IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received 3 October 2022, accepted 23 December 2022, date of publication 13 January 2023, date of current version 15 February 2023.

Digital Object Identifier 10.1109/ACCESS.2023.3236666

TOPICAL REVIEW

Blockchain Adoption in Food Supply Chains: A Systematic Literature Review on Enablers, Benefits, and Barriers

ABUBAKAR MOHAMMED[1], VIDYASAGAR POTDAR[1,2], MOHAMMED QUADDUS[1], AND WENDY HUI[3]

[1]School of Management and Marketing, Curtin University, Perth, WA 6845, Australia
[2]Symbiosis Institute of Technology, Symbiosis International University, Pune 412115, India
[3]Singapore Institute of Technology, Singapore 138683

Corresponding author: Abubakar Mohammed (abubakar.mohammed@postgrad.curtin.edu.au)

This research was funded by Curtin University Research Training Program (RTP) Australian Government Scholarship, Food Agility CRC Scholarship and Blockchain Research and Development Lab.

ABSTRACT Globalization of the food supply chain (FSC) has brought significant challenges to the food system, such as fraud, safety, security, and quality issues, due to information asymmetry. Globalization also increases the difficulty and complexity of solving these problems to improve FSC efficiency. Blockchain technology (BCT) has proven to have the capability to transform FSC based on its potential benefits. However, studies of BCT adoption in FSC are relatively new and scarce. This study systematically reviews the current state of research in the space of BCT and FSCs. In carrying out the research, a systematic literature review (SLR) was deployed using two prominent databases, Scopus and Business Source Complete (EBSCO), covering articles from 2016 to 2021, with 52 articles synthesized to identify blockchain enablers, benefits, and barriers. Based on this review, a conceptual framework was developed for BCT adoption within the FSC. The study identified scalability, interoperability, high cost, lack of expertise, and regulations as the most likely barriers to BCT adoption. It contributes to the body of knowledge by providing insights into BCT adoption in the FSC and offers evidence-based direction for other industries to build their BCT strategies.

INDEX TERMS Blockchain technology, food supply chains, enablers, benefits, barriers, systematic literature review.

I. INTRODUCTION

Food supply chains (FSCs), as defined by Folkerts and Koehorst [2], are a ''set of interdependent companies that work closely together to manage the flow of goods and services along the value-added chain of agricultural and food products, to realize superior customer value at the lowest possible costs''. The FSC is a complex system consisting of several stakeholders, such as consumers, farmers, manufacturers, distributors, retailers, and the government. Each of these stakeholders has different roles in FSC processes [3], [4], [5] from farmed crops to consumer forks.

According to estimates, the population of the globe will increase to 8.5 billion by 2030, 9.7 billion by 2050, and 11.2 billion by 2100 [5]. Food security has become a dominant issue globally and has received more attention in recent years due to increasing concerns within the food industry. Today, FSCs are becoming more complex because of globalization, and it is common for companies to outsource trade, manufacturing, logistics, and other tasks. However, the extent and intricacy of the supply chain increase the chances of product scams and loss of trust among supply chain stakeholders [6]. Consequently, traceability is a crucial prerequisite in the supply chain industry, particularly in the FSC [7], [8]. Consumers demand knowledge of a product's origin to confirm food quality.

There have been several food scandals around the world, such as the China milk scandal in 2008 [9] and India's immense ''food theft'' scandal in 2011 [10]. In 2013, there was a horsemeat scandal in the United Kingdom [11]. In the same year, an egg contamination scandal affected 15 European countries, including Hong Kong [12]. These issues

The associate editor coordinating the review of this manuscript and approving it for publication was Vivek Kumar Sehgal.

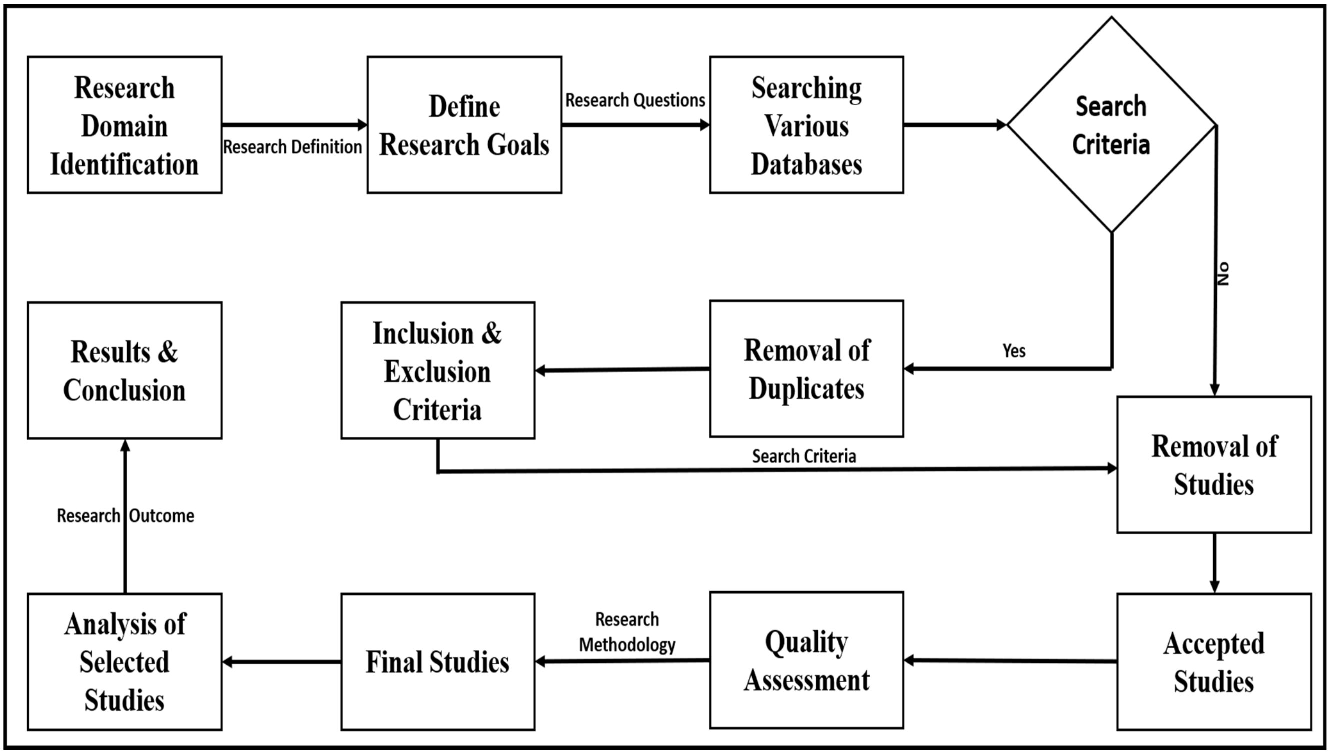

FIGURE 1. Outline of paper, adapted from Baviskar, et al. [1].

affect consumer attitudes toward the food market [8], resulting in a lack of trust, transparency, and inefficient food traceability [13], [14]. This indicates the need for an effective food traceability system [15], [16], [17], [18].

The emergence of BCT has transformed the supply chain based on its potential benefits and advantages [19]. It promises to improve the traditional supply chain processes [8], which have generally been more centralized. Blockchain has been used in finance [20], [21]. For many years, blockchain has also gained much attention, mainly in supply chain management, for improving transparency and creating trust among supply chain partners [22], [23]. Some big companies, such as IBM and Walmart, have explored blockchain technology to address food tracking and safety issues in China to improve food traceability across the supply chain [24].

Figure 1 shows the overall outline of the article process from start to finish. The remainder of this paper is organized as follows. Section II introduces the blockchain concept. The prior study is explained in section III. The method is discussed in section IV, and the analysis and results in V and the article concludes with a discussion, limitations, future research directions and conclusion.

II. BLOCKCHAIN TECHNOLOGY

A. CONCEPT

The core concepts behind blockchain technology (BCT) were anticipated in the late 1980s and the early 1990s. The Turing Award-winning Leslie Lamport established the Paxos protocol in 1989 as a consensus model for achieving a treaty in computer networks, where both the computer and networks may be untrustworthy [25]. Subsequently, in a series of articles [26] written from 1990 to 1997, the author presented the idea of a signed information chain that forms an electronic ledger [27]. This ledger comprised documents with a digital signature, which made it easy to prove that these signed documents had not been altered. These authors were acquainted with a few more developments to make this data structure more effective in three different ways: 1) using faster computable hashes instead of signing document links; 2) grouping documents into blocks in place of processing them separately; and 3) inside the respective block, connecting them with a binary Merkle tree structure as a substitute for linear document linking transaction hash indicators. In 2008, the concept of the BCT was revised and proposed by Nakamoto [28] and implemented as an open-source project in 2009 [20]. Bitcoin was the first real-world application of the BCT [28]. Bitcoin is a decentralized peer-to-peer network for cryptocurrency and a well-known use case of BCT. Technology is considered to have created the term ‘‘blockchain’’.

B. CHARACTERISTICS OF BLOCKCHAIN

Fundamentally, a blockchain is a connected distributed database managed among nodes in peer-to-peer (P2P) networks, as described in [29].

1) NETWORK LAYER

This layer is the bottom layer of the computing node and ensures the functionality of the network. P2P networks are vital for ensuring that blockchain nodes can communicate with each other in a decentralized manner.

2) PROTOCOL LAYER
This layer is the second bottom layer and consists of basic BCT-like consensus procedures and cryptographic techniques. This layer guarantees the proper operation of the structure.

3) LEDGER LAYER
The global ledger is the third layer from the bottom and is accountable for the reliable and secure transmission of transactions (including Smart Contracts), which is the mission of the main blockchain. This ensures that the system works correctly.

4) APPLICATION LAYER
APIs are offered by this top layer for numerous applications. The layer oversees interactions with the blockchain when a business needs to call for it.

C. TYPES OF BLOCKCHAIN
Blockchain is an underlying technology that powers Bitcoin and other cryptocurrencies. Blockchain follows a distributed approach, in which multiple nodes are interconnected without a central control node. The following section focuses on the various types of BCT [20], [29], [30].

1) PERMISSIONLESS
The best example of a permissionless blockchain is Bitcoin, which powers most digital currencies in the market, such as Bitcoin, Ethereum, and Litecoin [20], [29], [30]. There are no barriers to who can use them. Node-mining software can be used. Anybody following blockchain rules can access the wallet and write data to the transaction. These blockchains are open and translucent and can be reviewed by anyone. It has also been recognized as a public blockchain system.

2) PERMISSIONED
This is generally called "private blockchain". It acts as a closed ecosystem in which individuals cannot quickly join the blockchain network, views the history, or issue transactions that require permission. This belongs to an individual or organization with centralized authority to process permits. The consensus mechanism can be similar to a public blockchain or a tool such as Ripple, Hyperledger, or R3 Corda [20], [29], [30].

3) BLOCKCHAIN CONSORTIUM OR FEDERATION
This type of blockchain deprives individuals of their power. Instead of empowering a single unit, it is delegated to a group of people or individuals that form a group known as an association or federation, for example, Quorum, Hyperledger, or Corda [20], [29], [30].

D. BLOCKCHAIN PLATFORMS
This study also highlights different blockchain platforms described below in [30].

1) ETHEREUM
is an open-source, public distribution system of blockchain that permits inventors to construct and install software applications and utilizes a unique cryptocurrency token called Ether. It also offers users an Ethereum virtual machine that acts as a setting for Ethereum-based "smart contracts".

2) HYPERLEDGER
is an open-source technology platform built for enterprises for distributed ledgers. Using an authorized distributed ledger, the first distributed ledger allows "smart contracts" to be written in common programming languages such as Java, Google Go, and Node JS. Thus, enterprises do not require additional domain-specific language training. The core difference between this platform and other platforms is that it supports pluggable consensus and makes the platform more resourceful for specific use cases.

3) R3 CORDA
was designed to associate with the world's top banks. This is the platform for a distributed ledger. This depends on a structure with nodes accountable for applying smart contracts. It is a fully licensed network.

4) RIPPLE
is an open-source protocol designed for economic and swift transactions, which uses a general ledger controlled by a network of independent nodes. Interestingly, the Ripple Token XRP cannot be mined, such as Bitcoin or other cryptocurrencies, but is distributed from the beginning.

5) QUORUM
was established by JP Morgan. This is the initial stage of blockchain applications in the financial division. This is a licensed blockchain designed particularly for financial use, based on Go Ethereum. This is meant to protect the privacy of records, which is an essential aspect of financial organizations.

The comparisons of existing blockchain platforms are briefly summarized in Table 1

E. BLOCKCHAIN APPLICATIONS
This section reviews the status of blockchain applications in various industries Yli-Huumo et al. [31] provide a comprehensive overview and classification of the prevailing BCT literature. Existing blockchain applications, including finance [32], [33], [34], energy [35], [36], [37], [38] supply chain [21], [39], [40], [41], [42], Internet of Things (IoT) [43], [44], [45], government [46], [47], [48], [49] and healthcare [50], [51], [52] are some of the most frequently studied industries in relation to the blockchain. In addition, we provide a summary of blockchain applications according to the most dominant evolving areas.

1) FINANCE
The highest perspective on blockchain applications in the financial division is undisputed. Research studies have been

TABLE 1. Comparison of different blockchain platforms.

Parameter	Blockchain Platforms				
	Ethereum	**Hyperledger**	**R3 Corda**	**Ripple**	**Quorum**
Industry-focus	Cross-industry	Cross-industry	Financial service	Financial service	Cross-industry
Governance	Ethereum developers	Linux Foundation	R3	Ripple Labs	Ethereum dev and JP Morgan
Ledger Type	Permissionless	Permissioned	Permissioned	Permissioned	Permissioned
Consensus algorithm	Proof of Work (PoW)	Pluggable framework	Pluggable framework	Probabilistic voting	Majority voting
Industry focus	Ether	No currency	No currency	XRP	-
Smart contract functionalities	Yes	Yes	Yes	No	Yes

Source: *Adapted from Sheth and Dattani [30].*

devoted to improving performance and transaction [53], [54], safety, privacy, and confidentiality [55], business economics [56], and financial contracts [57].

2) HEALTHCARE

Blockchain applications have broad applicability in the healthcare field, including biomedicine [58], [59], insurance claims [60], [61], electronic medical record (EMR) management [62], [63], [64], and pharmaceutical supply chains [65], [66]. By 2025, the healthcare sector may save up to $100 billion annually by implementing BCT, according to a recent analysis by BIS Research. The cost savings will be seen in decreased operations costs, IT costs, fraud connected to counterfeit goods, and insurance fraud. According to the analysis, worldwide blockchain applications in the healthcare sector are anticipated to expand at a compound annual growth rate of over 64% between 2018 and 2025. By 2025, it will be worth around $6 billion [67].

3) INTERNET OF THINGS

IoT applications require a reliable mechanism that ensures the integrity and transparency of the gathered data and its interactions [68], safety [69], security [70], device management [71], identification [72], and confidentiality [73]. The Global Blockchain IoT Market, according to Custom Market Insights (CMI), was valued at USD 138.78 million in 2021 and is projected to grow to USD 152.8 million in 2022 and USD 22189 million by the end of 2030 at a CAGR of almost 73.5% over the forecast period 2022-2030 [74].

4) GOVERNMENT

Blockchain in government is intended to improve e-government [75], electronic voting [76], price archives [77], and virtual identification [78].

5) SUPPLY CHAIN

The blockchain supply chain market is anticipated to grow at a CAGR of 81.7% from 2021 to 2026. The significant growth drivers for the market include an increasing need for supply chain transparency and a rising desire for increased supply chain transaction security [79]. It is anticipated that implementing BCT in the supply chain will increase environmental, social, and economic sustainability [39], [80]. Chinese government research institutes have developed tracking supply chain policies for blockchain services. This development has helped track products throughout the supply chain and contributed to the country's development [81].

F. BLOCKCHAIN IN THE FOOD SUPPLY CHAIN

Several studies have provided significant views on how blockchain can improve the FSC Tian [45] IoT and blockchain were combined to suggest a system for tracking food, determining real-time food traceability using hazard analysis and critical control points (HACCP) Similarly, Bumblauskas et al. [82] developed an integrated system for tracking eggs from farms to forks using blockchain and the IoT. The study conducted by Cocco et al. [83] also proposed a system that could provide actors with the ability to verify product quality. Their results showed that participants could confirm the quality of a particular product. Tan and Ngan [84] developed a framework for food safety and traceability in the Vietnamese dairy industry. This study indicates that a food traceability framework is essential. Chan et al. [85] also developed a traceable and transparent supply chain management framework. Other areas that use blockchain as a service include the e-commerce JD of China, which tracks beef imports using blockchain platforms. Walmart also used a blockchain for distribution [81]. A recent study by Collart and Canales [86] summarized a list of food industries that have adopted blockchain-based platforms, as shown in Table 2. IBM Food Trust, created in 2017 in conjunction with Nestlé Unilever and Walmart, has embraced a BCT for traceability within the FSC [86].

III. PRIOR STUDY

As blockchain is still in its early stages, researchers and practitioners have explored blockchain applications in FSC in recent years. Table 3 presents the existing review studies on blockchain in FCS.

Duan et al. [90] investigated blockchain's current research, benefits, and challenges in the FSC between 2008 and 2019.

TABLE 2. Several food industries have implemented blockchain-based traceability software.

Industry	Blockchain platform	Products	Use cases	Information accessibility to consumers
Walmart and its subsidiary Sam's Club	IBM Food Trust	Leafy greens Food	Food safety, traceability	-
Albertsons Companies	IBM Food Trust	Romaine lettuce	Food safety, traceability (Pilot phase)	-
Carrefour (European grocery chain)	IBM Food Trust	Tomatoes, oranges, eggs, milk, salmon, and cheese	Food safety, transparency	QR code scanning
Cargill	Hyperledger Grid	Turkey	Food traceability, transparency, provenance	-
Dole	IBM Food Trust	Salads and fresh vegetables	Traceability	In progress, planned by 2025
Bumble Bee Foods	SAP Cloud Platform Blockchain	Fair Trade Yellowfin tuna	Traceability, food safety, provenance	QR code scanning
Nestlé	IBM Food Trust and other platforms pilots	Coffee, dairy, and palm oil	Traceability, provenance	QR code scanning
Golden State Foods (Supplier for fast food industry)	IBM Food Trust	Beef, produce	Traceability	-
Folgers	IBM Food Trust, in collaboration with Farmer Connect	Coffee	Traceability, supplier insight	QR code scanning
Certified Origin's Group (Bellucci brand)	Oracle Blockchain	Extra virgin olive oil	Traceability, transparency, provenance	Code entered in the app (Blockchain not yet deployed)
Starbucks	Microsoft's Azure Blockchain Service	Coffee	Food traceability	QR code scanning

Source: *Adapted from Collart and Canales [86].*

They performed a content analysis and suggested four benefits and five barriers to blockchain adoption within an FSC. A review of blockchain applications in agri-food from 2013 to 2018 [94] indicated the need for more remarkable real-world case studies. Likewise, research from 2013 to 2019 investigated future challenges of blockchain in agricultural supply chains [92] and discussed potential future blockchain challenges [7]. Liu et al. [88] combined information and communications technologies with blockchain technologies in agriculture using bibliometric and content analysis. Their findings provide a fundamental understanding of information, communications technologies, BCT in agriculture, possible challenges, and blockchain application in agribusiness [87]. Kayikci et al. [3] reviewed blockchain-based people, processes, and performance models to improve the food supply chain performance. Feng et al. [91], the use of blockchain was investigated to improve agri-food traceability by reviewing the methods, benefits, and challenges.

Similarly, Chen et al. [8] and Zhao et al. [95] used thematic analysis to examine the procedures, advantages, and barriers of implementing blockchain in the FSC and suggested how blockchain could enhance food supply chains. Vu et al. [89] reviewed blockchain implementation in an FSC. They provided a conceptual framework that decision-makers could use to determine whether blockchain would be a good fit for their company. Similarly, a conceptual framework for blockchain in the food business was proposed in another study [93].

A. MOTIVATION

To the best of our knowledge, the FSC has few systematic literature reviews (SLRs) articles on blockchain adoption within an FSC. We also noted that few studies had included other blockchain applications. This study aimed to review existing blockchain research in FSC and develop an integrated framework for blockchain adoption within the FSC. The proposed integrated framework overcomes the

TABLE 3. Summary of recent reviews on BCT in FSC.

References	Aim
[87]	To review the application of blockchain in agribusiness.
[88]	It aimed to review the application of information communication technologies and blockchain technology for agriculture.
[89]	It aimed to review blockchain adoption in FSCs.
[90]	It aimed to investigate how BCT has been used in the FSC.
[91]	It aimed to review the benefits and barriers of development methods in agri-food traceability.
[8], [95]	Its goal was to investigate whether the FSC would use blockchain technology.
[92]	It aimed to investigate current research trends and possible future challenges of blockchain in agriculture.
[7]	It aimed to review blockchain GS1 standards in the FSC.
[3]	To examine possible issues with blockchain in the food business.
[94]	To review blockchain technology in the food industry.
[94]	It aimed to review BCT applications in the agri-food sector

limitations related to FSC and encourages academics and practitioners to adopt and use it effectively in FSC.

B. GOALS

This study systematically reviewed and synthesized prior studies that explored the adoption of BCT in FSC based on the research questions in Table 4.

TABLE 4. Research questions.

#	Research Questions	Objectives/Justifications
RQ-1	What is the current state of research on BCT adoption in FSC?	To review the existing research on BCT in FSC.
RQ-2	What are BCT's enablers, benefits, and barriers in FSC?	The goal is to identify the enablers, benefits, and barriers of BCT in FSC.
RQ-3	What are the research gaps and future research directions?	To identify gaps and future direction to plan future work.

IV. METHODOLOGY

To answer our SLR research questions, we conducted a systematic review using the guidelines of Kitchenham and Charters [96] and Tranfield et al. [97], and in line with the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)," as was used by Liberati et al. [98].

A. SEARCH STRATEGIES AND DATA SOURCES

The authors selected two prominent databases to source literature for this systematic literature review: Scopus and Business Source Complete (EBSCO), replicating the methodological approach [99], [100]. The search was conducted between 2016 and 2021.

To identify the keywords searched to investigate blockchain in the food supply chain, a broad statement was initially used (blockchain and food supply chain). However, this led to limited results as a result of which the authors expanded the search with different terms, including "blockchain" "blockchains", "block chain", "block chains", "blockchain technology", "distributed ledger", "distributed ledger technology", "shared ledger", "decentralized ledger", "smart contracts", "smart contract", "hyper ledger", "Hyperledger", and "Ethereum". Alternate terms for food and agriculture were also used, including "food", "food supply", "food supply chain", "food security", "food fraud", "food quality", "food safety", "food scandal", "food trust", "food waste", "food traceability", "food transparency", "food supply chain management", "agriculture", "agri-food", and "agrifood". We used "AND" and "OR" logic for the search strings. The final search strings used in this study are presented in Table 5.

B. INCLUSION AND EXCLUSION CRITERIA

Table 6 presents inclusion and exclusion criteria and Table 7 is the quality assessment for this study, replicating the approach taken by Taylor et al. [101].

C. QUALITY ASSESSMENT

A quality assessment checklist was used to check the relevance of the articles in this study based on the approach taken by Taylor et al. [101] and Hosseini et al. [102]. The checklist consisted of five stages, as shown in Table 7.

D. SEARCH RESULTS

The initial search was limited to titles and abstracts. Based on the search criteria, 322 articles were identified from the two databases. A total of 168 duplicate papers were identified and removed, leaving 154. The authors reviewed the titles and abstracts and identified potential articles focusing on blockchain and food or agricultural supply chains. This resulted in 85. The authors then read the full articles to determine which were relevant or where full texts were unavailable. This resulted in 43 papers. Nine (9) papers were added based on snowballing techniques [96], leading to a final sample of 52 articles for further analysis. PRISMA's [96] flowchart is shown in Figure 3.

V. ANALYSIS AND RESULTS

The distribution of selected studies related to BCT in FSC in terms of publication year is illustrated in Figure 2. The findings indicate an increase in studies in the space in recent

TABLE 5. Search query for databases.

Final search strings	Databases	Search query
("blockchain" OR "blockchains" OR "block chain" OR "block chains" OR "blockchain technology" OR "distributed ledger" OR "distributed ledger technology" OR "decentralized ledger" OR "shared ledger" OR "smart contracts" OR "smart contract" OR "hyper ledger" OR "hyperledger" OR "ethereum") AND ("food" OR "food supply" OR "food industry" OR "food supply chain" OR "food security" OR "food fraud" OR "food quality" OR "food safety" OR "food scandal" OR "food trust" OR "food waste" OR "food traceability" OR "food transparency" OR "food supply chain management" OR "agriculture" OR "agricultural" OR "agri-food" OR "agrifood" OR "Agri*" OR "agro*")	**Scopus**	TITLE-ABS-KEY (("blockchain" OR "blockchains" OR "block chain" OR "block chains" OR "blockchain technology" OR "distributed ledger" OR "distributed ledger technology" OR "decentralized ledger" OR "shared ledger" OR "smart contracts" OR "smart contract" OR "hyper ledger" OR "hyperledger" OR "ethereum") AND ("food" OR "food supply" OR "food industry" OR "food supply chain" OR "food security" OR "food fraud" OR "food quality" OR "food safety" OR "food scandal" OR "food trust" OR "food waste" OR "food traceability" OR "food transparency" OR "food supply chain management" OR "agriculture" OR "agricultural" OR "agri-food" OR "agri-food" OR "agri*" OR "agro*")) AND (LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016)) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j"))
	Business Source Complete (EBSCO)	AB ("blockchain" OR "blockchains" OR "block chain" OR "block chains" OR "blockchain technology" OR "distributed ledger" OR "distributed ledger technology" OR "decentralized ledger" OR "shared ledger" OR "smart contracts" OR "smart contract" OR "hyper ledger" OR "hyperledger" OR "ethereum") AND AB ("food" OR "food supply" OR "food industry" OR "food supply chain" OR "food security" OR "food fraud" OR "food quality" OR "food safety" OR "food scandal" OR "food trust" OR "food waste" OR "food traceability" OR "food transparency" OR "food supply chain management" OR "agriculture" OR "agricultural" OR "agri-food" OR "agrifood" OR "Agri*" OR "agro*") OR TI ("blockchain" OR "blockchains" OR "block chain" OR "block chains" OR "blockchain technology" OR "distributed ledger" OR "distributed ledger technology" OR "decentralized ledger" OR "shared ledger" OR "smart contracts" OR "smart contract" OR "hyper ledger" OR "hyperledger" OR "ethereum") AND TI ("food" OR "food supply" OR "food industry" OR "food supply chain" OR "food security" OR "food fraud" OR "food quality" OR "food safety" OR "food scandal" OR "food trust" OR "food waste" OR "food traceability" OR "food transparency" OR "food supply chain management" OR "agriculture" OR "agricultural" OR "agri-food" OR "agrifood" OR "Agri*" OR "agro*")

years, as can be seen from 2016 to 2021, even though the BCT first appeared in 2008 (Nakamoto & Bitcoin, 2008). However, most articles were published in the financial sector. The authors noted that the first article was published in 2016. The authors also found that the highest number of articles (19) were published in 2020, and the lowest number was published in 2016, with just one article. Figure 2 further indicates that most studies were conducted from 2018 to 2021, signifying that publications will continue to grow in this area.

The following section analyses the articles identified in the literature after confirming 52 articles as the final sample for this study. Table 8 contains a list of the bibliographic information for each article. The articles are organized by journal name in Table 9. Methods employed in journal articles are tabulated in Table 10, and theories are tabulated in Table 11.

A. STATE OF RESEARCH ON BCT ADOPTION IN FSC

We first identified the current research on blockchain in the food supply chain based on four aspects: summary of studies, focus, method, and products (see Table 8).

B. RESEARCH METHODS USED IN THE LITERATURE

The authors also examined the research methods used in the selected articles, which are summarized (see Table 10). Findings showed that qualitative (N = 15) and proof of concept (N = 15) were the most employed methods,

TABLE 6. Criteria for inclusion and exclusion.

Inclusion	Exclusion
The paper must present an empirical study. Case studies papers presented blockchain and food or agricultural supply chains.	Papers that were focused on building blockchain technology were excluded.
The paper must be a peer-reviewed article published in a journal.	Conference papers, book chapters, white papers, technical reports, news/magazines, masters and PhD dissertations.

TABLE 7. Quality assessment criteria.

#	Statements
Stage 1	**Blockchain –** The article must be focused on the BCT in the FSC or agriculture.
Stage 2	**Context –** The article must have sufficient context for the research to help interpret the results.
Stage 3	**Blockchain and food supply chain –** To answer RQ1, the article must detail blockchain adoption within the FSC.
Stage 4	The article must explain the **enablers, benefits, and barriers** of blockchain in FSC for answering RQ2.
Stage 5	**Data –** A detail of how the data was acquired must be presented in the research.

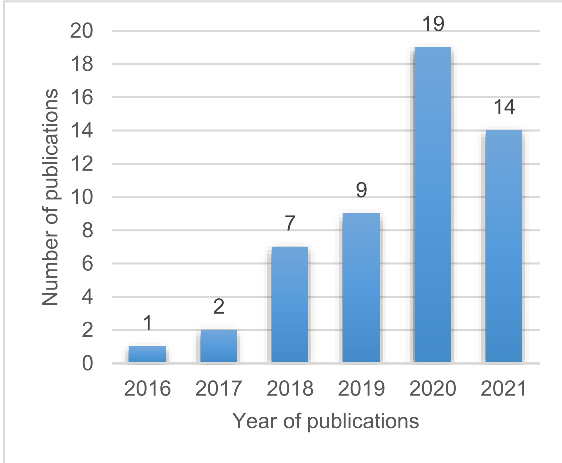

FIGURE 2. Publications by year.

followed by quantitative (N = 9). There was a smaller number of conceptual studies (N = 5) and finally, some articles (N = 8) did not specify any methods.

C. THEORIES AND FRAMEWORKS USED IN THE LITERATURE

A review of most theories and frameworks was conducted (Table 11). Frameworks to explain the adoption of blockchain in the supply chain have been proposed in earlier studies. For instance, Queiroz and Wamba [103] employed the unified theory of acceptance and use of technology (UTAUT) and theory of acceptance to comprehend blockchain adoption. These authors put up a blueprint for the deployment of blockchain in the US-India supply chain. This study demonstrates the enabling circumstances, social influence, and performance expectations and how these elements may affect blockchain adoption. Based on the Technology, Organization, and Environment Framework (TOE), Wong et al. [104] conducted a survey to assess the adoption of blockchain by small- to medium-sized businesses (SMEs) in Malaysia. Their findings demonstrate how behavioural intention to adopt blockchain is significantly influenced by cost, relative advantage, complexity, and competitive pressure. Meanwhile, Wamba and Queiroz [105] incorporated numerous theories such as the diffusion of innovations theory (DOI), resource-based view, dynamic capability, technological adoption model, and institutional approach to present a multi-stage model for blockchain diffusion. Martinez et al. [106] applied a resource-based perspective (RBV) and information processing theory (IPT). A research model based on the fusion of three theories, the theory of planned behaviour (TPB), technology readiness index (TRI), and TAM, was proposed in empirical research by Kamble et al. [107]. These authors discovered that subjective norms (SN) and perceived ease of use (PEOU) influenced perceived usefulness (PU).

A case study by Kshetri [23], identified key fundamental factors for adoption, such as speed, risk mitigation, flexibility, cost, quality, and sustainability, and created a framework for supply chain performance dimensions. In contrast, Morkunas et al. [108] developed a model based on the Osterwalder and Pigneur business frameworks. The knowledge-based approach and the Gold et al. 2015 model were used in a similar way by Caldarelli et al. [109] to investigate a single case study of an Italian agri-food company that launched a blockchain-based traceability project.

D. CONCEPTUAL FRAMEWORK

Based on the analysis results, we developed a conceptual framework that brings together the enablers, benefits, and barriers to BTC adoption in the FSC. The following Section discusses the core elements of this framework.

E. ENABLERS FOR BCT IN FSC

The literature identified the enablers of BCT adoption in FSC. These enablers are discussed in detail below.

1) TRACEABILITY

Food traceability serves as logistic management [93]. It is the capability to track and trace food processes throughout the entire FSC [8], [89]. Information can be tracked and organized using IoT devices such as QR codes, wireless sensor networks (WSN), and radio frequency identification (RFID). Blockchain can improve the food supply chain traceability [110], [111]. This shows how blockchain can also enhance the security and quality of agri-food. Researchers have proposed blockchain-based traceability systems with other emerging technologies. Feng [112] combined blockchain

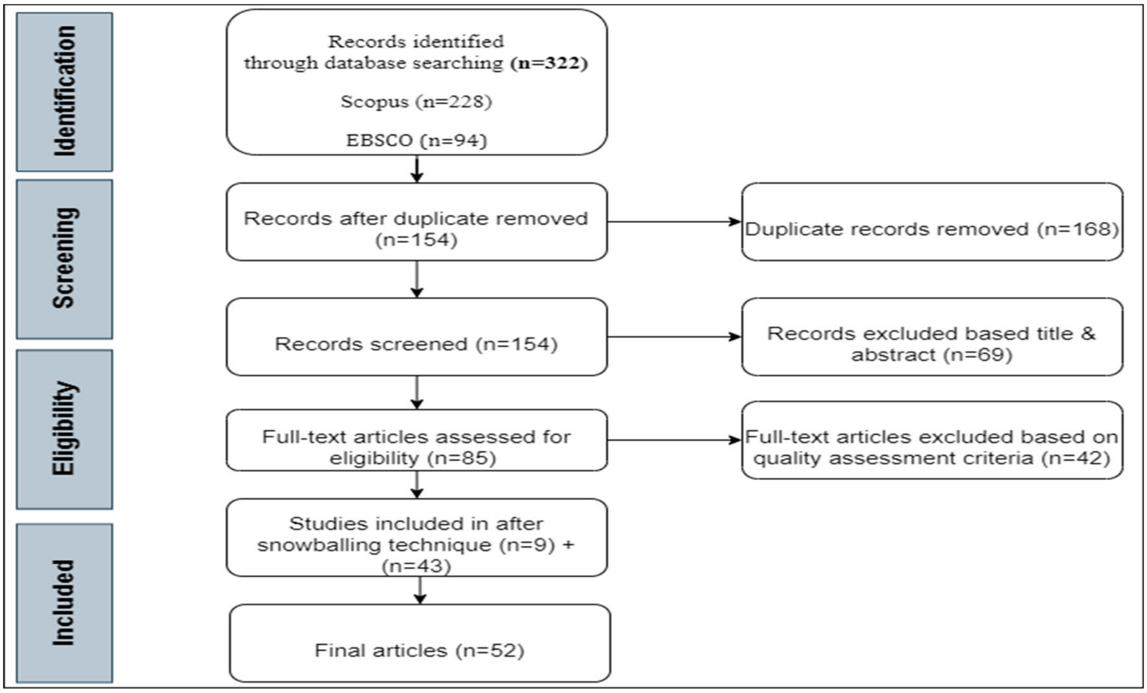

FIGURE 3. PRISMA flowchart for the selected articles.

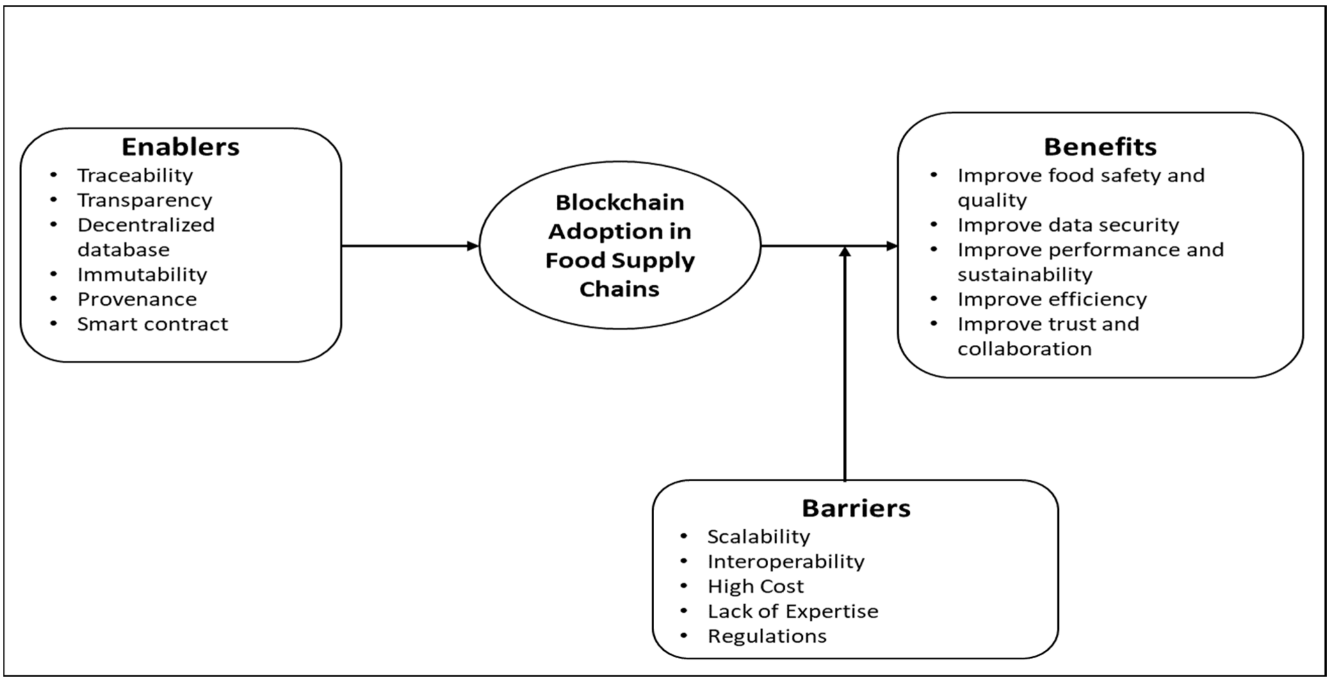

FIGURE 4. Conceptual framework for blockchain technology adoption within the food supply chain.

technology and RFID to propose an agri-food value chain traceability system to guarantee food safety and quality throughout production. Feng [45] later built a supply chain traceability system for real-time food tracing based on hazard analysis and critical control points (HACCP), providing supply chain members with real-time safety, reliability, and security. Their proposed system showed that RFID could be utilized for sharing and acquiring data in the agri-food value chain.

Similarly, Balamurugan et al. [113] proposed traceability techniques to improve food safety using blockchain and the IoT. The proposed system can avoid the entry of illegal food products into the supply chain. Tan et al. [114] propose a traceability framework for the halal food supply chain. Walmart and IBM conducted a pilot study on Blockchain traceability systems in 2016. These companies provide a blockchain traceability system for seven-day tracking of the origins of mangoes [115]. Walmart was said to intend to invest in this technology with $25 million over five years, beginning in 2017 [115].

2) TRANSPARENCY

Transparency is the potential enabler of blockchains in an FSC. Lack of transparency can affect food quality, and the use of blockchain in FSCs can improve transparency [89], [116], [117]. Despite it being in its infancy, Feng [45] refer o BCT as a ground-breaking innovation that can enhance supply chains by bringing openness, transparency, and dependability.

3) DECENTRALIZED DATABASE

The metadata used for communication in a blockchain is spread across the ledger and cannot be gathered in one place. This implies that the blockchain database is distributed. The data were not stored on a single server. Instead, it is stored simultaneously on many different computers, called ''nodes'' [118], [119]. Blockchain participants can have greater trust in each other because the database is not in one place.

4) IMMUTABILITY

Immutability implies that something does not change over time. Immutability makes it possible to create an audit trail of all actions that have been performed on the registry. This makes it possible to track any record at any given time. Blockchain provides an audit trail that cannot be changed [120], and because it is decentralized, it is harder for hackers to change or fake data in the blockchain network [121].

5) PROVENANCE

Kim and Laskowski [122], BCT makes it easier to find where things come from in the supply chain. Several industries obtain the value of their goods from their origin [19].

6) SMART CONTRACT

Stakeholders must agree to conduct digital supply chain transactions and document any changes. As a result, a smart contract is helpful because it contains agreed-upon terms of stakeholders [123]. Electronic contracts have significantly impacted business processes, particularly in the context of BCT [124]. A smart contract digitally transfers an asset or currency to a BCT application.

F. BENEFITS OF BCT IN FSC

1) IMPROVED FOOD SAFETY AND QUALITY

Blockchain will help solve some of the biggest problems in food supply chains, such as food waste, recalls, inefficiency, traceability, and fraud. The transparency and traceability of blockchain make it possible to determine where the food originated and improve its safety and quality. For example, Walmart tracks packages of sliced mangoes using a blockchain. Tracking was conducted within Mexico. Nestlé tracks milk from farms and production facilities to factories. According to Stranieri et al. [125], more knowledge of the product and process results in a better understanding of quality, which raises the perception of food quality.

2) IMPROVED DATA SECURITY

Blockchain can be used to accelerate transactions in the food supply chain. It can eliminate errors caused by traditional paper-based recordkeeping by retaining every digital transaction record. The distributed database, consensus mechanism, and cryptographic parts of the blockchain make it impossible for anyone to change the data.

3) IMPROVED PERFORMANCE AND SUSTAINABILITY

The performance of the food supply chain can be enhanced by better matching the supply and demand. Blockchain delivers real-time data regarding the ongoing activities of supply chains, such as data on stocks, demand, supplies, dwell time, and production dates. It helps food supply chains keep track of inventory [126]. Blockchain makes food supply chains more sustainable for the environment, economy, and society [126].

4) IMPROVED EFFICIENCY

Blockchain technology can improve the efficiency of FSCs in food operations. Blockchain provides real-time availability of food products [127]. For example, Walmart collected real-time information to monitor food procedures from cultivation, production, processing, and sales [128]. This means that one can always see the origin and quality of food [129]. In this way, if food is mistreated or has expired, Walmart identifies it before reaching the customer. Food waste occurs at all levels, from delivery centres to logistics processes to stores [127], [130], [131], [132]. In the 2018 Global Responsibility Report, Walmart [133] stated that the company wants to reduce or eliminate food waste. It plans to achieve zero food waste in Japan, the United States, the United Kingdom and Canada by 2025. Due to the complexity of the granularity of the recorded transactions, using blockchain in food recall processes in multi-party supply chains might help cut costs even further. Thus, food companies can avoid selling spoiled or dangerous food and prevent financial and reputational damage [134].

5) IMPROVE TRUST AND COLLABORATION

The introduction of BCT is a supreme model for Walmart to achieve the supportive effect of calculated alliances by developing collaboration in the food industry [127]. Supply chain partners can benefit from the blockchain through increased trust and cooperation [135], [136], [137].

TABLE 8. Journal articles reviewed a summary of blockchain studies in food supply chains.

Source	Summary	Focus	Methodology	Products
[148]	The paper demonstrates blockchain adoption and its implications in the agri-food sector.	Adoption	Not specified	Not specified
[149]	An operation of blockchain for food service.	Benefits	Qualitative – Case study	Food (General)
[150]	The study discusses adoption factors for blockchain in the agri-food supply chain.	Adoption Benefits Architecture Sustainable	Quantitative - Survey	Grape wine
[151]	This paper introduced a novel 3-stage methodology to integrate blockchain into the food supply chain.	Challenges Benefits	Proof of concept	Not specified
[111]	The authors examined how blockchain could change the agri-food sector.	Benefits	Qualitative - Interview	Not specified
[152]	This study examines the application of blockchain in food traceability for beef in the USA	Benefits Adoption	Quantitative - Survey	Beef
[153]	It examines consumers' intentions toward blockchain food traceability.	Adoption	Quantitative	Organic food
[125]	It explores the impact of blockchain on the perforation of the Agri-food supply chain.	Benefits Performance	Qualitative - Interview	Not specified
[86]	How blockchain adoption could impact the fresh produce supply chain in the USA.	Challenges Adoption	Conceptual	Fresh fruit and vegetables
[113]	This paper proposed a blockchain using IoT to map and avoid the entry of illegal foodstuffs through the supply chain.	Benefits	Proof of concept	Food (General)
[117]	It explores the benefits and challenges of blockchain for managing FSC.	Benefits Challenges	Qualitative – Case study	Food (General)
[154]	Public cognition of the application of blockchain in food safety management.	Adoption	Quantitative	Food (General)
[155]	This study aimed to strengthen trust in the cross-border beef supply chain between Australia and China from a consumer perspective based on a blockchain-based supply chain implementation.	Benefits Adoption	Qualitative – Focus group	Beef
[156]	The acceptance of blockchain technology in meat traceability and transparency.	Adoption	Quantitative - Survey	Meat
[157]	The influence of blockchain-based food traceability in retail.	Benefits	Quantitative - Survey	Food (General)
[158]	It proposed blockchain-based supply chain management for improved transparency.	Benefits	Proof of concept	Crops (General)
[159]	This study investigates blockchain-based Halal traceability.	Adoption	Quantitative - Survey	Halal food
[160]	Assessment of blockchain-based technologies in FSC	Benefits	Qualitative	Food (General)
[161]	They have developed a model for assessing the adoption of blockchain in the agri-food supply chain, which could help guild organizations and individuals to plan their blockchain adoption and achieve a higher level.	Adoption Benefits	Quantitative	Not specified
[82]	They have developed an integrated system for tracking eggs from farm to fork using blockchain and IoT to achieve food traceability.	Benefits	Case study Proof of concept	Eggs

TABLE 8. ***(Continued.)*** **Journal articles reviewed a summary of blockchain studies in food supply chains.**

[84]	This paper developed a framework for food safety and traceability in the Vietnamese dairy industry.	Benefits	Qualitative	Dairy (General)
[140]	The paper designed a blockchain fish system to ensure data integrity in agriculture.	Benefits	Proof of concept	Fish
[162]	It explores the application of blockchain and IoT to ensure tamper-proof data availability for food Safety.	Benefits Challenges	Proof of concept	Food (General)
[114]	It proposed a traceability framework using blockchain for the halal food supply chain.	Benefits Challenges Adoption	Qualitative - Case study	Halal Food (General)
[4]	Demonstrate blockchain for dairy products.	Benefits	Proof of concept	Dairy (General)
[163]	Demonstrates how blockchain could enhance visibility and trust in FSC.	Benefits Challenges	Qualitative - Case study	Food (General)
[164]	It explores blockchain adoption barriers in the agricultural supply chain	Benefits Challenges Adoption	Quantitative	Food (General)
[165]	The study analyzed the impact of blockchain on the agri-food supply chain.	Challenges Benefits	Not specified	Food (General)
[138]	It identifies boundary conditions for sharing information to ensure traceability.	Challenges Benefits	Qualitative - Case study	Food (General)
[166]	This paper proposed blockchain-based traceability and visibility system for agricultural products.	Benefits	Proof of concept	Food (General)
[167]	This paper explores patterns of business financing and the adoption of blockchain technology in the agricultural industry.	Adoption Benefits	Qualitative - Case study	Not specified
[168]	Integrated blockchain and IoT device food chain traceability.	Benefits challenges	Proof of concept	Fish
[169]	This study designed an Ethereum blockchain for traceability and monitoring of transactions of fresh milk from dairy farms to end consumers.	Benefits	Proof of concept	Fresh milk
[170]	This study identifies thirteen enablers that could influence the adoption of the blockchain in the agriculture supply chain.	Adoption Benefits	Quantitative - Survey	Not specified
[85]	This paper develops a framework for a traceable and transparent supply chain for the agri-food sector.	Benefits	Conceptual	Peppers
[171]	It designed a reliable prototype for food traceability using blockchain.	Benefits	Proof of concept	Food (General)
[172]	It explores the importance of blockchain in FSC.	Benefits	Conceptual	Not specified
[173]	This study explores the implementation of blockchain in food and agriculture in Canada.	Adoption	Not specified	Not specified
[174]	It developed automated food traceability based on blockchain technology and smart contracts.	Benefits	Proof of concept	Food (General)
[175]	This article examines the impact of blockchain technology on agriculture and the food supply chain.	Challenges	Not specified	Not specified
[176]	Implementation of blockchain in food and agricultural supply chain in Indonesia.	Benefits	Qualitative - Case study	Rice
[177]	Putting Food on the Blockchain	Not specified	Not specified	Not specified
[178]	Using blockchain for provenance and traceability for food logistics	Not specified	Not specified	Not specified

TABLE 8. *(Continued.)* **Journal articles reviewed a summary of blockchain studies in food supply chains.**

[23]	Explored the benefits of blockchain in supply chain management by conducting multiple case studies in achieving supply chain objectives. Blockchain could reduce cost and risk and increase the supply chain's flexibility, quality, speed, and sustainability.	Benefits	Qualitative - Case study	Not specified
[179]	It analyzed the implementation of blockchain for grains for quality assurance in Brazil.	Benefits	Qualitative-Case study	Grains
[180]	This study proposed a blockchain-based credit evaluation system to improve management supervision in FSC.	Benefits	Proof of concept	Not specified
[115]	Walmart's Pork and Mango Pilots with IBM	Challenges Benefits	Qualitative - Case study	Pork and Mango
[181]	This study investigated the future challenges of using blockchain in FSC.	Challenges	Conceptual	Food (General)
[182]	The paper then analyses the role of institutions in the food system as it has been organized and how this institutional setting might be changed to incorporate this new technology while safeguarding the objective of an overall economic optimum.	Not specified	Not specified	Not specified
[183]	The authors proposed a blockchain framework for the rice supply chain, ensuring safety throughout the supply chain.	Benefits	Conceptual	Rice
[45]	This study proposed a food traceability system based on the HACCP blockchain technology and IoT, which will provide real-time safety, reliability, and security of food products among supply chain members.	Benefits Challenges	Proof of concept	Food (General)
[112]	This study proposed a traceability system based on RFID and blockchain for the agri-food supply chain.	Benefits	Proof of concept	Fresh fruit and vegetables

G. BARRIERS TO BCT IN FSC

Although blockchain benefits FSCs, some problems still need to be addressed, such as scalability, complexity, lack of expertise, high cost, and regulations [138], [139].

1) SCALABILITY

BCT has gained popularity in recent years, and because of the rapid uptake of technology, a network's transaction volume is also increasing. The block size is restricted due to the increasing importance of the transactions. In addition, as the number of users and transactions increases, the number of nodes required to process them increases. Minimal scalability can simultaneously lead to many transactions, thereby slowing down the network [90], [140].

2) INTEROPERABILITY

Interoperability means that different blockchains can share and communicate with each other. Several blockchain projects are currently underway. These projects were written in different programming languages and on different run-on platforms. Various blockchain networks cannot connect because they cannot communicate with each other. This leads to network isolation and information asymmetry. Therefore, as suggested by Nurgazina et al. [141], and Liu et al. [142] the communication protocol should be able to work with other systems.

3) HIGH COST

The adoption of BCT may be hampered by the expenses associated with its acquisition, customization, and learning curve, particularly for small and medium-sized firms in the food supply chain [126], [143]. Building infrastructures and management capabilities for the blockchain requires significant investments [126].

4) LACK OF EXPERTISE

BCT is still in its infancy, and most stakeholders are unaware of it and its consequences on the economy [144]. Many organizations are concerned about their lack of understanding and experience with blockchain technology. Blockchain implementation is a complex and drawn-out process that requires a particular amount of technical expertise and infrastructure for business [104], [145], [146].

5) REGULATIONS

Another crucial aspect of deploying blockchain is establishing policies and a regulatory environment [95], [147]. Blockchain application is a topic on which policy and technical experts disagree. Therefore, regulatory hurdles have prevented the widespread adoption of BCT. Additionally, there is no set of precise guidelines and requirements for applying BCT to FSCs. To effectively deploy BCT in FSCs, it is vital to develop laws and standards. It is necessary to thoroughly investigate how BCT affects governance [146].

VI. DISCUSSION

This study summarizes the present state of knowledge on blockchain's enablers, benefits, and barriers in the FSC. The SLR findings highlight the relevance of blockchain in FSCs. The outcomes of the SLR analysis indicate that blockchain is a promising technology for transforming FSCs and has the potential to solve some of the issues inherent in FSCs.

TABLE 9. Articles by journal name.

References	Journal Name	#
[88], [91], [150], [154], [160], [171]	Journal of Cleaner Production	6
[23], [82], [103], [104], [138], [170]	International Journal of Information Management	6
[42], [141], [166]	Sustainability (Switzerland)	3
[66], [90], [153]	International Journal of Environmental Research and Public Health	3
[125], [157]	Food Control	2
[86], [148], [152]	Applied Economic Perspective and Policy	3
[139], [175]	Trends in Food Science & Technology	2
[19], [140]	Supply Chain Management: An International Journal	2
[94], [117]	Journal of the Science of Food and Agriculture	2
[140], [155]	Computer and Electronics in Agriculture	2
[156]	British Food Journal	1
[3], [105]	Production Planning & Control	2
[134]	IEEE Access	1
[4]	International Journal of Production Research	1
[95]	Computers in Industry	1
[181]	TrAC Trends in Analytical Chemistry	1
[84]	Sustainable Futures	1
[182]	Scientific Papers-Series Management Economic Engineering in Agriculture and Rural Development	1
[164]	Resources, Conservation and Recycling	1
[130]	Quality - Access to Success	1
[92]	Procedia Manufacturing	1
[93]	Logistics	1
[115]	The Journal of the British Blockchain Association	1
[167]	Journal of Science and Technology Policy Management	1
[165]	Journal of Food Science	1
[162]	Journal of Food Quality	1
[177]	Journal of Food Distribution Research	1
[111]	International Journal on Food System Dynamics	1
[114]	International Journal of Logistics: Research & Applications	1
[149]	International Journal of Logistics Management	1
[113]	International Journal of Information Technology (Singapore)	1

TABLE 10. Methods used.

References	Frequency
Qualitative [23], [84], [111], [114], [115], [117], [125], [138], [149], [155], [160], [163], [167], [176], [179]	15
Proof of Concept [4], [45], [82], [112], [113], [140], [151], [158], [162], [166], [168], [169], [171], [174], [180]	15
Quantitative [152], [153], [154], [156], [157], [159], [161], [164], [170]	9
Conceptual [85], [86], [172], [181], [183]	5
Not Specified [75], [89], [148], [165], [175], [177], [178], [182]	8
Total	52

TABLE 11. Theory used.

Theory	References
The Unified Theory of Acceptance and Use of Technology (UTAUT)	Queiroz and Wamba [103]
Technology, Organization, and Environment Framework (TOE)	Wong, et al. [104]; Rijanto [167]
Diffusion of Innovations (DOI)	Wamba and Queiroz [105]; Hew, et al. [159]
Resource-Based View (RBV)	Wamba and Queiroz [105]; Martinez, et al. [106]
Dynamic Capability (DC)	Wamba and Queiroz [105];
Technology Adoption Model (TAM)	Wamba and Queiroz [105];
Institutional Theory (IT)	Wamba and Queiroz [105]; Hew, et al. [159]
WARA Method	Ronaghi [161]
ISM-DEMATEL-Fuzzy MICMAC	Yadav, et al. [164]; Kamble, et al. [170]
Information Success Model (ISS)	Lin, et al. [153]
Theory of Planned Behaviour (TPB)	Lin, et al. [153]; Kamble, et al. [107]
Information Processing Theory (IPT)	Martinez, et al. [106]
Sensemaking Theory (ST)	Wang, et al. [143]
Technology Acceptance Model (TAM)	Kamble, et al. [107]
Technology Readiness Index (TRI)	Kamble, et al. [107]
Knowledge-Based View (KBV)	Caldarelli, et al. [109]

Blockchain can improve product traceability and speed up the process of determining the origin of products linked to recalls due to concerns about contamination, falsification, or other violations of food safety regulations. Blockchain also provides end-to-end product traceability, allowing the tracking of food products at every stage of the food supply chain. Our findings identify traceability, transparency, decentralized databases, provenance, and smart contracts as the most significant enablers driving blockchain adoption. Our results also discuss the benefits of BCT and how it can enhance food quality, safety, data security, trust, collaboration, performance, and sustainability in FSC processes. The results also show how helpful blockchain can be for FSC collaboration. Blockchain allows the FSC stakeholders to work together more efficiently and effectively. Our findings suggest that this could improve the performance and sustainability of food supply chains. This study proposed a conceptual framework for BCT adoption in an FSC. This framework integrates the enablers, benefits, and barriers to BCT adoption. The framework can also be used to further explore blockchain adoption within other industry contexts to understand the impacts and advantages of blockchain technology.

VII. LIMITATIONS

Although this review provides details on BCT adoption within the FSC, there are some limitations that should be considered for future research. First, this review is limited to food supply chains. Second, our inclusion criteria were limited to peer-reviewed journal articles. Our findings indicate the presence of few journal articles in the literature. Therefore, the authors suggest that it might be helpful to add conference proceedings, white papers, reports, newspapers and the like, to avoid missing available information. Third, our findings also revealed a minimal number of published blockchain adoption articles.

VIII. FUTURE RESEARCH DIRECTIONS

This study suggests that despite the potential benefits of BCT, specific barriers such as scalability, high cost, lack of expertise, and regulation are the main issues that need to be addressed.

Additional obstacles and pressures that can result from the deployment of blockchain technology should be understood through management. Our literature review framework thoroughly examined blockchain's enablers, benefits, and barriers in FSC. We propose the following future research:

- Future studies should develop real solutions to address organizational and technical barriers.
- Researchers must determine why blockchain is used (and not used) in the food industry.
- Researchers should provide examples of how blockchain influences people's lives and how they view it.
- Future research should examine how forensic testing and blockchain can be used together to ensure sure that food is safe, from the right place, and correct.
- Future studies should investigate the potential applications of blockchain in the FSC as a whole.

IX. CONCLUSION

It is clear from the review of past studies that blockchain applications in FSC are still evolving and nascent. As with many other technological innovations, the hype around blockchain has outstripped its potential benefits and opportunities. This study synthesizes the significant characteristics of blockchain, different platforms, applications of blockchain, blockchain in the food supply chain, and the barriers posed in the FSC. The main review findings were evident enablers, benefits, and barriers to BCT adoption in the FSC, which later helped to propose a conceptual framework for BCT adoption for the FSC and will provide a helpful basis for future research in this area.

ACKNOWLEDGMENT

The authors would like to acknowledge the contribution of Curtin University Research Training Program (RTP) Australian Government Scholarship, Food Agility CRC Scholarship and Blockchain Research and Development Lab for supporting this research.

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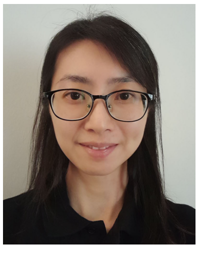
ABUBAKAR MOHAMMED received the Bachelor of Science degree in software engineering from the University of East London and the master's degree in computer science (information security) from Universiti Teknologi Malaysia. He is currently a Doctoral Researcher with the Blockchain Research and Development Laboratory, Curtin University, Perth, Australia. His doctoral research aims to investigate and examine blockchain technology's key factors and impacts on food supply chains. He is particularly interested in blockchain technology, supply chains, cloud computing, information security, and software engineering.

VIDYASAGAR POTDAR is currently the Director of the Blockchain Research and Development Laboratory (BRDL), Curtin University, Perth, Australia, where he leads a 15-member Research and Development Team that focuses on delivering commercial blockchain solutions to industry and government. In the last two years, the Blockchain Laboratory has led and successfully delivered 12 blockchain projects in Australia across a variety of industries including agriculture, sustainability, mining, art, healthcare, supply chain, photography, and recycling. He is also an Adjunct Professor at the Symbiosis Institute of Technology, Symbiosis International University, Pune, India. Furthermore, a multi-award-winning researcher, who has published over 160 articles, supervised more than 20 Ph.D. students, and raised over $3 million in research funds.

MOHAMMED QUADDUS was the Deputy Dean and the Dean of the Research from January 2009 to December 2011. From March 2013 to March 2014, he was the Director of the Curtin Graduate School of Business, Curtin Business School. He also acted as a Consultant for a number of organizations including, the DAFWA, Woodside Petroleum, and the World Bank. He is currently a Professor with the School of Management and Marketing, Curtin University, Perth. He has published over 300 papers in refereed journals, international conferences, and book chapters. His publications have appeared in Omega, the *International Journal of Production Economics*, the *European Journal of Information Systems*, *Decision Support Systems*, *Supply Chain Management*–An International Journal, *Information Systems Frontiers*, and *Rural Sociology*. His research interests include multiple disciplines, behavioral modeling in marketing and tourism, ICT and tourism, sustainability and tourism, information systems planning, logistics and supply chain management, and risk management in the supply chain. He successfully supervised over 60 Ph.D. students. In 1996 and 2005, he received the "Researcher of the Year" Award from Curtin Business School.



WENDY HUI received the Ph.D. degree in information systems from the Hong Kong University of Science and Technology. She is currently an Associate Professor with the Singapore Institute of Technology (SIT). Her teaching interests include data mining and business analytics. Her research interests include the economics of information security and research methods.