Blockchain technology in the agri-food supply chain: A systematic literature review of opportunities and challenges

Abstract

Blockchain technology (BCT) has emerged as a promising disruptive technology with significant applications in the agri-food supply chain (AFSC). This paper reviews the BCT's research trends, benefits, challenges, and applications in AFSC through systematic literature network analysis (SLNA). A total of 187 articles were selected through a systematic literature review of different reputed databases, and citation network analysis was carried out using "*VoSviewer*" software. The information related to annual scientific production, country-specific production, type of article, subject area and the most relevant sources was analysed using "*Biblioshinny*" software. The outcomes reveal prominent benefits, including traceability and transparency, immutability, trust, and decentralization.

On the other hand, policy and regulations, scalability issues, less skilled human resources, high investment, and interoperability hinder blockchain implementation. Smart contracts, cybersecurity, food safety, and public distribution systems are some of the identified applications of blockchain technology, thus enhancing agri-food supply chains. Various blockchain-based frameworks in AFSC are also discussed in this review. This review offers insights into how findings may guide practitioners and researchers in developing appropriate BCT systems for AFSC. It also provides practical implications and future research directions on the theme.

***Keywords**:* Blockchain technology; Agri-food supply chain; Systematic literature review; Citation network analysis; Technological interventions

1. Introduction

The agri-food supply chain (AFSC) is a complex network of interlinked functionaries and plays a vital role in the global economy in ensuring food availability (Zhao et al., 2019). The recent pandemic and several food frauds and scandals led to the mass spread of diseases (Stranieri et al., 2021) and have disintegrated consumer trust in the AFSC and need complete information about food product origin, quality, and nutritional values. Therefore, there is pressure on AFSC partners to enhance operational efficiency and transparency throughout the chain (Rejeb et al., 2020). Several digital technologies, including blockchain technology (BCT), are emerging towards advancements in the traceability, transparency, and safety of AFSC (Durugbo and Al-Balushi, 2022; Schäfer, 2023; Vern et al., 2023). BCT has emerged as a disruptive technology that can work on different dimensions to develop a traceable, transparent, sustainable, and safe AFSC (Zouari et al., 2021; Chen et al., 2021). BCT is a network of interconnected blocks in the digital environment of the internet, allowing transactional information to be stored, linked, and recovered, developing an extensive database (Rocha et al., 2021). BCT is a decentralized platform that allows direct peer-to-peer transactions and reduces information asymmetry and disintermediation (Duan et al., 2022; Elnadi and Abdallah, 2022; Anguiano and Parte, 2023; Ofulue and Benyoucef, 2022).

BCT is developing and advancing rapidly (Santhi and Muthuswamy, 2022), and the number of academic experts covering the topic has rapidly increased, reflecting the growing interest in investigating various aspects of BCT in AFSC (Zhao et al., 2019). Li et al. (2021) conducted a literature review on the benefits and challenges of blockchain platforms in food supply chains. It concluded BCT enhances visibility, transaction transparency, and food safety and reduces food wastage. Technology, cost, governance, regulation, and education were identified as BCT challenges. A review analysis conducted by Rana et al. (2021) identified challenges such as scalability, privacy, high cost and network problems. Niknejad et al. (2020) adopted bibliometric analysis to map prominent trends and themes on BCT in AFSC using potential articles, authors, countries and keywords from 2016 to 2019. The analysis revealed traceability, transaction, safety and food supply chain as the most used terms in the title and abstract.

Similarly, Yogarajan et al. (2023) identified themes of BCT in AFSC through a literature review. Identified themes shed light on adoption factors of BCT, AFSC practices and strategy policy foundations. Mavilia and Pisani (2021) discussed the importance of BCT application in the agricultural sector with literature analysis. The review highlighted various applications of BCT in agricultural supply chains, such as digital payment platforms, insurance, credit facilities and land registries. Previous studies claim that BCT may transform the traditional AFSC network into a digitally manageable and connected one. BCT offers undeniable benefits such as transparency, reliability, and information accuracy (Vern et al., 2023) and its application for traceability and combating food fraud by improving data management, food safety and eliminating counterfeit products in AFSC (Vern et al., 2022). Although the literature provides an exhaustive review covering studies of the last five years with different approaches and objectives. The studies have focused on the concept of BCT, its functionalities, and benefits, either through case study methods or survey-based research, and provide suitable frameworks and solutions (Aldrighetti et al., 2021; Vivaldini, 2021; Song et al., 2020). There is a lack of comprehensive studies that can provide the latest developments. Understanding how BCT could improve AFSC operations is limited (Feng et al., 2020). A few studies have systematically researched the theme, specifically focusing on AFSC (Duan et al., 2021). The motivation behind the study is to determine the opportunities resulting from BCT in AFSC. Thus, this review aims to provide an in-depth understanding of BCT in the AFSC; the following research questions (RQs) are designed:

RQ1. What are the benefits and implementation challenges of blockchain technology in agri-food supply chains?

RQ2. What are the different applications of blockchain technology in agri-food supply chains?

The study adopted a systematic literature review approach to address RQs. The study will provide a background of BCT to allow researchers from diverse fields to position their research. It will summarize existing research and developments related to the BCT in AFSC by outlining the benefits, challenges and applications. To the best of the authors' knowledge, no review has provided such a composite and exhaustive review in a single article in this area through systematic literature review and citation network analysis, and that's the novelty of this research. This review also has its essence in providing the future research scope where researchers must ponder various dimensions.

The organization of the review is structured as follows. The first section addresses the subject and provides an overview. Section two provides background on the BCT and related topics. Section three presents the methodology adopted for the review. The detailed findings are discussed in the fourth section. The remaining sections discuss implications for future research, conclusions, and limitations.

2. Literature Review

2.1 Agri-food supply chain

The agri-food supply chain is a chain of events linked with *'field to fork'*, including agricultural production, food processing, packaging, transportation, and consumption (Mor et al., 2018). The increased globalization has led to the increased mobility of products and information. AFSC faces unprecedented demands and proliferates to fulfil consumer needs. According to the food and agricultural organization (FAO) of the United Nations, approx. 30% of food produced yearly is unconsumed due to food loss and waste. About 14% of farm products get wasted during transportation and storage after harvesting (FAO, 2019). Lack of storage space, improper care, wastage, poor post-harvest management and information asymmetry lead to food loss. Due to the unpredictable nature of AFSC, the agri-food sector requires traceability to reduce food loss, food safety and fraud.

Food traceability demands that AFSC be skilled at maintaining product information (Mirabelli & Solina, 2020). Digital technologies like the internet of things (IoT) and BCT have been adopted in the agri-food supply chain to ensure food safety and quality (Saurabh & Dey, 2021). Adopting digital technologies helps achieve collaboration and integration among various stakeholders in the AFSC and reduces food loss (Lezoche et al., 2020).

2.2 Blockchain technology

Blockchain technology is a distributed and mutually verifiable ledger technology. It is a ledger in which various actors record information on the generation, transaction, and consumption of a product and service (Kramer et al., 2021). BCT was proposed in 2008 in the finance sector, from where it was popularly known as a peer-to-peer electronic cash system (Nakamoto, 2008). The evolution of BCT from blockchain 1.0 to blockchain 4.0 (Huang et al., 2020), where Bitcoins and cryptocurrencies were the first implementations of BCT. Concerning Blockchain 2.0, the smart contract was the second implementation of distributed ledger technology. The motive behind smart contracts is to develop a tamper-proof system. Blockchain 3.0, i.e., a decentralized application, provides an open network to all the members, avoiding the centralized infrastructure and enabling decentralized communication (Santhi and Muthuswamy, 2022). Blockchain 4.0 provides solutions to fulfil business and market demands in different areas such as healthcare, supply chain management, agri-food supply chains, financial & asset management, and energy (Yang, 2019). Rejeb et al. (2020) define blockchain as "a digital, decentralized and distributed ledger in which transactions are logged and added in chronological order to create permanent and tamper-proof records". The system provides data traceability, sharing, and integrity by storing it in a single block within the network, meeting consumer transparency needs (Baralla et al., 2019).

2.3 Blockchain for traceability in the agri-food supply chain

The application of BCT in AFSC helps build holistic solutions to many of the problems encountered in the current supply chain. Integrating BCT with IoT could enable real-time data collection through sensors, overcome information asymmetry and transparency issues and ensure data provenance and integrity. Recent developments in BCT for traceability positively impact the overall performance of AFSC (Chan et al., 2019). Implementing BCT enhances collaborations, reduces information asymmetry, and increases trust among AFSC stakeholders (Stranieri et al., 2021). Blockchain-based traceability offers farm-to-fork traceability and transaction records. Also, it leads to decentralization, eliminates bureaucracy, enhances safety, reliability, and coordination, reduces costs, and maximizes profits (Aldrighetti et al., 2021). BCT addresses various supply chain problems, varying from large global platforms like IBM Food Trust (Shew et al., 2022) to companies like AgriChain, ripe, and honeysuckle white.

3. Review methodology

The review assesses the articles on the Web of Science, Scopus, IEEE Access, Science direct, and other reputed research databases about blockchain technology in the agri-food supply chain. The methodology adopted for the review is based on systematic literature network analysis (SLNA), which includes systematic literature review (SLR) and citation network analysis (CNA). Two software, "*Biblioshinny*" and "*VoSviewer*", have been used to analyse performance and develop the citation network for selected articles.

3.1 Systematic literature review (SLR)

SLR is a method of identifying, evaluating, and interpreting all available research related to the research topic to answer research questions (Andrian et al., 2018). This study opted for the SLR approach as it delivers a transparent and reproducible overview of available research. It assists in identifying research trends and, gaps and opportunities for future research through the use of the relevant data (Kushwah et al., 2019). Since management research is interdisciplinary and dependent on other fields, SLR assisted in compiling data from various journals, fields and countries. The systematic literature review has three phases, i.e., "planning", "conducting", and "reporting & analysis" (Tranfield et al., 2003).

A. Planning the review

In this phase, the scope of the review is defined. The research theme is identified to understand the published studies on blockchain technology and agri-food supply chains in the last five years (2018-2022). A review protocol was designed to maintain objectivity throughout the procedure. The review protocol states the search query, inclusion and exclusion criteria, language, research databases, publication type, and period, see Table 1.

Table 1. Review protocol for SLR

Criterion	Explanation
Research database	Major research databases used for the review were Scopus and Web of Science. Additionally, other leading research databases were also referred to collect the articles: ScienceDirect (Elsevier); Emerald insight (Emerald); Wiley Online Library (Wiley); Taylor & Francis Online (Taylor & Francis); IEEE Xplore Digital Library (IEEE) & Springer Link (Springer).
Publication Type	Articles published in peer-reviewed journals and conferences

Language	English
Period	The search was conducted for the last five years (2018- 2022)
Search Field	Titles, abstracts, and keywords
Search Terms	TITLE-ABS-KEY ("blockchain technology OR blockchain" AND "agri-food supply chain," "blockchain OR blockchain technology" AND "agri-food value chain")
Inclusion Criteria	Articles focusing on application, benefits, challenges, and blockchain technology in agri-food supply chains.
Exclusion Criteria	Articles focusing only on technical aspects of the technology
Source: Queiroz et al. (2020)	

B. Conducting the review

The review was conducted in this phase based on the objectivity defined in the review protocol (Table 1). This review includes only the articles that met the full criteria specified in the modelled protocol. This phase involved identifying research, selecting studies, and synthesising data (Figure 1). A comprehensive list of core contributions was collected to answer the review questions by searching the eight major databases, i.e., Scopus, Web of Science, ScienceDirect, Emerald, Wiley, Taylor & Francis, IEEE, and Springer. One hundred eighty-seven articles were considered for the review.

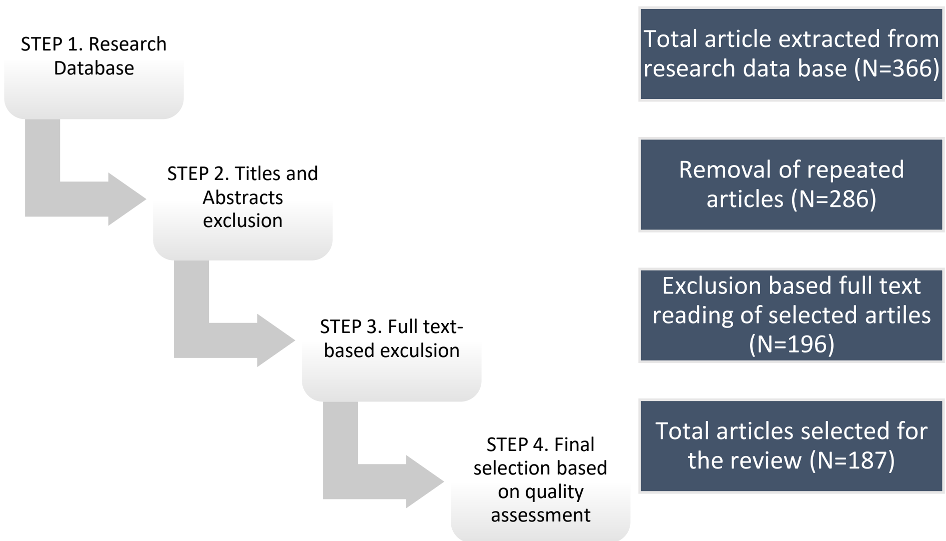

Figure 1. Conducting the review and article selection

The search was performed using a combination of terms like "blockchain technology OR blockchain" AND "agri-food supply chain", "blockchain OR blockchain technology", AND "agri-food value chain".

C. Reporting and analysis of results

This section is dedicated to analysing the bibliometric results obtained for this review. The bibliometric methodology is famous for exploring and analysing extensive scientific data (Donthu et al., 2021). The enrichment technique used for the performance analysis of the 187 selected articles for the review is "*Biblioshinny*" software (Aria & Cuccurullo, 2017). With the help of "*Biblioshinny*" software, information captured pertains to annual scientific production, country-specific production, type of article, subject area, and most relevant sources, presented in tables in the Annexure. In this review, citation network analysis (CNA) (Figure A2) is done using "*VoSviewer*" software based on the bibliographic coupling of selected documents. The study opted for "*Biblioshinny"* and "*VoSviewer"* software as both are fit for providing domain visualization. "*VoSviewer"* is a freely available user-friendly software that offers simplicity, flexibility, and responsiveness to explore numerous data relationships. Kirby (2022) emphasized that "*VoSviewer"* is suitable for performing science mapping analysis. "*Biblioshinny*", powered by *Bibliometrix,* has a user-friendly interface that requires no coding knowledge, thus simplifying its usage (Arruda et al., 2022). It is a comprehensive mapping tool with extensive data analysis techniques (Moral-Muñoz et al., 2020). CNA is a network analysis method representing articles as nodes and citations as connecting arrows. An arrow extends from the sink article (cited article) to the source article in the network, which allows chronological monitoring of the citation network. CNA provides a better understanding of the impact of previous studies on subsequent studies. Bibliographic coupling is conducted for all reviewed articles that cite the same research literature, i.e., the higher the similarity of the referred article, the more similar the research content of the two articles. The nodes/articles of a network can be separated into clusters. Each cluster is regarded as a group of well-connected articles in a theme with little connection to other cluster nodes. The analysis generated four clusters, i.e., red, blue, green, and purple, for the 60 articles by taking a citation threshold of four per article from 187 articles. The analysis generated four clusters: red (benefits and implementation challenges), blue (Commercial blockchain solutions), green (blockchain frameworks), and purple (sustainability). The red cluster contains articles more focused on various benefits, adoption challenges, and deployment strategies of BCT in AFSC.

The green cluster consists of articles that focus on the commercial application of BCT in seafood provenance, restaurants, food traceability, dairy, and beef supply chains. The blue cluster includes articles that provide BCT frameworks for public distribution systems, soybean supply chains, grain supply chains, and perishable agri-food products. Some suggested BCT frameworks are integrated with the Internet-of-things, machine language, and fuzzy logic to achieve food safety, traceability, and transparency. Lastly, articles of the purple cluster talk about how BCT adoption helps attain sustainability and trust among stakeholders for AFSC. With the help of CNA, authors were able to identify current research trends and themes of BCT in the AFSC. The authors have utilised the identified themes for an in-depth review. The review utilised a systematic literature review methodology and identified the benefits, challenges, and applications of blockchain technology in the agri-food supply chain based on the findings of CNA.

4. Results and Discussion

This section addresses research questions by comprehensively understanding the literature through content analysis. The following subsection sheds light on blockchain technology's benefits, challenges, and applications in the agri-food supply chain.

4.1 Results

4.1.1 Benefits of BCT in the AFSC

Blockchain technology provides a platform for agri-food companies to build a holistic solution to tackle challenges like food safety, food authenticity, food fraud, illegal trade, harsh environmental impact, animal welfare, and inefficient processes (Dutta et al., 2020; Katsikouli et al., 2021). With the help of BCT, coordination and collaboration among stakeholders of the supply chain are more straightforward because all the information related to products is available on the shared ledger (Vivaldini, 2021). Validation of information throughout the supply chain enhances the traceability and reliability of processes and products (Chen et al., 2021). BCT positively impacts consumers' purchasing decisions by reducing the complexity of validating the product origins and certification labels, thus enhancing the transparency and traceability system (Afrianto et al., 2020). The application of smart contracts helps the company design the contract based on company requirements (Dutta et al., 2020). Other than the benefits, there are some drivers of BCT in the agri-food supply chain, including dis-intermediation, traceability, trust, coordination, compliance related to trade, price of technology (Saurabh & Dey, 2021), transparent system, fraud detection, secure system, inventory management, scalability, cost reduction, safe and quality food, government regulations (Tayal et al., 2021). In Table 2, a summary of significant benefits is identified through literature and addresses the first part of RQ1. The results are categorised as functional, business, social, environmental, and economic benefits.

Table 2. Benefits of BCT in AFSC

Benefits	Explanation	References
a) Functional Benefits	i. Transparency	Bermeo-almeida et al.,2018; Galvez et al., 2018; Meidayanti et al., 2018; Chan et al., 2019; Haroon et al., 2019; Madumidha et al., 2019; Madumidha et al., 2019; Mondal et al., 2019; Musah et al., 2019; Shih et al., 2019; Botelho et al., 2020; Bumblauskas et al., 2020; Chen et al., 2021; Duan et al., 2020; Dutta et al., 202 0; Enescu et al., 2020; Jaiyen et al., 2020; Kohler & Pizzol, 2020; Kshetri & DeFranco, 2020; Mezquita et al., 2020; Patelli & Mandrioli, 2020; Prashar et al., 2020; Shahzad and Zhang, 2020; Song et al., 2020; Thejaswini & Ranjitha, 2020; Wallace et al., 2020; Ali et al., 2021; Bai et al., 2021; Baralla et al., 2021; Cocco et al., 2021; Ekawati et al., 2021; Katsikouli et al., 2021; Kramer et al., 2021; Mukherjee et al., 2021; Pawar et al., 2021; Pranto et al., 2021; Shivendra et al., 2021; Shwetha & Prabodh, 2021; Sudha et al., 2021; Fakkhong et al., 2022; González-Puetate et al., 2022; Kumar et al., 2022(a); Marchese & Tomarchio, 2022; Singh & Sharma, 2022; Vern et al., 2022; Xie et al., 2022.
	ii. Traceability	Aich et al., 2019; Casino et al., 2019; Chan et al., 2019; Felippe & Demanboro, 2019; Kamilaris et al., 2019; Lin Q et al., 2019; Madumidha et al., 2019; Musah et al., 2019; Pearson et al., 2019; (a); Tsang et al., 2019; Afrianto et al., 2020; Bumblauskas et al., 2020; Chen Y et al., 2020; Chen S et al., 2021; Dong et al., 2020; Gao et al., 2020; Hedge et al., 2020; Kohler & Pizzol, 2020; Pooja et al.,

		2020; Prashar et al., 2020; Saji et al., 2020; Shahzad and Zhang, 2020; Vincent et al., 2020; Wang et al., 2020; Al-Amin et al., 2021; Chen et al., 2021; Cui et al., 2021; Ekawati et al., 2021; Espinoza et al., 2021; Hong et al., 2021; Katsikouli et al., 2021; Lee et al., 2021; Shivendra et al., 2021; Sun et al., 2021; Wang L et al., 2021; Balamurugan et al., 2022; Fakkhong et al., 2022; Fan et al., 2022; González-Puetate et al., 2022; Kumar et al., 2022(a); Kumar et al., 2022(b); Lin et al., 2022; Marchese & Tomarchio, 2022; Marchesi et al., 2022; Oguntegbe et al., 2022; Qian et al, 2022; Shew et al., 2022; Varavallo et al., 2022; Xie et al., 2022.
iii.	Provenance	Basnayake & Rajapakse, 2019; Cong An et al., 2019; Longo et al., 2020; Afrianto et al., 2020; Thejaswini & Ranjitha, 2020; Wallace et al., 2020; Zhou et al., 2020; Baralla et al., 2021; Marchesi et al., 2022.
iv.	Security	Bermeo-almeida et al., 2018; Galvez et al., 2018; Cong An et al., 2019; Madumidha et al., 2019; Kamilaris et al., 2019; Salah et al., 2019; Casino et al., 2020; Dinesh et al., 2020; Dong et al., 2020; Dutta et al., 2020; Enescu et al., 2020; Mezquita et al., 2020; Peña et al., 2020; Pooja et al., 2020; Putri et al., 2020; Shahzad and Zhang, 2020; Zhang et al., 2020; Chen et al., 2021; Cui et al., 2021; Park & Li, 2021; Sathya et al., 2021; Tao et al., 2021; González-Puetate et al., 2022; Kumar et al., 2022(a); Rejeb et al., 2022; Xie et al., 2022.

v.	Privacy of information	Haroon et al., 2019; Botelho et al., 2020; Dutta et al., 2020; Peña et al., 2020; Cui et al., 2021; Mukherjee et al., 2021; Kumar et al., 2022(a).
vi.	Immutability	Aich et al., 2019; Cong An et al., 2019; Harshavardhan et al., 2019; Madumidha et al., 2019; Terzi et al., 2019; Casino et al., 2020 (b); Dutta et al., 2020; Gao et al., 2020; Kohler & Pizzol, 2020; Shahid et al., 2020; Ekawati et al., 2021; Hong et al., 2021; Mukherjee et al., 2021; Pawar et al., 2021; Sathya et al., 2021; Shwetha & Prabodh, 2021; Sudha et al., 2021; Kumar et al., 2022(b); Wünsche & Fernqvist, 2022.
vii.	Reliability	Bermeo-almeida et al., 2018; Salah et al., 2019; Chen S et al., 2021; Dong et al., 2020; Patelli & Mandrioli, 2020; Pooja et al., 2020; Peña et al., 2020; Zhang et al., 2020; Lee et al., 2021; Park and Li, 2021; Shivendra et al., 2021; Fakkhong et al., 2022; Marchese & Tomarchio, 2022; Vern et al., 2022; Wünsche & Fernqvist, 2022.
viii.	Efficiency	Bermeo-almeida et al., 2018; Galvez et al., 2018; Guo et al., 2018; Aich et al., 2019; Longo et al., 2020; Madumidha et al., 2019; Salah et al., 2019; Bumblauskas et al., 2020; Casino et al., 2020; Dutta et al., 2020; Kshetri & DeFranco, 2020; Vincent et al., 2020; Al-Amin et al., 2021; Baralla et al., 2021; Shivendra et al., 2021.
ix.	Improved information management	Meidayanti et al., 2018; Adeeb et al., 2020; Ahmed et al., 2020; Chen Y et al., 2020; Chen

				et al., 2021; Chopra, 2020; Dutta et al., 2020; Kamble et al., 2020; Kohler & Pizzol, 2020; Yang and Sun, 2020; Zhang et al., 2020; Ekawati et al., 2021; Stranieri et al., 2021; Sun et al., 2021; Tao et al., 2021; Yang et al., 2021; Oguntegbe et al., 2022; Vern et al., 2022; Wünsche & Fernqvist, 2022.
		x.	Consensus mechanism	Lin Q et al., 2019; Gao et al., 2020; Kramer et al., 2021.
b)	Food Security Benefits	i.	Food fraud, or preventing counterfeitin g	Guo et al., 2018; Musah et al., 2019; Bumblauskas et al., 2020; Chen S et al., 2021; Danese et al., 2021; Pranto et al., 2021; Collart & Canales, 2022; Marchesi et al., 2022.
		ii.	Food quality	Basnayake & Rajapakse, 2019; George et al., 2019; Kamilaris et al., 2019; Afrianto et al., 2020; Casino et al., 2020; Chen et al., 2021; Hedge et al., 2020; Jaiyen et al., 2020; Zhang et al., 2020; Zhou et al., 2020; Cocco et al., 2021; Wang L et al., 2021; Balamurugan et al., 2022; Fan et al., 2022;
		iii.	Food Recall	Bumblauskas et al., 2020; Chen et al., 2021; Duan et al., 2020.
		iv.	Food safety	Guo et al., 2018; Mao et al., 2018; Lin Q et al., 2019; Longo et al., 2020; Dinesh et al., 2020; Dutta et al., 2020; Ji et al., 2020; Kshetri & DeFranco, 2020; Patelli & Mandrioli, 2020; Wang et al., 2020; Zhou et al., 2020; Zhang et al., 2020; Wang et al., 2021; Balamurugan et al., 2022; Collart & Canales, 2022; Fan et al., 2022; Lin et al., 2022; Vern et al., 2022.

c) Environmental benefits	i.	Improved food wastage management	Kamilaris et al., 2019; Bumblauskas et al., 2020; Chen et al., 2021; Hedge et al., 2020; Vincent et al., 2020; Mangla et al., 2021; Park & Li, 2021; Oguntegbe et al., 2022; Vern et al., 2022; Wünsche & Fernqvist, 2022.
d) Social benefits	i.	Fair pricing throughout the supply chain	Harshavardhan et al., 2019; Kamilaris et al., 2019; Kumarathunga, 2020; Afrianto et al., 2020; Dutta et al., 2020; Hedge et al., 2020; Kshetri & DeFranco, 2020; Lezoche et al., 2020; Pooja et al., 2020; Saji et al., 2020; Xu et al., 2020; Pranto et al., 2021; Park & Li, 2021.
	ii.	Disintermediation	Basnayake & Rajapakse, 2019; Harshavardhan et al., 2019; Jaiswal et al., 2019; Kamilaris et al., 2019; Prashar et al., 2020; Salah et al., 2019; Chen Y et al., 2020; Chen S et al., 2021; Dutta et al., 2020; Jaiyen et al., 2020; Pranto et al., 2021; Shivendra et al., 2021; Tao et al., 2021; Wang et al., 2021; Kumar et al., 2022(b); Wünsche & Fernqvist, 2022.
	iii.	Empowered consumers as trust increases (Between retailers and consumers)	Guo et al., 2018; Baralla et al., 2019; Afrianto et al., 2020; Enescu et al., 2020; Kohler & Pizzol, 2020; Pooja et al., 2020; Putri et al., 2020; Qian et al., 2020; Song et al., 2020; Thejaswini & Ranjitha, 2020; Wallace et al., 2020; Balakin et al., 2021; Baralla et al., 2021; Cao et al., 2021; Ekawati et al., 2021; Garaus & Treiblmaier, 2021; Hong et al., 2021; Hu et al., 2021; Hu et al., 2021; Orjuela et al., 2021; Shwetha & Prabodh, 2021; González-Puetate et al., 2022; Singh & Sharma, 2022; Oguntegbe et al., 2022; Wünsche & Fernqvist, 2022.

e) Business benefits	i.	Integrity	Salah et al., 2019; Prashar et al., 2020; Pawar et al., 2021; Shivendra et al., 2021.
	ii.	Enhance members' collaboration	Guo et al., 2018; Longo et al., 2020; Madumidha et al., 2019; Awan et al., 2020; Bumblauskas et al., 2020; Chen S et al., 2021; Espinoza et al., 2021; Sudha et al., 2021; Sun et al., 2021; Kumar et al., 2022.
	iii.	Decentralized operations	Bermeo-almeida et al., 2018; Basnayake & Rajapakse, 2019; Casino et al., 2019; Felippe & Demanboro, 2019; Harshavardhan et al., 2019; Jaiswal et al., 2019; Salah et al., 2019; Afrianto et al., 2020; Casino et al., 2020; Kohler & Pizzol, 2020; Peña et al., 2020; Prashar et al., 2020; Torky & Hassanein, 2020; Wang et al., 2020; Chen et al., 2021; Cui et al., 2021; Ekawati et al., 2021; Hong et al., 2021; Kramer et al., 2021; Mukherjee et al., 2021; Orjuela et al., 2021; Pawar et al., 2021; Sathya et al., 2021; Shivendra et al., 2021; Sun et al., 2021; Yang et al., 2021; González-Puetate et al., 2022.
	iv.	Enhances trust among stakeholders	Guo et al., 2018; Baralla et al., 2019; Afrianto et al., 2020; Enescu et al., 2020; Kohler & Pizzol, 2020; Pooja et al., 2020; Putri et al., 2020; Qian et al., 2020; Song et al., 2020; Thejaswini & Ranjitha, 2020; Bai et al., 2021; Baralla et al., 2021; Ekawati et al., 2021; Hong et al., 2021; Hu et al., 2021; Orjuela et al., 2021; Shwetha & Prabodh, 2021; Sun et al., 2021; Rejeb et al., 2022.

v.	Better return on investments and profits	Balakin et al., 2021; Stranieri et al., 2021; Vern et al., 2022.
vi.	Cost benefits (reduces transaction costs, cost of quality, time, activity)	Cong et al., 2019; Harshavardhan et al., 2019; Jaiswal et al., 2019; Kamilaris et al., 2019; Afrianto et al., 2020; Bumblauskas et al., 2020; Kumarathunga, 2020; Perez et al., 2020; Xu et al., 2020; Baralla et al., 2021; Singh & Vinay, 2022; Oguntegbe et al., 2022; Varavallo et al., 2022; Wünsche & Fernqvist, 2022.

4.1.2 Challenges of BCT in the AFSC

Implementing blockchain technology for agri-food traceability has long-term positive impacts on research and practical implementation, as described in section 4.2. Vivaldini (2021) suggested researching the challenges of blockchain technology platforms. Implementation challenges to address the second part of RQ1 were also identified (Table 3). BCT is error-proof and increases the challenges of immutability and irreversibility to data alteration. It doesn't allow modifying the data or verifying transactions. Thus, there is no scope for errors due to human inefficiency (Dutta et al., 2020; Kamble et al., 2020; Pranto et al., 2021;). Smart contracts, once deployed, cannot be changed (Kumar et al., 2020; Pranto et al., 2021). BCT in AFSC is evolving, but the implementation challenges must be addressed. In addition, there are challenges relating to blockchain infrastructure, interoperability, standardization, and social and institutional issues, including legal and regulatory issues.

Table 3. Implementation challenges of BCT in AFSC

Challenges		Explanation		References
a.	Cultural challenges	i.	Trust	Fu et al., 2020; Rogerson & Parry, 2020; Yadav et al., 2020.
		ii.	Digital culture	Kamilaris et al., 2019; Afrianto et al., 2020; Lezocho et al., 2020; Rogerson & Parry, 2020.

	iii. Rapid changes in consumer preferences	Kamilaris et al., 2019.
b. Technical challenges	i. Data Management a. (Data integrity, ownership, retention)	Wu et al., 2019; Chen et al., 2021; Chopra, 2020; Demestichas et al., 2020; Kumar et al., 2020; Kamble et al., 2020; Mirabelli & Solina, 2020.
	ii. Garbage In-Garbage Out	Katsikouli et al., 2021.
	iii. Scalability	Kamilaris et al., 2019; Pearson et al., 2019; Wu et al., 2019; Chen et al., 2021; Demestichas et al., 2020; Duan et al., 2020; Liu P et al., 2020; Song et al., 2020; Torky & Hassanein, 2020; Mondragon et al., 2020; Yadav et al., 2020; Nugazina et al., 2021; Astill et al., 2019; Amin et al., 2021; Kouhizadeh et al., 2021; Pawar et al., 2021; Marchese & Tomarchio, 2022.
	iv. Immutability	Chen et al., 2021; Kamble et al., 2020; Kumar et al., 2020; Aldrighetti et al., 2021; Kouhizadeh et al., 2021; Pranto et al., 2021.
	v. Interoperability	Chandra et al., 2019; Afrianto et al., 2020; Chen et al., 2021; Demestichas et al., 2020; Iftekhar et al., 2020; Kamble et al., 2020; Liu Y et al., 2021; Kouhizadeh et al., 2021; Mondragon et al., 2020; Song et al., 2020; Yadav et al.,

		2020; Rana et al., 2021; Tan et al., 2022.
vi.	Energy consumption	Moudoud et al., 2019; Demestichas et al., 2020; Kamble et al., 2020; Lezocho et al., 2020; Liu Y et al., 2021; Torky & Hassanein, 2020; Yadav et al., 2020; Aldrighetti et al., 2021; Astill et al., 2019; Pawar et al., 2021; Varavallo et al., 2022.
vii.	Latency	Moudoud et al., 2019; Zhao et al., 2019; Kouhizadeh et al., 2021; Lezocho et al., 2020; Torky & Hassanein, 2020.
viii.	Storage capacity	Moudoud et al., 2019; Wu et al., 2019; Zhao et al., 2019; Fu et al., 2020; Mirabelli & solina, 2020; Song et al., 2020; Torky & Hassanein, 2020; Yadav et al., 2020; Astill et al., 2019; Pawar et al., 2021.
ix.	Throughput	Wu et al., 2019; Zhao et al., 2019; Lezocho et al., 2020; Torky & Hassanein, 2020; Kouhizadeh et al., 2021; Pawar et al., 2021.
x.	Digital infrastructure	Galvez et al., 2018; Lezocho et al., 2020; Rogerson & Parry, 2020; Yadav et al., 2020; Vern et al., 2022.
xi.	Security and privacy	Kamilaris et al., 2019; Pearson et al., 2019; Zhao et al., 2019; Kamble et al., 2020; Liu Y et al., 2021; Torky & Hassanein, 2020; Aldrighetti et al., 2021; Etemadi et

				al., 2021; Kouhizadeh et al., 2021; Rana et al., 2021.
		xii.	Blockchain architecture	Kamilaris et al., 2019; Afrianto et al., 2020; Kumar et al., 2020; Yadav et al., 2020; Katsikouli et al., 2021; Kouhizadeh et al., 2021.
ii.	Social and institutional challenges	i.	Lack of Skilled human resources	Kshetri, 2019; Zhao et al., 2019; Chen S et al., 2021; Fu et al., 2020; Kshetri & DeFranco, 2020; Lezocho et al., 2020; Aldrighetti et al., 2021.
		ii.	High investment cost	Kamilaris et al., 2019; Zhao et al., 2019; Kshetri, 2019; Madumidha et al., 2019; Chen S et al., 2021; Demestichas et al., 2020; Kamble et al., 2020; Kshetri & DeFranco, 2020; Patelli & Mandrioli, 2020; Rogerson & Parry, 2020; Yadav et al., 2020; Aldrighetti et al., 2021; Ali et al., 2021; Fu et al., 2020; Kouhizadeh et al., 2021; Hu et al., 2021; Pawar et al., 2021; Pranto et al., 2021; Rana et al., 2021; Oguntegbe et al., 2022.
		iii.	Rank effect	Kshetri, 2019; Kshetri & DeFranco, 2020.
		iv.	Lack of training and education	Kamilaris et al., 2019.
iii.	Regulatory challenges	i.	Industry standards and Governance	Pearson et al., 2019; Afrianto et al., 2020; Chen et al., 2021; Chopra, 2020; Rogerson & Parry, 2020; Voswinckel et al., 2020; Katsikouli et al., 2021.

		ii.	Law, policy, and regulations	Galvez et al., 2018; Chandra et al., 2019; Kamilaris et al., 2019; Zhao et al., 2019; Afrianto et al., 2020; Duan et al., 2020; Fu et al., 2020; Iftekhar et al., 2020; Kamble et al., 2020; Kumar et al., 2020; Lezocho et al., 2020; Yadav et al., 2020; Aldrighetti et al., 2021; Ali et al., 2021; Oguntegbe et al., 2022; Vern et al., 2022.
iv.	Organizational challenges	i.	Aversion from organizations to change their existing revenue model	Kamble et al., 2020; Kouhizadeh et al., 2021.
		ii.	Aversion from supply chain intermediaries (Due to unethical behaviour and decentralization)	Duan et al., 2020; Kamble et al., 2020; Yadav et al., 2020; Aldrighetti et al., 2021; Astill et al., 2019; Kouhizadeh et al., 2021; Shahid et al., 2021.
		iii.	Lack of sound knowledge about technology	Chandra et al., 2019; Demestichas et al., 2020; Kamble et al., 2020; Duan et al., 2020; Yadav et al., 2020; Astill et al., 2019; Kouhizadeh et al., 2021; Oguntegbe et al., 2022; Vern et al., 2022.
		iv.	Coordination and collaboration	Madumidha et al., 2019; Fu et al., 2020; Kamble et al., 2020; Yadav et al., 2020; Kouhizadeh et al., 2021.

The rank effect is one of the significant implementation challenges that occur due to high cost and complexity. Technology deployment tends to move from large to small organizations. Due to the high cost, complexity, and lack of internet facilities, small organizations may not be able to adopt BCT independently in their processes (Kshetri, 2019; Kshetri & DeFranco, 2020). Blockchain forking causes fake transactions, economic uncertainty, and confusion (Torky & Hassanein, 2020). In AFSC, multiple product lines will result in a higher number of daily transactions, and new block generation will take more time to process data due to the original setup of a blockchain network. This gives rise to latency and throughput issues within the blockchain network. The current AFSC setups are not designed to process millions of transactions in real-time (Zhao et al., 2019; Kayikci et al., 2022; Lezoche et al., 2020). Multichain management gives rise to scalability. Integrating BCT with existing traceability systems and configuring multiple BCT platforms in the standalone system leads to security, stability, storage, and system speed problems. Maintaining confidentiality is difficult, given the possibility of getting information through the shared blockchain network. Hence, setting specific standards, regulations, and policies is essential.

As BCT has many implementation challenges in AFSC, it is necessary to understand boundary conditions for its implementation. The review identified a few articles that discuss strategies and boundary conditions for implementing AFSC. Samal et al. (2019) suggested that supply chains must be modified, and significant organizational measures should be taken before BCT implementation. Many agri-food companies fail to understand the requirements to be fulfilled before implementing BCT. Behnke et al. (2019) concluded that before technology implementation, all supply chain actors should have sound knowledge of technology to access the traceability information system. Data collected and stored is used to maintain internal traceability. Blockchain develops a transparent system for consumers, producers, retailers, and farmers. It is crucial to decide on the level of information to be shared on traceability information systems. Hew et al. (2020) suggested implementing an orientation strategy for manufacturers to understand the system and institutional pressure to adopt BCT. It is essential to analyse the technological characteristics of the system and develop desired results. The technology should be assumed to match the manufacturers' expected results if its technical features match them. Chandra et al. (2019) suggested a comprehensive risk assessment to ensure the existing system integrates and mitigates the risks associated with blockchain adoption. Risks like cost, participant incompetency, scalability, and cryptographic key management. Erol et al. (2021) identified various feasibility indicators for blockchain implementation for multiple industries, i.e., logistics, agriculture, supply chain, health, and finance. The study concluded that the logistics and supply chain sector is feasible for blockchain projects. It is vital to understand regulations and governance, the level of technological maturity, the potential to increase revenue and reduce operational cost, and the need for building trust & improved visibility and traceability. Wu et al. (2021) investigated strategies for adopting BCT in the perishable supply chain. Consumers' preference for traceability information and traceability cost for implementing the BCT system. The BCT in AFSC should be adopted if the implementation cost is low and consumers' preference for traceability information is high. Hence, before implementing BCT in AFSC, these strategies and conditions can be considered to assess the feasibility.

4.1.3 Applications of BCT in AFSC

Most literature mainly focuses on the benefits of blockchain technology, such as traceability, transparency, and other technical aspects. Increasing consumer demand to know the origins of the products is a major driving force for companies to invest in blockchain (Rogerson & Parry, 2020). Products within food supply chains are prone to fraud, which makes them vulnerable. Blockchain can be applied to counter fraud to ensure food safety and food quality (Rogerson & Parry, 2020). An empirical study concluded that consumers are willing to shift towards innovative electronic labels based on QR and blockchain products (Violino et al., 2019). There are different types of blockchain platforms- public/private/hybrid. Cost analysis of different platforms concludes that public ledgers are expensive, whereas private and local storages are the simplest and cheapest with the best blockchain architecture (Voulgaris et al., 2020). It can also be used for environmental management to keep track of payments related to environmental services, forest mapping, traceability, soil, and climate control (Rocha et al., 2021). BCT application helps in data management related to smart farming and efficient trading in the supply chain. Walmart and IBM worked closely to address provenance traceability and food authentication (Fang et al., 2020). To address RQ2, various BCT applications in AFSC were identified through the review (Table 4). Many agri-food companies are experimenting with BCT to achieve enhanced transparency, traceability, and sustainability.

Table 4. Applications of BCT in AFSC

	Applications	References
1.	Public distribution system	Kumar, 2021; Thakare et al., 2021
2.	Smart contracts	Liu P et al., 2019; Liu Y et al., 2021; Ronaghi, 2021
3.	Food traceability	Pearson et al., 2019; Salah et al., 2019; Dutta et al., 2020; Grecuccio et al., 2020; Liu P et al., 2019; Prashar et al., 2020; Pranto et al., 2021; Shahbazi and Byun, 2021; Bhat et al., 2021

4.	Precision agriculture	Torky & Hassanein, 2020; Liu W et al., 2021
5.	Smart farming	Zhao et al., 2019; Lin W et al., 2020; Liu P et al., 2020
6.	Food and feed safety recalls	Lara Gracia, 2020; Hong et al., 2021
7.	Certification and auditing	Galvez et al., 2018
8.	Cybersecurity	Liu et al., 2021
9.	Carbon footprint	Shakhbulatov et al., 2019
10.	Management of the credit system	Mavilia and Pisani, 2021
11.	Business process reengineering	Li Yet al., 2020; Johng et., 2020
12.	Land registry	Mavilia and Pisani, 2021
13.	Logistics (Fleet monitoring, Geolocation, Delivery statistics in real-time)	Liu W et al., 2021; Rocha et al., 2021; Remondino and Zanin, 2022

BCT has been adopted for food products like coffee, fish, beef, beer, pork, fresh food, milk, and pasta to ensure data immutability, sustainability claims, provenance, and security and food safety (Chopra, 2020; Shew et al., 2022). Its applicability in e-agriculture can address food contamination and fraud (Mavilia & Pisani, 2022), safety, and authenticity (Creydt & Fischer, 2019). Implementing BCT in the milk delivery system economizes the system by reducing cost, time spent on each quality test, faster delivery, and product monitoring (Makarov et al., 2019). BCT with RFID tags can determine the provenance and validate seafood authenticity (Gopi et al., 2019). Integrating BCT with other prevailing future technologies like the IoT and big data will positively impact agri-food supply chains (Karunanayaka & Wickramarachchi, 2020; Amin et al., 2021). It helps to address HACCP standards and ensure food safety (Biscotti, 2020). Besides these applications, various BCT-based frameworks are developed and designed in studies. The application of BCT is at an infant stage; many pilot studies/ solutions/ frameworks have been developed for AFSC, such as Agriblockiot (Caro et al., 2018; Dey et al., 2021), FOODSQRBlock (Arena et al., 2019), BRUSCHETTA (Shaikh et al., 2019), AgroVita (Patel et al., 2021), Kranti (Malik et al., 2018).

4.2 Discussion

Blockchain technology has been a far-reaching area of research and holds the power to redesign the agri-food supply chain. This review offers a guide for practitioners and researchers to understand the various dimensions of BCT in AFSC. Based on the study findings, a theoretical framework is proposed for adopting BCT in AFSC (Figure 2). The framework brings together the various implementation challenges that occur during BCT adoption. The framework also discusses the benefits of the BCT, which will create value for AFSC stakeholders involved. The proposed framework provides a distinction between the challenges and benefits. Policy and regulations, scalability issues, less skilled human resources, and high investment are significant challenges. Feng et al. (2020) identified issues such as security, scalability, legal and regulations as major implementation challenges of blockchain-based traceability systems in AFSC. Similarly, Li et al. (2023) concluded issues related to governance and regulations, high investment costs, and lack of sound knowledge about technology are challenges to BCT adoption in food supply chains. Vern et al. (2023) and Choi et al. (2020) revealed high investment cost, lack of regulations and scalability as influential barriers to BCT implementation in AFSC. Interoperability, traceability, transparency, immutability, trust, and decentralization are revealed as benefits. Review findings are in line with the findings of Santhi and Muthuswamy (2022), Yogarajan et al. (2023), and Vu et al. (2023).

The review reveals various potential areas where BCT can be implemented in the agri-food supply chain, such as smart contracts, cybersecurity, and food safety. Yadav et al. (2022) suggested that BCT can emerge as a game changer in AFSC in ensuring food safety. Xiong et al. (2020) also highlighted smart agriculture as an application of BCT in AFSC. For example, Taiwan’s farmland irrigation associations use BCT to archive data related to water irrigation. The application of BCT brings transparency, which helps improve water resource use. This framework provides new theoretical constructs that will improve the knowledge of BCT adoption.

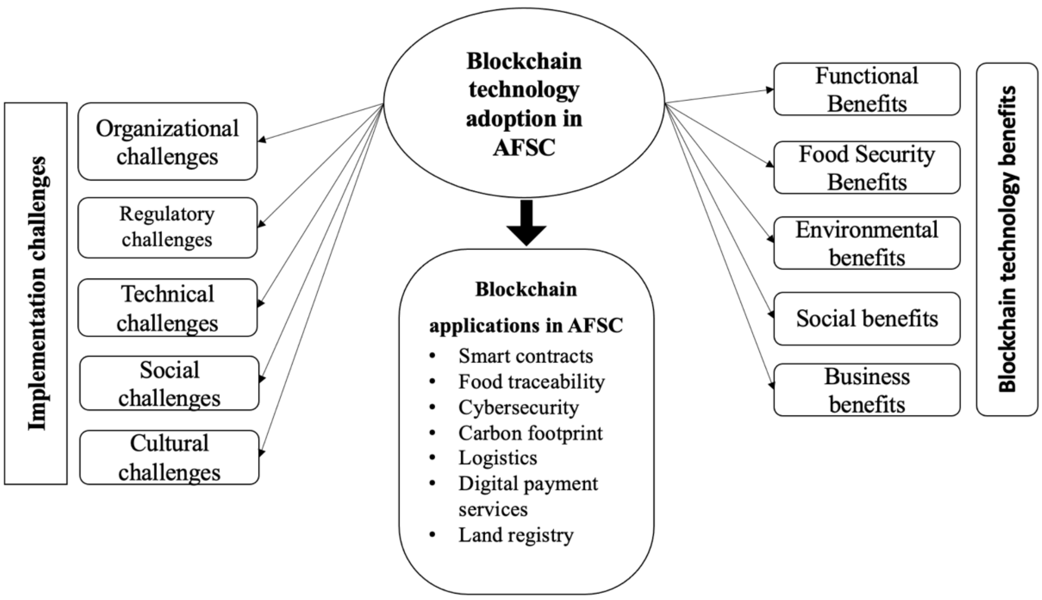

Figure 2. Theoretical framework of the study

Managers can gain an overview of BCT developments in AFSC regarding its benefits, implementation challenges and potential applications. Additionally, although conceptual, the framework can assist managers in planning and executing BCT. It will enable the managers to adopt early changes in this domain, become competitive, and gain benefits.

5. Implications for future research directions

This literature review comprehensively analyses BCT's benefits, implementation challenges, and applications in the agri-food supply chain. In this prominent area of research, there are several unexplored topics like the role of blockchain in addressing protection challenges, security of smart contracts, examining food fraud, and security & safety of traceability databases. The study has summarized the research gaps and future research directions in the field of BCT for AFSC proposed by various researchers in managing and understanding the technology based on the literature review. On the technological front, future research can investigate the willingness of different supply chain stakeholders towards public/private/hybrid blockchain platforms. It is difficult for AFSC to adapt to other commercial BCT platforms, which will give rise to various challenges. Thus, conducting empirical studies on identifying these challenges and suggesting strategies to overcome them will be insightful. Research can also focus on developing and designing a different mechanism to ensure the authenticity and originality of the data entering the system. Various studies have suggested that the security of IoT networks can be improved if implemented with BCT. Yet, few studies have empirically investigated the critical success factors for adopting blockchain in AFSC to reduce IoT security risks and threats. Therefore, integrating IoT with BCT and its effect on enhancing the system's security can be studied.

It is interesting to note that several contributions also highlight that BCT has the potential to enhance organizational collaborations and trust between different stakeholders to facilitate transparency and traceability. Thus, theoretical and empirical research is required to understand the effect of BCT on consumer awareness, consumer knowledge, and consumers' understanding of different food quality dimensions in food firms. Additionally, the role of BCT in strengthening the vertical relationship among the supply chain stakeholders can be studied. The consumers' level of adoption, trust, and acceptance of BCT applications would be a promising area for future research. It would also be insightful to explore further and assess the economic impacts of BCT adoption in AFSC. Governance is usually considered an economic sustainability pillar in supply chain management. Effective, sustainable governance can improve a firm's competitiveness and boost overall profits.

Further research can focus on studying the influence of BCT on AFSC governance and improving overall sustainability. This review produced several useful insights that would interest academics and researchers. Future research can empirically explore the review findings further by combining them with management theories and extending the work on BCT adoption in AFSC. The framework provided in the study can further be explored using multi-criteria decision-making techniques such as structural equation modelling, fuzzy decision-making trials, evaluation laboratories, etc.

6. Conclusions

The current state of blockchain technology in the agri-food supply chain is examined in the review. The research is timely because it offers a firm framework for comprehending a technology whose benefits are not yet fully understood, whose challenges are unpredictable, and whose application path remains unclear. The literature regarding blockchain technology in the agri-food supply chain was analysed for five years, between 2018 and 2022. A total of 366 articles were collected from Web of Science, Scopus, IEEE Access, Springer link, and refereed journals, out of which 187 were considered for the review. The bibliometric method was used for performance analysis of the literature. The review depicts increased publications where most authors are from China and India. The *'VoSviewer'* software was used for citation network analysis, which provided four clusters indicating different research trends within the umbrella of BCT in AFSC, viz. benefits and challenges, commercial applications, BCT-based frameworks, sustainability, and trust. The four clusters were treated as building blocks of the review and were further explored in depth through content analysis of 187 articles by identifying the benefits, challenges, and applications of BCT in AFSC. The identified benefits were grouped under heads of functional, social, business, food security and environmental. Similarly, the review grouped implementation challenges under the heads of organizational, regulatory, cultural, technical, and social. Lastly, we explored the potential applications of BCT in AFSC.

There are a few limitations to this review. Many articles were chosen to drive insights, and the search query/string was carefully formulated. There might be a possibility that some of the relevant studies may have been overlooked. The review lacks empirical justification for the obtained results. Nevertheless, this review provides a valuable theoretical contribution to the topic. The nature of the SLR methodology is qualitative and descriptive. This review offers evidence-based future avenues for implementing BCT in AFSC.

Data availability statement: This manuscript has no associated data.

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Annexure

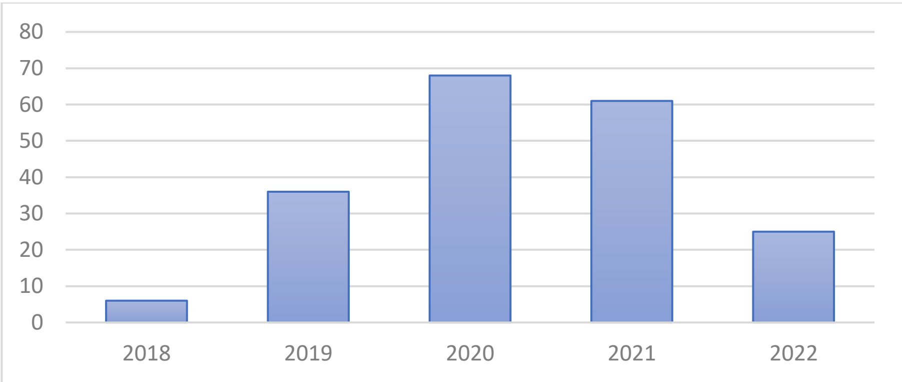

Figure A1. Annual scientific production

Table A1. Country-specific production

Country	Number of Articles
China	156
India	106
Italy	87
United States of America	51
United Kingdom	42
Greece	22
Canada	18
Malaysia	18
Australia	17
Indonesia	17

Table A2. Top journals

Sources	No. of Articles
IEEE Access	10
Journal of Cleaner Production	8
Sustainability	8
Advances in Intelligent Systems and Computing	7
IOP Conference Series: Earth and Environmental Science	5
Applied Economic Perspectives and Policy	3
Communications in Computer and Information Science	3
Food Control	3

International Journal of Environmental Research and Public Health	3
International Journal of Information Management	3
Trends in Food Science and Technology	3
ACM International Conference Proceeding Series	2
British Food Journal	2
Computers and Electronics in Agriculture	2
Computers in Industry	2
Electronics	2
International Journal of Advanced Computer Science and Applications	2
International Journal of Production Economics	2
International Journal of Production Research	2

Table A3. Primary information about articles

Description	**Results**
Timespan	2018:2022
Sources (Journals, Books, etc)	131
Documents	187
Average years from publication	1.68
Average citations per document	40.02
Average citations per year per doc	13.78
References	8833
DOCUMENT TYPES	
Research Articles	92
Book Chapter	2
Conference Paper	70
review	23
DOCUMENT CONTENTS	
Keywords Plus (ID)	995
Author's Keywords (DE)	412
AUTHORS	
Authors	677
Author Appearances	727
Authors of single-authored documents	8
Authors of multi-authored documents	669
AUTHORS COLLABORATION	
Single-authored documents	8
Documents per Author	0.27
Authors per Document	3.62
Co-Authors per Documents	3.89
Collaboration Index	3.74

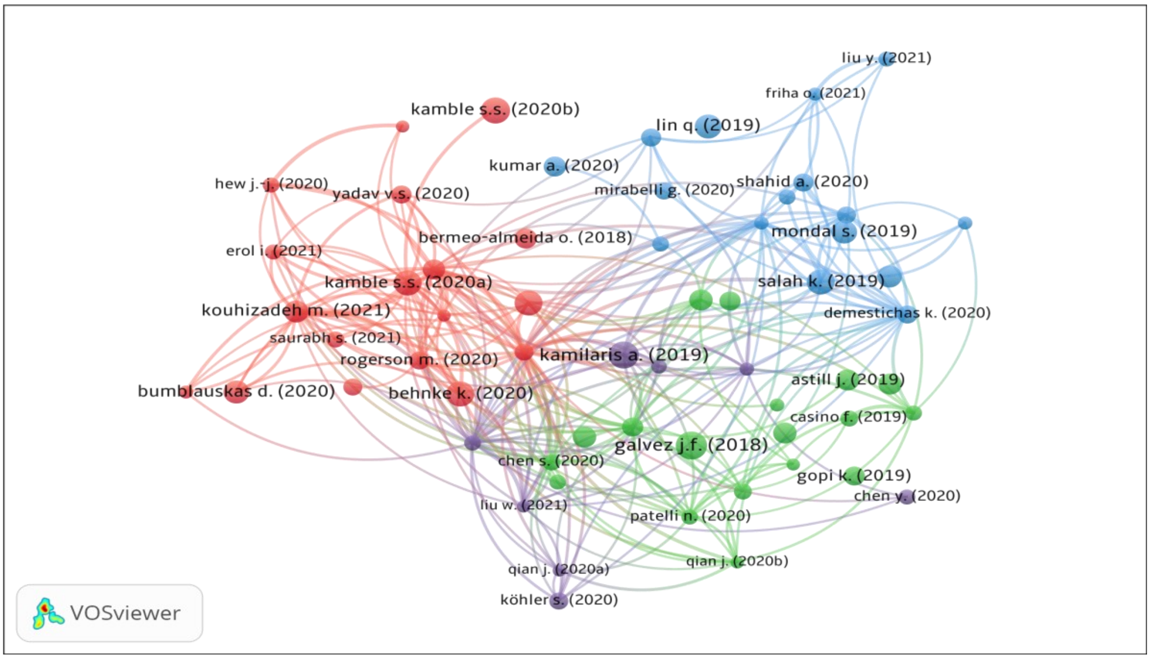

Figure A2. Citation Network Analysis