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The Integration of Blockchain Technology in Food Supply Chain Management – A Systematic Literature Review

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Abstract: *In the current global context of food supply chain management, blockchain technology promotes transparency, assurance, traceability, authenticity, and security—imperative attributes in a domain where balancing transparency, sustainability, and efficacy is crucial. This article endeavors to elucidate the integration and advancement of blockchain technology's role within the food supply chain through a systematic review of the literature. Through the meticulous analysis of specialized, empirical, theoretical, and conceptual works, a coherent perspective on the trends, challenges, and opportunities inherent in implementing blockchain technology within the food supply chain emerges. While blockchain technology is ready to offer transparency, security, and compliance to the food supply chain, optimal implementation necessitates the consideration of organizational, technological, and environmental factors. The article not only serves as a foundation for future research but also as a catalyst for practical applications in the food supply chain sector, with the ultimate goal of increasing efficiency, sustainability and transparency.*

1. INTRODUCTION

Blockchain technology has revolutionized various sectors due to the principles of decentralization, transparency and immutability, the transformational potential of supply chain management has been fueled by growing concerns about food safety, authenticity and traceability. The integration of blockchain technology into supply chain management has been due to this technology's ability to ensure transparency, traceability and authenticity of transactions.

The food supply chain is a complex process that includes many stages from production to harvesting, processing, packaging, transportation, storage and consumption (Trienekens & Zuurbier, 2008). Each stage is critical in maintaining food quality and safety, these stages require a monitoring and verification system to ensure compliance with applicable health standards and regulations.

Transparency is a challenge in the food supply chain due to the global nature of the modern supply chain, thus geographical distances, different regulatory standards and the multitude of actors involved make it difficult to maintain transparency regarding the origin of food, handling processes and safety protocols, which can lead to significant problems such as food fraud, contamination or waste (Aung & Chang, 2014). The introduction of blockchain technology into the food supply chain is proposing a change in the way information is recorded, stored and shared. Through a decentralized ledger, blockchain provides a unified platform where data from different stages of the supply chain can be securely and transparently recorded. Every transaction, from a farmer recording harvest details to a retailer recording sales data, can be recorded in a

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tamper-proof environment (Tian, 2016). Thus, customers can scan a code on the chosen product to find out the exact origin and route of the product. In addition, contaminated products can be quickly identified and withdrawn before further losses and consumers are affected (Mansfield-Devine, 2017).

By introducing smart contracts, the supply chain becomes faster, processes are automated, and when the terms of the contract are respected, the supplier can receive payment automatically, in a short time, and without an intermediary (Mihaylov et al., 2018).

In order for the implementation of blockchain technology to be effective, data recording protocols must respect data confidentiality, this is possible through standardization of protocols.

2. LITERATURE REVIEW

Blockchain technology became known for its decentralized nature, which records transactions in chronological order. These transactions, also called blocks, can create a chain of transactions that can be stored on different blocks in the same network. The design regarding decentralization proposed by Nakamoto is fundamental to the security of the blockchain, and the failure of one point cannot compromise the total integrity of the data because no entity has control over the entire chain (Nakamoto, 2008).

In food supply chain management, blockchain does more than just keep track of transactions. It gives a new way to share information and be open about it. Conventional supply chains can have a lack of clear information, which causes problems like inefficiency, distrust, and the inability to fix problems quickly. Blockchain solves these problems by creating a safe, unchangeable, and clear platform where all transactions, from making to selling, can be recorded (Casino et al., 2019).

One big benefit of blockchain is that it can't be changed and everyone can see what's happening. Once a transaction is written down, it can't be altered or taken away. This feature is really important in the food supply chain, where it's very important to know where the food comes from and who is responsible for it. For instance, blockchain can help people know where their food comes from and if it's good quality and made ethically. This can stop problems like fake food and wrong labels (Tian, 2016).

Blockchain technology is all about spreading out the work of processing, recording, and checking transactions across lots of computers, instead of just one central authority. This means that everyone in the network can see the same record of transactions, which makes the system more secure and transparent (Nakamoto, 2008).

In old-fashioned food supply chains, a small number of important groups, like main distributors or regulators, usually control the information. This can make it hard to see what's going on and cause problems with sharing and reporting data. Because security and reliability depend only on a few entities, in a central structure, the system can become vulnerable over time (Casino et al., 2019).

A transformative approach to data management in food supply chains can be achieved through the decentralization of blockchain technology (Ambrozie & Sorcaru, 2021). Copies of the

registers are stored by each participant or each note of the network, in this way the transactions are verified and can contribute to a consensus protocol that helps to validate blocks of transactions. Through this complex process, a single entity can't control or modify the registration data in a blockchain (Mihaylov et al., 2018).

Against unauthorized access or manipulation, a multifaceted security system of the food supply chain has been printed, giving at the same time accuracy and data protection, and, last but not least, food integrity. Traditional supply chain management systems often rely on centralized databases that, despite their best efforts, are susceptible to hacking, corruption, or loss due to their reliance on single control points. These vulnerabilities can have serious ramifications, including, economic loss, damage to brand reputation, and public health risks (Casino et al., 2019).

Blockchain technology effectively addresses several of these security concerns through its structure. One of the fundamental security features of blockchain is the use of cryptographic principles to create and link blocks, making the data structure tamper-resistant. This cryptographic linking of blocks makes it nearly impossible to change a single block without changing all subsequent blocks and achieving consensus from the majority of the network, which is virtually impossible (Nakamoto, 2008).

For food supply chains, this level of security is crucial. In this way, it is ensured that data, once entered, regardless of whether they are about the origin, ingredients, transport, or storage conditions of a food product, recorded in the blockchain cannot be fraudulently modified (Tian, 2016). Due to its decentralized nature blockchain ensures data security. The information is stored in a network of computers, instead of a single centralized database. Decentralization protects data that could be compromised due to a cyberattack, technical failure, or natural disaster. In the field of food supply, data integrity is very important because it can have major implications for public health and safety (Mihaylov et al., 2018).

The smart contracts that are possible thanks to blockchain technology, are executed automatically when the terms written in a code are fulfilled, without the need for the intervention of intermediaries, thus the costs are reduced, the waiting times are reduced, the procedures are efficient and the risk of fraud is minimized (Szabó, 1996). Smart contracts can be optimized by joining other technologies, such as IoT, which can record in real time data about the transport time, the transport conditions, or the temperature of the products during the entire transport period, helping the automatic management of quality control. If a product's temperature deviates from an agreed range, a smart contract could instantly trigger a quality inspection or even reject the shipment, ensuring that only products that meet specified standards reach consumers (Tian, 2016).

Traceability in food supply chains refers to the ability to trace any food through all stages of production, processing and distribution (including import and retail). Traceability, as part of broader supply chain transparency efforts, has always been a significant concern in the food industry. It is not only vital for ensuring food safety and quality, but also for managing recalls, verifying sustainable or ethical practices, and complying with applicable regulations (Aung & Chang, 2014).

Traditional traceability ways to track things use a lot of paper or digital systems that are all in one place. These can take a lot of time, make mistakes, and be changed or lost easily. These systems can make it hard to follow a product's journey from the farm to your table because the

information between different stages of the supply chain is not connected or available (Manning & Soon, 2016).

Blockchain technology can help with these problems. Blockchain helps to keep track of all the transactions and data in the food supply chain in a secure and easily accessible way. Each item has its special code, and every time something happens to that item, it gets written down in the blockchain. This makes a digital record of how each product travels from start to finish (Tian, 2016).

3. METHODOLOGY

A systematic review of the specialized literature is chosen because the challenges faced by the agri-food system are well known, and it currently needs a technology that offers a 'complete solution' to combat inefficient recalls and fraud (Shahid et al., 2020). A 'complete solution' for food supply management could be blockchain technology, therefore, through a systematic review of the specialized literature, we can elucidate the trends, challenges, and opportunities of its application.

For this article, Scopus, WoS, and Google Scholar were chosen as databases, designing a meticulous search strategy for as many relevant publications as possible. The search was conducted using keywords, employed in various combinations and queries, such as 'blockchain technology', 'food supply chain', 'blockchain', 'traceability', 'sustainability', 'food quality', 'food safety', and 'agri-food' to ensure broad coverage of writings on the theme of integrating blockchain innovation in various aspects of the food supply chain.

The publications were subjected to a screening process. The inclusion criteria were the following:

Relevance: The paper must focus on the application of blockchain technology in the food supply chain. Studies that mentioned blockchain only peripherally were excluded.

Date of publication: Given the rapid evolution of blockchain technology, only works published since 2020 have been considered to ensure the timeliness and relevance of the data.

Publication Type: Both empirical and theoretical studies were included to ensure a comprehensive understanding of the topic.

Language: only studies published in English were included.

The search yielded 218 papers, highlighting the growing interest and extensive research in integrating blockchain technology into the food supply chain.

The volume and complexity of the literature obtained through our initial search necessitated the use of analytical tools. Atlas.ti software was used for an in-depth analysis. For preliminary analysis, we used code words such as "traceability", "sustainability", "efficient", "supply chain", "food safety" and "smart contracts". The codes were chosen due to the objective of the research topic and due to the content of the text.

After initial coding, codes were categorized into looser themes and analyzed "Blockchain Technology in Food Supply", "Challenges", "Opportunities" and "Future Directions".

For relevance we resorted to selective coding, where we used refined codes and categories, the focus was on content that referred to the integration of blockchain technology in food supply chain management.

Atlas.ti facilitated cross-document analysis, where codes from different papers were compared. Thus, we could follow the consistency of the themes in the analyzed works and identify the works that had different perspectives.

The criteria that were the basis of the selection of specialized works were: empirical data about blockchain technology in the supply chain, works that presented methodologies and results about blockchain technology in the supply chain, or theoretical analyses about the topic of interest.

Following the steps taken, we arrived at a total selection of 57 works. These were subjected to comparative analysis to identify convergences, divergences and research gaps. This process was achieved by thematically grouping articles into common themes such as: "technological advances", "implementation challenges", "case studies" and "future perspectives". This thematic approach facilitated a targeted comparison in certain specific areas.

Cross-comparison: Within each thematic group, we conducted a detailed cross-comparison to identify similarities and differences in perspectives, findings and methodologies. Atlas.ti's network visualizations and concurrent coding tools were instrumental in visualizing relationships and disparities between studies.

The results of the comparative analysis. Our benchmarking provided some key insights:

Overall benefits: There has been a consensus among studies on blockchain's potential to revolutionize the food supply chain. Key benefits identified include improved traceability, improved food safety protocols, reduced fraud and increased consumer confidence.

Implementation Challenges: Despite its potential, researchers have consistently highlighted several challenges. These include technological issues (such as system interoperability and data privacy), organizational obstacles (such as resistance to change and collaboration challenges between stakeholders), and regulatory concerns (the need for standardized protocols and legal frameworks).

Diverse methodological approaches: We observed a rich diversity in research methodologies, ranging from case studies and systematic reviews to conceptual papers and empirical research. This diversity underscores the multifaceted nature of blockchain research and its interdisciplinary implications.

Sector-Specific Applications: Several papers have provided insight into blockchain applications in specific sectors of the food supply chain, such as dairy, agriculture and seafood.

Ethical and sustainability considerations: A growing trend in the literature is exploring the role of blockchain in promoting sustainability and ethical practices in the food supply chain. The papers discussed how transparent and immutable record-keeping could support fair trade practices and sustainable sourcing.

Future Directions: The analysis revealed an optimistic outlook for the future of blockchain in the food supply chain, with researchers advocating continued technological innovation, collaborative initiatives and supportive regulatory frameworks.

Research Gaps: Our review also uncovered several gaps in the literature, particularly in empirical research on long-term implementations, economic impact assessments, and studies of consumer responses to blockchain-tracked food products.

4. RESULTS

General presentation of the analyzed literature.

Our comprehensive review of the 57 selected papers revealed rich content around the application of blockchain technology in food supply chain management. These studies, diverse in methodology and scope, have collectively highlighted the transformative potential of blockchain while underscoring the complexities and challenges of its implementation.

Through the coding and classification capabilities of Atlas.ti, several key themes emerged from the literature, reflecting the primary concerns of the current research landscape and areas of interest:

Traceability and transparency: A prevalent theme in the literature has been the role of blockchain in improving traceability and transparency in food supply chains. Food fraud is eliminated through a transparent and trustworthy tracking method provided by the blockchain (Centobelli et al., 2022).

Food safety and quality: Several articles have talked about how blockchain affects the safety and quality of food. Blockchain technology helps the food industry share information quickly and securely, so safety issues can be resolved quickly and risks to people's health and food reputation are reduced (Choi & Lee, 2020).

Blockchain can help the food industry become more ethical and sustainable. Studies have shown that this technology can trace the origin of food and its route without this data being able to be altered. In this way, fair trade, ethical sourcing and compliance with environmental regulations are encouraged (Pirju, 2011).

In order to be able to use this technology successfully, a legally regulated framework is needed worldwide. These rules should protect people's information, and ensure safety and interoperability. The challenges of implementing blockchain in the food supply chain are related to the size of the data stored, data privacy and interoperability. Research shows that blockchain technology will make progress on these challenges but also that it can be improved by connecting with other technologies like IoT and AI (Wang et al., 2021).

Our analysis also revealed interesting methodological trends. While case studies and empirical research provided practical insights into the real-world applications and impact of blockchain, conceptual papers and systematic reviews contributed to a deeper theoretical understanding. There was a noted need for more longitudinal studies to assess the long-term implications of blockchain adoption in food supply chains (Davis et al., 2021).

While the papers reviewed provided extensive insights, they also highlighted gaps in current research. In particular, there is a dearth of studies exploring consumer perceptions of blockchain-tracked food products and the economic feasibility of blockchain adoption for small-scale producers. In addition, research on the integration of blockchain with other emerging technologies in the context of food supply chains remains limited but presents interesting future perspectives.

5. CONCLUSION

Through the systematic literature review, we were able to explore multiple aspects regarding the adoption of blockchain technologies in the food supply chain. The implementation of this technology presents the opportunity to increase transparency and improve traceability and sustainability of the food supply chain.

The systematic literature review shows that the food supply chain can benefit from the implementation of blockchain. Supplier accountability and increased consumer trust through full chain traceability and transparency are made possible by blockchain technologies capabilities to establish decentralized and immutable records, serving as a sustainable mechanism in the pursuit of food safety, ethical sourcing practices and quality assurance.

Implementing blockchain technology requires a holistic approach, the critical factors to be addressed are: scalability, regulations, data privacy and interoperability.

At a time when climate change and responsible consumption are hot topics, blockchain technology can become a catalyst for positive changes such as responsible sourcing, fair trade and environmental stewardship. Blockchain can also have positive implications for sustainability and ethical practices, increasing the potential of blockchain in addition to its operational efficiency within the food supply chain.

The analysis conducted indicates that further research is still needed to investigate the impact of the implementation of blockchain technologies under different aspects, such as the integration of blockchain technologies with other emerging technologies such as AI and IoT, and consumer perceptions of products tracked through blockchain technology. These research imperatives are a good opportunity for scientists and industry professionals to make progress in the field. Blockchain's potential isn't just theoretical, it's a catalyst for trust, accountability and efficiency.

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