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Blockchain Technology in Food Supply Chains: A Narrative Review and Analysis

Ruohan Sun

Macau University of Science and Technology, Macau, China
zzsunruohan@126.com

Abstract: Given the advent of high-speed computing capabilities and the widespread accessibility of data, blockchain technology (BCT) has emerged as a highly promising and transformative innovation, particularly in the realm of food supply chain management. This technology has garnered considerable interest from global researchers, as evidenced by the exponential growth in scholarly publications focused on this topic over the past few years. This narrative review offers a critical evaluation of the multifaceted applications of blockchain technology within the food supply chain (FSC) through a comprehensive examination and analysis of existing literature. In addition to providing an overview of the application of blockchain in FSCs, this study also identifies areas or challenges where its potential remains underutilized and suggests the future development direction. This not only helps us fully understand the current status of blockchain in the food supply chain, but also provides a reference for exploring the broader potential applications of blockchain in shaping the future food supply chain.

Keywords: Blockchain technology, Food supply chain, Narrative literature review, Barriers.

1. Introduction

In contemporary society, particularly within the context of the burgeoning sharing economy, there exists a pressing and unprecedented demand for transparency, clarity, and traceability in the food supply chain. Historically, consumers have often found themselves at a disadvantage when it comes to knowing the exact provenance of the ingredients on their plates at restaurants. This lack of information becomes even more pronounced in an era where the interconnectedness of global supply chains has reached unprecedented levels. Consumers have suffered psychological distress due to a multitude of scandals involving harmful chemicals or bacteria found in food products, as well as the associated illnesses transmitted through contaminated food sources. One particularly notorious example that highlights the gravity of these issues is the 2008 China milk scandal. The consequences were devastating, with thousands of infants falling ill and some even succumbing to their illnesses. Providing food safety and traceability is an urgent matter. Additionally, the global food supply chain (FSC) is under increased pressure due to the rapid expansion of the global population and the resulting rise in demand for food that ensures quality, prevents waste, preserves forests, and mitigates carbon emissions [1,2].

At this time, the advent of high-speed computational capabilities and the widespread accessibility of data have paved the way for the emergence of blockchain technology (BCT) as a transformative force with profound implications for the food supply chain sector. BCT, characterized by its

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decentralized, immutable, and transparent ledger system, has rapidly ascended to the forefront of technological innovation, offering unprecedented opportunities to revolutionize traditional supply chain management practices, which is evidenced by the exponential increase in scholarly publications dedicated to exploring its potential applications and benefits [3].

In light of this, this study examines the existing literature using the narrative literature review approach to answer research questions. Based on this review, this study constructed a conceptual framework for the application of BCT in FSC. The study pointed out that blockchain has applications in FSC aspects such as product authentication, finance, and logistics. At the same time, scalability, interoperability, and high costs are the main obstacles to the application of BCT. This research contributes to the expansion of the knowledge base by offering valuable perspectives on the implementation of blockchain technology (BCT) within the food supply chain (FSC) framework, while also furnishing empirically grounded guidance for other sectors to devise their own BCT-centric strategies.

2. Definition and types of blockchain technology

Blockchain, a pioneering distributed information technology, presents itself as a formidable solution to address longstanding challenges and bolster business integrations within food supply chains. This is primarily attributed to its intrinsic characteristics, namely transparency, traceability, and tamper resistance, which collectively render it a robust framework for ensuring data integrity and operational efficiency.

The architectural design of blockchain can be bifurcated into two primary categories: permissionless and permissioned. While the former category encompasses a singular subtype, namely the public blockchain, the latter is further delineated into two distinct subtypes: private blockchain and federated blockchain. This architectural diversity empowers blockchain to function as a dependable and trustworthy third-party entity, fostering an environment where transactions between participants are securely and immutably recorded [4-6].

3. Application

Blockchain technology stands out as a revolutionary innovation with the potential to significantly enhance traceability and transparency within various industries, all while minimizing the need for intermediaries. By guaranteeing uniform and precise information accessibility for all shareholders, blockchain reduces the likelihood of misinformation and fraud, which can be particularly beneficial in sectors where data integrity is paramount, such as agriculture and food supply chains. Currently, both emerging startups and established enterprises are actively integrating blockchain solutions into their business operations. So, in the realm of food safety, blockchain is being leveraged to create robust systems that monitor and track the journey of food products from farm to table.

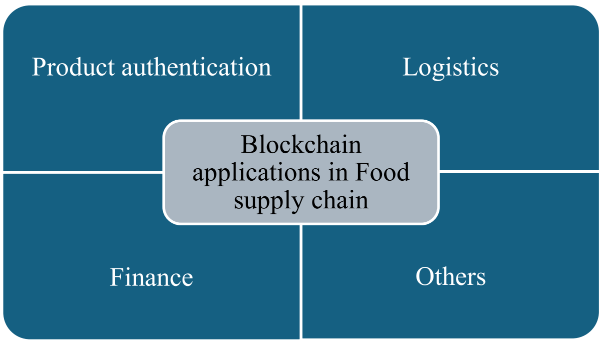

Figure 1: Application of blockchain in FSCs

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In the food supply chain (FSC), blockchain is mainly used in product authentication, finance, and logistics, as these areas have higher requirements for transparency and traceability. Therefore, this literature study is divided into four categories (as shown in Figure 1): (i) product authentication; (ii) finance; (iii) logistics; and (iv) others.

3.1. Food authentication

3.1.1. Current status and pain points of food authentication

Livestock products currently account for more than 15% of the total global agricultural trade. The international trade in livestock products has grown from 56 billion euros in 2000 to 152 billion euros in 2018. With the escalating demand for food, the risk of food safety issues is also on the rise. The World Health Organization emphasizes that maintaining food quality and safety poses ongoing challenges to the food industry and scientific community, as millions of individuals are adversely affected by foodborne contaminants and fraudulent practices annually. Therefore, extensive livestock farming and the associated food supply chain have assumed paramount importance. However, during the rectification of food safety issues, most supply chain reforms and activities related to food recalls are costly and challenging. For example, conventional approaches for monitoring and validating food items frequently encounter challenges such as operational inefficiencies, susceptibility to data manipulation, and restricted access to up-to-date information. Therefore, the application of new technologies with traceability, such as the Internet of Things (IoT), to the food supply chain has become particularly popular. More and more studies show that the application of blockchain in food authentication is emerging and widely used in different regions.

3.1.2. Blockchain technology drives changes in food authentication

On the one hand, Blockchain technology offers a robust mechanism for achieving end-to-end traceability within the food supply chain (FSC) framework. By leveraging blockchain's inherent characteristic of providing an unalterable, consensus-based ledger system. This results in a traceability system that is not only tangible and verifiable but also inherently resistant to alterations or disputes, thereby enhancing transparency and trust throughout the FSC. [1]. Multiple studies have put forward important views on how blockchain can improve FSC from traceability. Tian et al. [2] combined the Internet of Things with blockchain and proposed a food tracking system that uses hazard analysis and critical control points (HACCP) to determine real-time food traceability. Similarly, Bumblauskas et al. [3] designed a comprehensive tracking solution that employs blockchain technology and the Internet of Things (IoT) to monitor the journey of eggs from agricultural farms to consumer tables. Hua, J. [4] introduced a blockchain-powered system for tracing the origin of agricultural products, with the objective of fostering trust among stakeholders within the agricultural supply chain.

On the other hand, blockchain-driven food authentication greatly enhances consumer trust. In an era where consumers increasingly seek detailed information regarding the products they purchase, blockchain technology emerges as a dependable framework for validating assertions related to organic certification, sustainable production practices, or ethically sourced materials. By scanning the QR code displayed on the product packaging, consumers can access comprehensive information detailing the product's lifecycle, from its initial production stages through to its retail distribution. This transparency not only bolsters consumer confidence but also facilitates effective oversight of food quality and safety standards, ensuring a seamless transition from farm to table [5]. As a result, some well-known e-commerce platforms have already begun to adopt blockchain technology. For example, in 2017, Chinese e-commerce giant JD.com partnered with Inner Mongolia beef producer Kerqin to deploy the first supply chain based on the open source blockchain platform Hyperledger

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Fabric [6]. Buyers can query the historical records of the animals used, nutritional information, food safety test reports and slaughter-related information through the platform.

3.2. Finance

3.2.1. Current status and pain points of finance

A criminal syndicate with illicit profits amounting to billions of pounds operates stealthily within the aisles of our supermarkets. Food-related criminal activities not only inflict financial harm on consumers but also pose a significant threat to public health. The global economy incurs substantial social and economic costs as a result of the circulation of inaccurate, mislabeled, contaminated, and adulterated food products. The intricacies of the food supply chain, coupled with the globalization of food markets and a lack of transparency, heighten the susceptibility of the food industry to various risks. Currently, food-related criminal activities are estimated to incur annual costs of approximately $40 billion (equivalent to £31 billion) globally. The UK Food Standards Agency delineates food crime as "severe fraudulent practices and associated criminal conduct within the food supply chain." The food industry is particularly appealing to fraudsters due to its substantial profit margins. But this not only results in poor income for upstream suppliers such as farmers, but also causes physical and financial fraud to us as buyers downstream. Therefore, it is imperative to rethink how to apply blockchain technology to combat food crime [7].

3.2.2. Blockchain technology drives changes in finance

For improving the economic situation of upstream farmers, according to the study of B. Tan et al. [8], blockchain and IoT technologies can be used, which mainly focus on food quality, safety, transparency and data privacy. At the same time, the establishment of a streamlined agricultural marketing system holds promises for enhancing the economic well-being of farmers by optimizing supply chain processes and ensuring fair compensation. Jaiswal, A et al. [9] put forth a conceptual framework grounded in blockchain technology, utilizing the Ethereum blockchain and smart contracts to address the problem of inadequate returns for farmers in India. In addition, A. Fernandez et al. [10] presented a blockchain model constructed upon the Hyperledger framework, with the aim of reducing intermediary involvement and optimizing the income of farmers. The model took into account three aspects: cost, quality, and origin.

For improving socioeconomic sustainability, L. Song et al. [11] proposed a mechanism for integrating blockchain technology into existing Agricultural Food Supply Chains (AFSCs) with the objective of enhancing environmental and social sustainability while preserving economic viability. Furthermore, P. Liu et al. [12] delves into the intricacies of investment decision-making and coordination within green agricultural product supply chains, leveraging information services derived from blockchain and big data technologies. Their study also explores the optimal supply chain architecture within a fusion application environment. Notably, the findings from the Analytic Hierarchy Process (AHP) analysis underscore the pivotal role of blockchain technology in constructing an efficient supply chain. The theoretical model of a public blockchain built on the Ethereum platform can achieve fair trade and circular economy [13].

3.3. Logistics

3.3.1. Current status and pain points of food logistics

The intricate design of the supply chain and its associated information flows initially reveal a pressing necessity to enhance the efficiency of both tangible goods and information circulation. This challenge

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is further compounded by an environment marked by intense competition and fragmentation, which often results in value-eroding scenarios for numerous entities within the supply chain. The multitude of stakeholders involved contributes to the prevalence of non-standardized procedures, lack of transparency, and the formation of data silos [14]. As customer expectations continue to rise, Customers now demand faster, more flexible, and cost-effective delivery of their goods than ever before. To meet these escalating expectations, it is imperative for supply chain processes to undergo more dynamic digitalization. This encompasses robust tracking and tracing mechanisms for items, as well as enhanced transparency and visibility across associated processes.

3.3.2. Blockchain technology drives changes in finance

For full logistics information traceability, Terzi, S et al. [15] introduced a solution anchored in blockchain technology and smart contracts, designed to bolster security, integrity, and reliability within the logistics sector. Notably, the solution exhibited enhanced transparency and facilitated the authentication process during transportation, thereby ensuring the traceability and authenticity of goods.

For logistics process optimization and coordination, some studies proposed the Carbon Footprint Chain (CFC) system, which first appeared in the study of D. Shakhbulatov et al. [16] and is a cluster-based architecture. This system is a streamlined, decentralized platform designed for monitoring the carbon emissions associated with food products throughout their lifecycle stages. It comprises six distinct clusters, each corresponding to a specific phase within the food life cycle, and employs a consensus mechanism akin to the Raft protocol. Blocks track the movement of food at various stages. Each block contains the transport product, carbon footprint, mileage, and previous cluster information.

For reducing logistics costs, Perboli, G et al. [17] proposed a comprehensive methodology for the development of blockchain use cases, which expanding upon the application of blockchain technology. By scrutinizing the outcomes of a fresh food delivery scenario, they drew a pivotal conclusion that blockchain technology holds significant potential in mitigating logistics expenses. This reduction in costs can be attributed to the technology’s ability to streamline processes, enhance supply chain visibility, and reduce instances of fraud and inefficiencies.

4. Existing barriers of blockchain

The applicability and importance of blockchain in FSCs is clear, as it can improve traceability, maintain transparency, and build trust between suppliers, farmers, vendors, retailers, and consumers. However, as some researchers have pointed out, blockchain is currently in its initial stages of development and must face certain obstacles that hinder its application in FSCs. Most researchers discuss three major challenges facing blockchain applications, namely scalability, interoperability and high cost. These will be discussed in the subsequent subsection.

4.1. Scalability

Scalability remains a persistent challenge across diverse blockchain platforms, primarily due to the escalating block sizes that adversely impact key performance metrics, including transaction throughput, computational energy expenditure, and associated costs. As blockchain networks evolve and become increasingly intricate, computational power emerges as a critical concern, necessitating enhanced processing capabilities to validate an increasing number of blocks efficiently. This heightened computational demand not only strains the underlying infrastructure but also exacerbates energy consumption, further complicating the scalability landscape. The research community has recognized scalability as a formidable obstacle to the widespread adoption and sustainable growth of blockchain technology.

4.2. Interoperability

Interoperability denotes the ability of blockchain systems to interact and exchange information seamlessly across disparate platforms. Despite the proliferation of numerous blockchain initiatives within the Food Supply Chain (FSC) domain, many of these projects remain siloed, hindered by the heterogeneity of underlying technologies, including diverse programming languages, protocol architectures, and security frameworks. This lack of interoperability not only impedes collaboration but also limits the potential synergies that could arise from a more integrated blockchain ecosystem. To address this challenge, blockchain development strategies must embrace flexibility and adaptability, ensuring compatibility with a wide range of regulatory environments and technological platforms.

4.3. High cost

The utilization of Blockchain Technologies (BCTs) may encounter obstacles due to the financial implications tied to their procurement, adaptation, and the steep learning curve inherent in their implementation. This challenge is particularly pronounced for Small and Medium-sized Enterprises (SMEs) operating within the food supply chain, where the establishment of robust blockchain infrastructure and the cultivation of associated management competencies necessitate substantial capital outlays.

5. Future directions

Future investigations ought to delve into the uncharted possibilities of blockchain technology within domains where its application remains nascent, including food donation and redistribution mechanisms, supply chain financing solutions, animal welfare initiatives, food waste reduction strategies, and food data analytics frameworks. Broadening the geographical ambit of future research endeavors will provide a more holistic comprehension of how regional nuances influence the adoption and operationalization of blockchain across diverse food supply chains.

Moreover, the integration of longitudinal research designs to monitor the tangible impacts of blockchain within food supply chains over extended periods, alongside qualitative methodologies, will enrich our understanding of its efficacy and illuminate the specific contextual challenges it encounters. Furthermore, fostering interdisciplinary collaborations among stakeholders from the agricultural, technological, and policymaking spheres is also paramount for advancing the comprehensive development of blockchain-enabled food supply chains.

6. Conclusion

This study aims to analyze the application of blockchain in the food supply chain (FSC) through an extensive literature survey and analysis. The study was conducted using the scoping literature review method. For this purpose, a number of publications were collected from the database using specific keywords.

The conclusions based on this study are as follows: The results of this research underscore the pivotal role of blockchain technology in augmenting food traceability and streamlining supply chain management, as corroborated by its successful implementation across various studies. By integrating blockchain innovations into different facets of the food supply chain, a nuanced and thorough depiction of the blockchain-driven supply chain ecosystem emerges. Within a relatively brief period of five to six years, the application of blockchain technology in the food supply chain (FSC) domain has garnered considerable attention from researchers, a trend evidenced by the inclusion of pertinent research papers in this study. Furthermore, the publication of blockchain-related research outcomes in high-impact journals underscores the escalating interest in this field. Reflecting on the current landscape, certain segments of the food supply chain remain unexplored by blockchain technology and necessitate adequate infrastructure (encompassing both hardware and software resources) for its deployment. As highlighted by numerous scholars, key impediments to the widespread adoption of this technology encompass scalability, privacy concerns, interoperability challenges, and prohibitive costs. Addressing these barriers is crucial for unlocking the full potential of blockchain technology in transforming the food supply chain landscape.

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