessed through distributed systems and provides security (Dong et al., 2020; Kayikci et al., 2020). Decentralized, distributed note and storing procedures, consensus processes, smart contracts, and asymmetric encryption are among blockchain's impressive features (Chen et al., 2020; Dutta et al., 2020; Juma et al., 2019; Tsolakis et al., 2021). Encryption is a key component of blockchain. Cryptography can be used to verify knowledge of important data without disclosing it and confirm the data's validity (Dujak & Sajter, 2019).

The fundamental function of blockchain technology is to record and identify transactions in real time, hence removing the requirement for independent third-party verification (Singh & Singh, 2020; Wang et al., 2019). The expense of acquisition and sensitivity to cyber-attacks and data

manipulation are examples of issues with the current traceability systems that blockchain has the potential to solve (Galvez et al., 2018; Westerlund et al., 2021).

When putting blockchains into place, there are a number of things to think about, such as the size of the technological application, the origin and nature of the activities being targeted, the kind of information to be collected and shared, and the players (Tsolakis et al., 2021). The three levels of blockchain development are blockchain 1.0 driven by currencies, blockchain 2.0 driven by contracts, and blockchain 3.0 which is not related to currency/finance (Tan et al., 2020). Tsolakis et al. (2021) also developed the principle of blockchain application, i.e., data models, data capture, data consistency, and data interoperability.

Blockchain, as a promising new distributed ledger technology, is growing rapidly due to its wide variety of uses, especially in supply chain management (Sunny et al., 2020). Blockchain can transform the fully integrated food supply chains that are managed. This technology also provides transparency, safety, traceability, convenience, and authenticity (Galvez et al., 2018; Kayikci et al., 2020; Kramer et al., 2021; Park & Li, 2021). Furthermore, blockchain significantly alters both information and financial flows that facilitate material flows, allowing for directly optimizing the material flows and increasing exchange based on effective supply chain trust (Dujak & Sajter, 2019).

The key characteristics of blockchain technology that are necessary for its adoption in food supply chains are the safe, validated, and reliable transfer of information in real-time and the potential for auto-verification and execution. These distinctive characteristics emphasize the optimization of the global supply chain (Dujak & Sajter, 2019; Juma et al., 2019). For example, the adoption of blockchain allows for verifying information such as supply origins, food authenticity, and preventing food safety issues. Moreover, all product information is digitally tracked and stored along the supply chain stages (Kittipanya-Ngam & Tan, 2020).

Food safety concerns are now a component of blockchain implementation in the food supply chain. Lin et al. (2019) state that adopting the blockchain should consider the specification, i.e., data accuracy and reliable system. Data on the blockchain has to be as accurate as possible. The system should also ensure the accuracy and credibility of the information submitted, prevent malware threats, ensure the accessibility of the data, and be resistant to manipulation.

3.4.1. Features of blockchain

Blockchain consists of four primary features, i.e., decentralization, security, immutability, and smart contract (Duan et al., 2020; Westerlund et al., 2021; Yadav & Singh, 2020). The features will lead to distributed blockchain systems with reduced counterparties (Kouhizadeh et al., 2021).

The amount of control in a blockchain system is referred to as **decentralization**. Blockchain minimizes limited objectivity, exploitation, and asymmetric information by allowing users to interact directly, ensuring continuous transparency through decentralization, and reducing transaction costs in the food supply chains (Duan et al., 2020; Kramer et al., 2021). A blockchain database is decentralized since its communication data is shared over the ledger and cannot be captured in a single node. The data is dispersed over several computers, referred to as nodes, instead of being stored on a central server. Blockchain uses a public database that enables decentralization. The decentralized database improves the trustworthiness of the users in a blockchain (Kamble et al., 2020). Each node determines its own decision, and then the whole system's activity is the summation of those decisions. Decentralization removes the need for systemic intermediaries, simplifying economic and social interactions (Mukherjee et al., 2021).

Blockchain uses ring signatures to guarantee that users remain anonymous and **data security** without endangering the stakeholder's privacy. An encrypted cryptographic signature is used in blockchain to secure data privacy and safety (Sharma et al., 2020). Furthermore, blockchain

ensures that each node in the network duplicates the transaction, allowing for real-time examination and strengthening transparency in the food supply chain (Mukherjee et al., 2021). Traceability and control can be provided without all participants exposing their customers' and suppliers' privacy to a singular entity in the food supply chain. The system's users can determine the degree of privacy (Dong et al., 2020). The complexity of blockchain networks with more users avoids hacking activities. Blockchain protects records and data, reducing the danger of data theft, and hacking in the food supply chain (Duan et al., 2020).

Immutability describes that something is immutable across time or cannot be changed (Kamble et al., 2020). Data saved in blocks cannot be changed, tampered with, or altered over time (Mukherjee et al., 2021). The blockchain automatically offers immutable data integrity (Dong et al., 2020). Immutability also reduces the necessity of human involvement in records. It indicates that the information is safe and irrevocable (Duan et al., 2020; Mukherjee et al., 2021).

A **smart contract** is a lighter version of a contract developed in the computer language (Khan et al., 2020). Decentralized code implemented on a blockchain node to carry out a certain transaction digitally and moves automatically until those business requirements are met can also be used to define it. The smart contract can significantly accelerate transactions, increase trust, and be implemented with an agreement signed among members (Duan et al., 2020; Etemadi et al., 2021; Mukherjee et al., 2021). Two parties can automate their trade without intermediaries (Khan et al., 2020; Yadav et al., 2020). Furthermore, when a trusted third party evaluates all essential transaction contracts involving two parties, it becomes viable to develop and implement business processes across the organizational border (van Hilten et al., 2020).

Technology allows people to self-verify and fulfill contracts, which is good for how businesses run. Stakeholders should cooperate to come to a consensus to undertake digital supply chain transactions and document exchanges. Consequently, a smart contract is advantageous since it incorporates the terms agreed upon by all parties. Electronic contracts had a significant influence on corporate operations recently. For example, a smart contract is used to digitally transfer an asset or cash into a business technology application (Riahi et al., 2021).

Smart contracts make it possible to track items along the supply chain, keep track of who owns them, and authorize automatic payments (Kramer et al., 2021). In addition, the capability of smart contracts lowers the danger of technical interruptions in the supply chain and fraud, which helps make the food supply chain more efficient (Mukherjee et al., 2021).

3.4.2. Type of blockchain

Blockchain is classified into four categories according to the level of access provided to participants: public, private, consortium, and hybrid (Dwivedi et al., 2020; Feng et al., 2020; Köhler & Pizzol, 2020; Shingh et al., 2020; Wang et al., 2019).

A **public blockchain** is an open network, and the participants do not require permission from a central entity to set up the network. Public blockchain can also be considered a decentralized network (Cao et al., 2021; Dujak & Sajter, 2019; Fortuna & Risso, 2019; Holmberg & Åquist, 2018; Juma et al., 2019; Rogerson & Parry, 2020). The participants can be anonymous and invite other participants to settle into the network (Fortuna & Risso, 2019; Ghode et al., 2020; Wang et al., 2019). Transaction data will be protected and perpetual after it has been validated (Chen et al., 2020; Kramer et al., 2021). The collected data is public, making it easily accessible to all network users. Ethereum and Bitcoin are two popular instances of public blockchains (Cao et al., 2021; Dujak & Sajter, 2019; Dwivedi et al., 2020; Fortuna & Risso, 2019; Ghode et al., 2020).

A public blockchain is advised for entities engaged in crypto economics (Demestichas et al., 2020). Participants obtained public and private cryptographic keys after completing the registration process (Rejeb, 2018a). Considering Proof of Work (PoW) consensus algorithms in a public

blockchain, the Byzantine configuration is required to be taken into account. Unfortunately, it is costly and non-deterministic, so it does not fit the use instances involving reliable management of many transactions (Khanna et al., 2020).

The advantages of public blockchain in the supply chain enable command over a group of participants working on the same level using a decentralized approach without a competent collaborator as an intermediary. Furthermore, public blockchain implementation improves the food supply chain by enhancing transparency to supply chain players, stakeholders, and consumers (Behnke & Janssen, 2020).

A **private blockchain** network requires authorization to operate. Only prequalified parties can operate networks, and most counterparts are clearly stated (Behnke & Janssen, 2020; Chen et al., 2020; Demestichas et al., 2020; Rejeb, 2018a). A private blockchain is classified as centralized regarding authority access, and internal participants manage the blockchain (Dujak & Sajter, 2019; Holmberg & Åquist, 2018; Juma et al., 2019; Lin et al., 2020; Rogerson & Parry, 2020). Numerous organizations implement private blockchain networks to take advantage of while maintaining their integrity. The consensus is controlled singly and hence is comparatively faster than in public blockchain, a commonly used consensus method besides PoW. However, as an outcome, the transaction rates increased (Demestichas et al., 2020; Kramer et al., 2021).

Private blockchain has various practical features that limit visibility while providing a moderate level of security (Rogerson & Parry, 2020). It enables a common repository while still ensuring that private or financially essential data is only shared within the internal system (Wang et al., 2019). Moreover, the system can perform customizable smart contracts (Kumar et al., 2020). Private blockchain also has several non-practical features. The system consumes substantial total energy and should be extensible and enable using a private blockchain. In addition, the data models should be created so that the information flow is transmitted electronically end-to-end (Perboli et al., 2018). Examples of private blockchains include Hyperledger Fabric, Corda, and Ripple-Cryptocurrency (Dwivedi et al., 2020). Private blockchain implementation is in a supply chain where the participants collaborate to manufacture and distribute products. In this context, the certifiers would emerge as the certification providers while maintaining the private network (Saberi et al., 2019).

The **consortium blockchain** is a combination of a private and public blockchain. The model was developed from a private blockchain with permission from participants on the features of a public blockchain system (Gramoli, 2020; Juma et al., 2019; Kramer et al., 2021; Perboli et al., 2018; Rogerson & Parry, 2020). The system of access was managed by a group of participants or individuals (Fortuna & Risso, 2019; Rogerson & Parry, 2020). The characteristics of a consortium blockchain consist of consensus nodes, a high transmission operating efficiency, and fast transaction speed (Wang et al., 2021). The consortium blockchain was built using many permitted nodes to generate a decentralized ledger at a low cost. All nodes linked to the consortium blockchain have accessibility to a shared ledger (Antonucci et al., 2019). The main two nodes of the consortium blockchain are user nodes and scheduling nodes. Depending on the context, the user nodes might be purchasers or vendors. Meanwhile, scheduling nodes were used to authenticate and validate the systems' transactions (Khan et al., 2020).

Each network participant has a specific part to play, which the participants are all aware of in the consortium. The consortium participants must approve modifying the role before it may be adjusted (Iftekhar & Cui, 2021)). Moreover, consortium participants are not restricted only to industries. They also might involve government agencies. The participants create policies and judgments to manage the consortium. Most of the time, a consortium takes decentralized methods for decision-making (Iftekhar et al., 2020).

Consortium blockchain's main objective is technology and business, with the latter being a hybrid version. The prime advantages that businesses expect from a consortium are cost reductions, rapid learning, and risk transfer (Kramer et al., 2021). A consortium blockchain is applicable when one or both market participants are several people (Juma et al., 2019). The consortium blockchain is a system that maintains data security and efficient on-chain capabilities despite involving several participants for data storage (Lin et al., 2020). In addition, a consortium blockchain connects resembling groups, allowing for a new degree of reliability and transparency focused on a particular interpretation of events. As a result, blockchain consortiums are generally recognized and acceptable business structures (Kayikci et al., 2020).

Consortium blockchain platforms allow participants to evaluate advanced business operations depending on an established blockchain system (Kramer et al., 2021). Examples of consortium blockchain platforms include Ethereum, DelivChain, Hyperledger Fabric, Multi-chain, Quorum, and Corda (Khanna et al., 2020; Kramer et al., 2021; Lin et al., 2020). Hyperledger Fabric, Multi-chain, Quorum, and Corda are open-source consortium blockchain platforms with data that is necessary maintained by government or regulatory agencies (Lin et al., 2020).

Due to its organizational strategy, consortium blockchains are most popular in food supply chain applications because they meet most user needs (Lin et al., 2020). The consortium blockchain removes the asymmetry of information in the food trade to build a trustworthy system. Furthermore, it also deals with the complicated food supply chain's difficulties and allows participants to collaborate (Haji et al., 2020). Privacy security, transaction speed, and internal oversight are rigorous criteria for food traceability systems. The existing problem can be effectively resolved by the systems in conjunction with smart contracts (Wang et al., 2021).

The **hybrid blockchain** is developed as cryptocurrency components, enabling only on-chain data to be uploaded to the network (Hu et al., 2021). A hybrid blockchain may be referred to as a consortium in some contexts (Holmberg & Åquist, 2018). Moreover, hybrid blockchain integrates centralized databases or even other database servers. Information and responsibilities are controlled via a hybrid blockchain, while others are restricted (Shingh et al., 2020). The hybrid design can fulfill the necessity of moderate data storage while guaranteeing data integrity (Lin et al., 2020). The middle network organization can use a hybrid "relationship contract" that includes authority factors (Fu et al., 2020).

Hybrid blockchain is widely applied in the financial and aquaculture industries (Shingh et al., 2020; Tsolakis et al., 2021). This technology allows participants to identify process hazards and maximize supply chain efficiency (Saurabh & Dey, 2021). In addition, it offers the exchange of a variety of data with the public, whereas private data are distributed to authorized participants across the supply chain (Tsolakis et al., 2021). Therefore, a hybrid blockchain was indeed ideal for sustaining a customized competitive advantage. The flexible hybrid blockchain offers traceability and reliability. It does not involve the destruction or reconstruction of the whole supply chain but rather exploits existing technologies like QR codes (Westerlund et al., 2021).

3.5. The use of blockchain in the food supply chain

The use of blockchain technology attracts several food sectors, one of them being the food supply chain. Therefore, many researchers developed new frameworks from the existing blockchain application. Bechtsis et al. (2019) developed the blockchain framework of transshipment food supply chains. Transshipment is an essential activity in the food supply chain, especially for fresh products, because the product must be received by the end customers in fresh conditions (Malik et al., 2021). Meanwhile, the transshipment of fresh products causes significant damage (Amalia et al., 2018). Material handling operations account for 65.8% of the logistical cost of fresh products, with expenditures for procurement, transshipment, inventory, maintenance, and information accounting for the remaining 34.2% (Dharmawati et al., 2020). Bechtsis et al. (2019) analyzed the Hyperledger Fabric platform's utilization and performed a sample adoption.

Hyperledger Fabric is a peer-to-peer system with a compact structure that enables various encryption, identification, and consensus algorithm implementations (Mao et al., 2018; Perboli et al., 2018). The result shows that blockchain has grown rapidly. Its use in the food supply chain offers considerable importance by establishing crucial parameters and improving traceability. Simultaneously, blockchain integrated with other digital tools potentially supports global food supply chain efficiency.

Casino et al. (2020) developed an optimized, immutable, and safe blockchain framework for the traceability of the food supply chain in the dairy industry. The proposed process model consists of system identification, system framework development, and system demonstration. The proposed system's model featured smart contracts (truffle4) and private blockchain (Ethereum: node2 and ganache-cli3). Ethereum allowed smart contracts and decentralized applications (dApps) to make the solutions more adaptive and flexible (Kramer et al., 2021). The proposed model presents numerous benefits, including increased efficiency, trust, durability, and quality of products in the dairy supply chain, but the study did not consider the impact of the improvement on the environment. According to Agustin et al. (2021), waste from dairy industry production is still poorly managed, negatively affecting the environment. Assessing the environmental effects of waste produced during the manufacturing of the dairy industry is essential.

Kamath (2018) used blockchain for food supply chain traceability, as demonstrated by Walmart's Pork and Mango Pilots with International Business Machines (IBM) Corporation. IBM implements a blockchain system using Hyperledger Fabric. As a result, blockchain technology decreased the time needed to identify mango origins and improved transparency throughout Walmarts' food supply chain. In addition, the results highlight the challenges of adopting blockchain technology and the possibilities for deploying blockchain solutions internationally in the food supply chain to improve food safety and waste reduction.

Sander et al. (2018) assessed the acceptability of the proposed blockchain model for meat supply chain traceability and transparency. Traceability and transparency are essential in the meat supply chain, especially for consumers who need a particular requirement, such as halal meat for Muslims. Each point of the meat supply chain has risks to animal welfare, halal, and safety (Noerdyah et al., 2020). The proposed blockchain model uses third-party transparency service providers (3pTSP). It combines blockchain and DNA tagging and offers the highest potential for a comprehensive traceability model for meat supply chains. DNA tagging collects information from a specific animal and its origin. The result indicates that customers are overburdened by the number and certification label complexity. Blockchain adoption greatly affected customer purchase decisions relayed through customers' quality perceptions.

Khan et al. (2020) combined blockchain and IoT to create an efficient traceability system for the food industry 4.0 using Advanced Deep Learning (ADL) in the meat supply chain. The value of such advances in supply chain management may be included in various ways, such as improved exposure, traceability, digitization, decentralization, and smart contracts. The suggested model utilizes a private blockchain platform (Hyperledger Fabric) and a hybrid deep learning model that employs ADL methods. The study will benefit supply chain practitioners in adopting the proposed technology and formulating the regulations according to the projection of ADL.

Tsolakis et al. (2021) adopted blockchain in Thailand's aquaculture industry. The proposed blockchain design in food supply chains promotes Sustainable Development Goals. The four main elements adopted in this study are data patterns, data collection, data consistency, and data interoperability. Implementation of the type of blockchain depends on the company's strategy. The ideal form of blockchain for the aquaculture industry is a hybrid/private blockchain. The public would have access to data selections, but private data would only be distributed to shareholders along the supply chain. The results are useful in the supply chain management area and

potentially influence the sustainability of aquaculture ecosystems and the accomplishment of Sustainable Development Goals.

van Hilten et al. (2020) used blockchain to track the organic food supply chain. The study aims to evaluate blockchain applications and reveal information on the organic food supply chain's challenges and drivers. Four blockchain case studies were assessed. Two key decisions employ blockchain to improve food traceability in organic food supply chains, i.e., optimizing the supply chain partner collaboration and data selection in the blockchain. The challenges are data encryption, data input verification, and interoperability. Quick and efficient food traceability is more useful in a complicated food supply chain, depending on what drives companies.

Bumblauskas et al. (2020) wrote about how a company in the United States used blockchain technology to track the flow of eggs from producer to consumer. The study aims to track items using blockchain and the internet of things (IoT) integration technology. The blockchain platform was examined with proof of concept (PoC). Hyperledger Sawtooth v1.0 and Smart Contracts were used to build the proof-of-concept blockchain layer. The results indicate that customers will get the information necessary to make wise decisions about their purchases. In addition, the companies will maintain traceable and transparent food supply chains. Traceability and transparency improve consumer interactions, raise efficiency, and eliminate food returns, fraud, and waste. Thus, the proposed blockchain application is clearing the way for repairing and changing the global food supply chain system.

Fu et al. (2020) investigated the implementation of blockchain for the traceability of the food supply chain in China. The research case is concentrated on the poultry and farming industry. Blockchain, IoT, and big data are integrated to remove information barriers. The digital consensus algorithms, such as Proof of Work (PoW) and Proof of Stake (PoS), alleviate the problems of "double payment" and "byzantine general". The outcome emphasizes potential blockchain-related challenges in the food supply chain from three perspectives: network chain design, transparent trust system, and smart contract system. Furthermore, the issues in which opportunism is completely controlled in blockchain-based on the food supply chain are from three perspectives, i.e., unpredictability, trade frequency, and asset specificity.

Latif et al. (2021) adopted blockchain at the retail level for the product supply chain using the truffle platform. The study offers a blockchain model for product tracing. Smart contracts keep track of all previous commodity transactions in an immutable ledger. The product identification, transactions, and inspection stages are coordinated using smart contracts. The framework was created for Ethereum's virtual computer but may be used with any blockchain system. Additionally, a technological prototype is developed with the assistance of truffle research nets. Truffle is a smart contract development platform for Ethereum that provides a test system to facilitate the establishment of distributed applications. A system creates and supports a user login form to add the stock-keeping unit (SKU) registration to become a member of the blockchain. The SKU registers the product or item to the blockchain, and the transaction is finished. As a result, the user can see the product's history by scanning the QR codes up until the user blocks in-network. As consumer trust increases, sales reflect consumer satisfaction.

Moudoud et al. (2019) built a blockchain-IoT framework using Oracles and Smart Contracts in the food supply chain. The proposed framework is intended for usage in a supply chain comprised of several distributed IoT entities. The study adopted public or private blockchains with lightweight consensus for IoT (LC4IoT). Extensive simulations are used to assess the consensus. The public blockchain is utilized for production tracking and information dissemination to the general public. The findings indicate that the suggested consensus requires a small amount of computing power, storage capacity, and time. The suggested structure has four tiers, i.e., overlay IoT network, smart farm, Oracle's network, and Cloud. Smart contracts ensure that parties in an overlay network adhere to governing norms and regulations. Smart contracts are utilized in two ways, i.e., by a third party to provide transparency and by stakeholders to control operations.

Perboli et al. (2018) adopted blockchain in the food supply chain with a GUEST (GO, UNIFORM, EVALUATE, SOLVE, and TEST) approach. The case study is about a European e-commerce food retailer. The study incorporates existing literature to address a gap in the digital strategy literature, resulting in a standard design approach. In addition, the research offers the findings of a fresh food delivery use case, demonstrating the essential components of establishing a blockchain system. Furthermore, the study explores how blockchain may assist in cutting logistic costs and improving operations while also addressing research issues. The private blockchain system is built on the Hyperledger Fabric network, working on the Amazon AWS Cloud. The results suggest that blockchain will help reduce transportation costs, improve operations, and solve research problems. Utilizing blockchain technology in the food supply chain is a potential advancement that will benefit all parties involved.

Rogerson and Parry (2020) examined how blockchain has progressed beyond cryptocurrencies. The researchers then used blockchain to improve supply chain visibility and security, as its boundaries and possible implications. Case studies from four food industries were used to conduct qualitative research, which included semi-structured interviews. The first and second case studies use private Quorum blockchain and public Hyperledger blockchain integrated with RFID tags. The third and fourth study cases use the public Ethereum blockchain integrates with RFID tags and QR codes. The result indicates blockchain is a supply chain visibility enhancer. The chance of scalable applications is greatest for products for which consumers are ready to pay the existing premium to support the technology. However, the four issues remain, i.e., technology trust, human error and border fraud, regulation, access to customer data, and desire to pay.

Shahbazi and Byun (2021) developed a methodology for tracking perishable food supply chains based on blockchain, ML, and fuzzy logic. In order to handle perishable food based on the shelf-life management system, the blockchain-ML-based food traceability system is created. It integrates new blockchain technology, ML technology, and fuzzy logic traceability system. The suggested blockchain system was invented to handle lightweight evaporation, warehouse transactions, and delivery time. The smart contract in Ethereum is built using a layer-limited bytecode programming language executed by the Ethereum virtual machine (EVM). The blockchain data transmission is designed to illustrate the use of machine learning in food traceability. Furthermore, the supply chain employs trustworthy and valid data to increase shelf life.

Stranieri et al. (2021) evaluated the impact of blockchain on the performance of the food supply chain. A range of performance variables discussed in the literature, such as response efficiency, responsiveness, flexibility, food quality, and supply chain transparency, are all included in the suggested conceptual framework. Three separate food supply chains used private blockchain, i.e., the chicken meat supply chain, the lemon supply chain, and the orange supply chain. The data indicate that blockchain has a beneficial effect on supply chain profitability and return on investment. In addition, it reinforces extrinsic food quality attributes and encourages better information management across food chains as a result of improved information accessibility, availability, and sharing. The recent results suggested enhancing the management of behavioral indecision among supply chain participants and improving companies' current knowledge and supply chain management capabilities.

Wang et al. (2021) suggested a concept for the traceability of the agri-food supply chain process using consortium blockchain and smart contracts. Food supply chains considered traceability, sharing ability, breaking down the information between companies, and increasing transaction records' integrity, constancy, and security. Farmers record information on the environment and the growth of their crops using the InterPlanetary File System (IPFS), and they employ smart contracts to store IPFS hashes. However, due to several limitations, the framework has effectively implemented features such as decentralization and tracking agri-food product information using QR codes. In addition, the framework provided a strong correlation and benchmark value for businesses to use to guarantee both the quality and safety of their products.

A comprehensive summary of blockchain adoption in the food supply chain can be seen in Table 2. Blockchain adoptions in the food supply chain were mainly used for traceability, with public/private blockchain as a widely used platform. The transaction data is about the product origin information, transaction information, and product label information.

3.6. Opportunities-challenges of blockchain use in the food supply chain

3.6.1. Opportunities

Blockchain builds a significant system by integrating transparency, security, and privacy. Blockchain technology may be used in the entire food supply chain stages, from procurement through product delivery (Mangla et al., 2021). Moreover, the platforms are equipped with transparency, secure, decentralized ledgers, data immutability, smart contracts, and dependable networks (Kouhizadeh et al., 2021; Mukherjee et al., 2021; Wang et al., 2019).

Behnke and Janssen (2020) state that blockchain is used in the food supply chain to enhance traceability and transparency, with several requirements that must be fulfilled before blockchain can be adopted. Chen et al. (2020); Fortuna and Risso (2019) also describes the benefit of blockchain adoption, such as providing real-time data, exact traceability, and definite record along with each transaction. In addition to increasing transparency and trust, using blockchain in the food supply chain also regulates food quality, boosts supply chain efficiency, promotes collaboration in the food supply chain to strengthen relationships between participants, and eliminates necessary mediators. Blockchain adoption also benefits the customer level by strengthening customer relationship management.

Blockchain also presents cost-saving and profit advantages by preventing uncontaminated food from being discarded, which directly benefits all supply chain participants (Dong et al., 2020; Stranieri et al., 2021). As a result, the supply chain visibility improved, the number of supply chain frauds was reduced, and the involvement of stakeholders was improved (Ray et al., 2019). Blockchain can improve information validity, reduce information biases, enable security, and build confidence regarding the supply chain information-sharing mechanism (Duan et al., 2020; Dujak & Sajter, 2019; Galvez et al., 2018). The usage of blockchain has resulted in more efficient transaction processing by reducing behavioral uncertainty, as well as enhanced coordination among supply chain players (Stranieri et al., 2021).

3.6.2. Challenges

The use of blockchain also has a weakness, Gao et al. (2020) and Wang et al. (2019) describe that blockchain can destabilize the supply chain system. Traceability information recorded comes from a single source, which makes the information validity hard to ensure. Many traceability solutions do not include a simple enterprise resource planning (ERP) system, resulting in a lack of trust between data on-chain and data off-chain.

Cost is considered a big obstacle to blockchain technology in the current situation. A blockchain-based system might be expensive due to its complicated network and frequent transactions. Decentralized signature verification is computationally tricky and challenging, especially for traceability in the food supply chain, which deals with thousands of products and necessary information (Agrawal et al., 2018). Additionally, using blockchain technology necessitates fundamental changes in how businesses conduct their daily operations (Fortuna & Risso, 2019). Therefore, the company interprets the development of blockchain as both a concern and an advantage. According to the business, blockchain adoptions span international food supply chains, require a long history, and demand global cooperation and assistance (Kittipanya-Ngam & Tan, 2020). The external disadvantages of blockchain adoption include government, ethics, legislation, criminality, safety, privacy, intellectual theft, system unemployment, and technological vulnerability challenges. For example, significant cryptocurrencies have been the victim of several cyber-attacks. The misapplication of blockchain has been related to cyberattacks, economic crime, market manipulation, Internet Protocol (IP) hacking, and public safety and security issues (Wang et al., 2019).

Table 2. Blockchain adoption in the food supply chain

Author	Proposed model	Sector	Blockchain utilization	Platform	Transaction Data
Bechtsis et al. (2019)	Developed the blockchain framework	Transshipment supply chains on frozen food products	Traceability	Hyperledger Fabric	Capacity, weight, type of hazards, container type (e.g., size, refrigerator code) and controller information (e.g. temperature tolerance limits)
Casino et al. (2020)	Developed the blockchain framework	Dairy supply chain	Traceability	Private blockchain (Ethereum: node2 and ganache-cli3)	Product description, chemical analysis of the product, location, temperature, total traces of the product, participant information, and participant status
Kamath (2018)	Elaborated the challenges of adopting blockchain	Walmarts' Pork and Mango Pilots with International Business Machines Corporation (IBM)	Traceability	Hyperledger Fabric	Walmarts' pork: The animal movement, temperature, humidity, location, expiration dates, farm origin information, batch numbers, and processing data Mango pilots: temperature, humidity, a total of product damage in shipping process, and expiration dates
Sander et al. (2018)	Evaluated the acceptance of the proposed blockchain framework: 3pTSP (combines blockchain and DNA tagging)	Meat supply chain	Traceability	—	Meat certification labels: animal-specific information and farm origin information
Khan et al. (2020)	IoT-blockchain integration using ADL methods	Meat supply chain	Traceability	Private blockchain (Hyperledger Fabric)	The product information: production, quality, market, and price information

(*Continued*)

Author	Proposed model	Sector	Blockchain utilization	Platform	Transaction Data
Tsolakis et al. (2021)	Adopted blockchain for supply network framework	Thailand's aquaculture industry	Traceability	Hybrid/private blockchain	Fish origin (temperature, fish farming time, etc.) and updated weight of the products
van Hilten et al. (2020)	Adopted blockchain framework in four study case	Spice, fish, fruit, and rice industry	Traceability	Public/private blockchain	Origin of the product and transaction information
Bumblauskas et al. (2020)	Adopted the integration of blockchain-IoT	Egg supply chain	Traceability	Hyperledger Sawtooth v1.0	Farm: egg specification, pickup time. temperature, location, humidity location and time, farm name, temperature, and humidity Packaging sites: departures and arrivals time, processing and packaging time, egg specification, certification data, batch number and volume, expired date, brand, color, and product labels
Fu et al. (2020)	Adopted the integration of blockchain, IoT, and big data	Poultry and farming industry	Traceability	—	Poultry: location, slaughter information, and transportation Farming industry: time and geographic information, crop production information, and management data
Latif et al. (2021)	Adopted blockchain at the retail level	Retail	Traceability	Ethereum	Product information: brand, production date, expired date, company origin, and website

(*Continued*)

Table 2. (*Continued*)

Author	Proposed model	Sector	Blockchain utilization	Platform	Transaction Data
Moudoud et al. (2019)	Developed blockchain-IoT framework using Oracles and Smart Contracts	Dairy supply chain	Traceability	Public/private blockchain (Ethereum)	Product and transportation information
Perboli et al. (2018)	Adopted blockchain framework with GUEST (GO, UNIFORM, EVALUATE, SOLVE, and TEST) approach	E-commerce food retailer	Traceability	Hyperledger Fabric	Product information
Rogerson and Parry (2020)	Examined blockchain adoption to improve supply chain visibility and security	Agri-food supply chain (farming, milk powder, tuna, and wine)	Traceability	Private blockchain (Quorum/ Ethereum) and Public blockchain (Hyperledger)	Farming: crop growing and production information, transportation and operational practices information Milk powder: production and transportation information, product picture and a list of scan tag Tuna: container (cold) conditions, fish farming time, and production information (location and time) Wine: product information
Shahbazi and Byun (2021)	Developed the integration of blockchain, machine learning, and fuzzy logic	Perishable food supply chain	Traceability	Ethereum	Temperature, humidity, relative humidity, energy activation, gas constant, moisture sensitivity, and transit time
Stranieri et al. (2021)	Investigated the influence of blockchain on food supply chains' performance	Chicken meat supply chain, lemon supply chain, and orange supply chain	Traceability	Private blockchain	Product and transaction information

(*Continued*)

Author	Proposed model	Sector	Blockchain utilization	Platform	Transaction Data
Wang et al. (2021)	Developed the blockchain framework	Buckwheat supply chain	Traceability	Consortium blockchain	On-farm information, crop growth, batch number, quantity and inspection information, quality and regulation information, company information, and basic retailer information

Blockchain use in the food supply chain faces various challenges. Chen et al. (2020), Jarka (2019), and Mukherjee et al. (2021) state that supplier integration with a blockchain system can be complex and expensive. Suppliers must record operational information, such as raw materials. As a result, companies confront several obstacles. Moreover, it also requires investments in human resources, technical processes, and infrastructures. Demestichas et al. (2020) outlined the difficulties in implementing blockchain in the food supply chain, citing the lack of technical expertise among many stakeholders, products that have undergone significant changes, the diversity of roles and operations of numerous stakeholders, and the rapidly evolving global supply chain that has encountered significant problems. Duan et al. (2020), Fortuna and Risso (2019), and Wang et al. (2019) added that there is a potential for data manipulation and policy change challenging the use of blockchain in the food supply chain. The present complicated network of policies in many countries, primarily on ownership and data security, generates regulatory ambiguity. Therefore, applicable inter-organizational policies, regulations, and industry standards are essential.

4. Conclusion and future research opportunities

Food supply chains are a complex framework that includes all agri-food upstream and downstream sectors. Food traceability solves several issues in food supply chain management, such as hacking, privacy breaches, data manipulation, and fraud. Blockchain has emerged as one of the most widely used technologies in the food supply chain. Distributed blockchain systems consist of decentralization, immutability, security, and smart contract features. The category of platform is divided into a public blockchain, private blockchain, consortium blockchain, and hybrid blockchain.

Blockchain adoptions in the food supply chain offers several opportunities, such as enhanced traceability and transparency, with public/private blockchain as a widely used platform. Many of the previous case studies employed the smart contract. The data is about product origin, transaction, and product label information. Blockchain adoption enhances traceability and transparency, manages food quality, improves supply chain performance, encourages collaboration in the food supply chain, and eliminates necessity mediators. The challenges bound to technology demand significant investment in financial, human resources, and infrastructure. In addition, the limited technical knowledge of stakeholders, significant product changes along the chain, the diversity of responsibilities and operations of several stakeholders, the rapid development of the global supply chain, the potential for data manipulation, and policy change become obstacles. The misapplication of blockchain also has been the victim of several cyberattacks.

The food supply chain is strengthened by blockchain, and its adoption may be sustained with the right capital support. The government needs to support the development of blockchain networks by establishing specific regulations. Regulation plays a major role in investigating misapplication, such as cyberattacks and data manipulation.

Further research is required to establish a more substantial framework of blockchain that maintains the concepts of sustainability, adaptability, reliability, and tenacity while adapting to developments in the global supply chain. It can be done by evaluating existing blockchain frameworks for their ability to fulfill the principles of sustainability, adaptability, reliability, and tenacity in real-world applications. It is also essential to identify the social and economic factors and their impact on adopting and deploying blockchain in the global supply chain. Research ways to reduce the energy consumption of blockchain systems, making them more sustainable. Integrating blockchain with other computing paradigms or technologies also can be obtained, such as investigation blockchain and Internet of Things (IoT) technology integration to provide a more robust and secure supply chain ecosystem. It also can be done by investigation methods to improve interoperability and standardization across different blockchain platforms to promote collaboration in the supply chain. Developing a framework with more in-depth key observations, such as transaction data, is crucial to produce accurate and transparent information.

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