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A Survey on Blockchain Technology in Food Supply Chain Management

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Abstract

Integrating blockchain technology into the traditional food chain holds promise for increased transparency, traceability, and security. This review begins with an overview of blockchain fundamentals, including its principles, different types of blockchains, the Secured Hashing Algorithm-256 encryption algorithm, and the consensus process that ensures data integrity, fairness, and trust. We then focus on the challenges of integrating blockchain technology into existing food products, such as efficiency, collaboration, high costs, and changes. We explore solutions and show how blockchain can address these issues and increase the performance and reliability of the food supply chains. Finally, we present several open questions and new studies that demonstrate the future potential and impact of blockchain in changing the food supply chain. The goal of this article is to provide critical insights into the opportunities and challenges of integrating blockchain into the food industry while setting guidelines for future research.

Categories: Blockchain and Cryptocurrency, Security and Privacy, Cryptographic Algorithms
Keywords: blockchain technology, smart contract, sha-256, food supply chain, pow

Introduction And Background

Overview of the food supply chain

The food chain is a key link between farmers and consumers through various stakeholders, such as producers, suppliers, distributors, and retailers [1]. All participants will ensure that food is produced, processed, and delivered to good standards and with safety. This process is essential to ensure global food supply and availability [2]. This chain accounts for approximately 30% of the Food and Agriculture Organization's staff. While agriculture alone accounts for approximately 4% of global GDP, this figure rises to over 25% in developing countries, and agriculture is critical to economic growth. The demand for agricultural food is expected to increase by 60%, with around 1 billion. This growing need reflects the need for more efficient, transparent, and productive systems to secure food supplies, reduce waste, and ensure equity across the region [3].

Challenges in the food supply chain

The food supply chain is plagued by issues such as a lack of transparency and traceability, making it difficult to monitor food products from their origin to the consumer [4]. This leads to food fraud, contamination risks during storage and transportation, and overall poor quality control. Inefficiencies in collaboration among stakeholders, along with mismatches between food production and demand, contribute to significant food waste. International trade adds complexity due to inconsistent regulations across regions, making compliance challenging [1].

Price volatility, complex supply chains, and logistical difficulties, especially in ensuring packaging integrity and last-mile delivery, further degrade food quality. Additionally, food fraud and counterfeiting in global markets undermine consumer trust. The World Trade Organization has flagged food safety as a major concern, with 44% of issues raised in 2020 focused on the need for greater transparency in nutrition, processing, and origin, emphasizing the need for clearer information to ensure consumer trust and safety [5].

Blockchain technology: A process to transform food industry

Blockchain is a decentralized digital record keeping system that provides solutions to challenges affecting the food industry. Blockchain provides data transparency, immutability, and security by recording transactions across multiple systems. In the food industry, this advanced system can trace the journey of product from farm to the consumer. With transparent data on all transactions, stakeholders can track the origin and flow of food, reduce the risk of fraud, and ensure authenticity. This increased visibility not only makes work easier but also increases food safety by quickly identifying and separating contaminated products during returns. Additionally, as consumers increasingly seek greater transparency in food, blockchain increases trust by ensuring traceability and tamper-proofing of the product journey. This allows consumers to make an informed choice knowing exactly where their food comes from and how it was made [6].

Objective and scope of the study

The goal of this paper is to explore the unification of blockchain technology in the food supply chain and to highlight the current research and challenges associated with this integration [5]. The main contributions of this paper are summarized as follows:

1. We begin with the traditional food supply chain and then introduce blockchain and explain how it has solved existing problems in the food supply chain [1].

2. We then begin with a brief discussion of blockchain technology, covering its fundamentals, types, and key algorithms.

3. After that, we provide a methodical examination of the difficulties and potential fixes for incorporating blockchain technology into the food supply chain [4].

4. In conclusion, we list a number of outstanding questions and new research directions that provide light on where blockchain technology is headed in this industry [5].

Review

Traditional food chain

The conventional food supply chain (see Figure *1*) operates through a network of intermediaries, including farmers, manufacturers, suppliers, and retailers, wherein tracking mechanisms rely on disparate digital systems. This fragmented structure results in inefficiencies, leading to gaps in traceability and difficulties in monitoring the entire process [4].

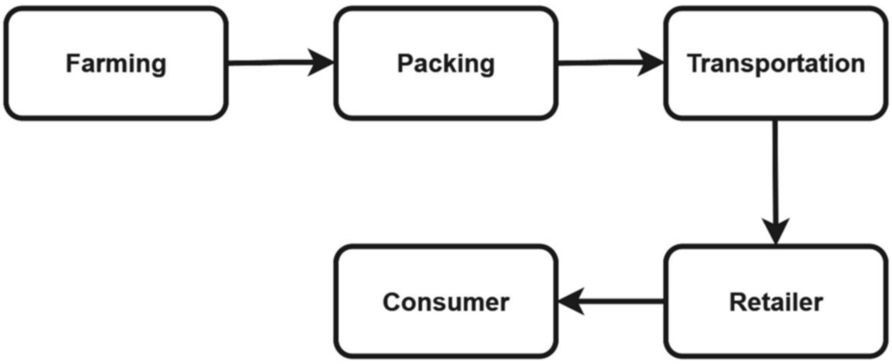

FIGURE 1: Traditional food supply chain

Lack of Transparency

The disjointed coordination among stakeholders impedes seamless tracking of food products along the supply chain, increasing susceptibility to fraud and inefficiencies. A significant concern is the mislabeling of products, where lower-quality goods are sometimes falsely marketed as organic, leading to erosion of trust between sellers and consumers [7]. Furthermore, the decentralized storage of data exacerbates delays in problem detection and resolution [2].

Recent studies highlight that a significant percentage of food supply chain organizations identify the absence of transparency and robustness as a key operational deficiency [6]. Inadequate digitization further compounds this issue, with many firms lacking the digital infrastructure required for real-time monitoring [1]. Additionally, sustainability challenges persist, as an increasing number of food manufacturers now prioritize waste reduction and operational efficiency due to growing environmental concerns [8].

Supporting Research

Recent industry analyses underscore the increasing transformation of the global food supply chain toward a more localized, transparent, and digitalized ecosystem, driven by regulatory demands and sustainability goals [3]. These trends highlight the necessity for enhanced tracking and traceability mechanisms, pushing the industry toward modernization [5].

Blockchain to food industry

Blockchain technology emerges as a transformative tool to address persistent inefficiencies in food supply networks. Operating as a decentralized and immutable ledger, blockchain facilitates real-time transaction recording, ensuring all network participants access uniform, tamper-proof data [8].

Blockchain technology solutions to key challenges in food supply networks:

• Enhanced Transparency: Blockchain enables real-time visibility of food product movement from origin to shelf, mitigating fraudulent practices and bolstering consumer confidence [3].

• Efficient Recall Mechanism: Contaminated or defective food products can be swiftly identified and removed from circulation, significantly reducing the risks associated with foodborne illnesses [5].

• Cost Optimization: By eliminating redundant intermediaries and enhancing traceability, blockchain streamlines operations and reduces overall expenditures while maintaining accountability [1].

Recent industry adoption trends demonstrate a significant shift toward AI and blockchain integration for food traceability. Studies indicate that supply chain leaders regard blockchain as a competitive advantage in enhancing operational efficiency [7]. Furthermore, circular supply chains, which emphasize sustainability and minimal waste, are increasingly reliant on blockchain to ensure ethical sourcing and regulatory compliance [4].

Supporting Research

Recent technological advancements highlight how blockchain enhances resilience and agility within food supply chains, reducing inefficiencies while ensuring compliance with stringent global food safety regulations [6]. The findings substantiate the growing role of blockchain in overcoming conventional supply chain bottlenecks [2].

A brief introduction to blockchain technology

Among the major disruptions of the twenty-first century is blockchain technology. Originally created as the backbone of cryptocurrencies like Bitcoin, its capabilities have spread to many industries, including supply chain, healthcare, and finance. The foundations of blockchain technology and many forms of blockchain that are already in use must be thoroughly understood. In this examination, we will look at the fundamental components of the document.

Fundamentals of Blockchain Technology

Blockchain functions as a kind of digital ledger that records transactions between several computers and prevents changes to the recorded data from being undone. The concept may seem simple, but its power lies in its decentralization, immutability, and security. The main elements that form the fundamentals of blockchain technology are as follows [6]:

Distributed ledger technology: The basis of blockchain is distributed ledger technology (DLT). A ledger is a ledger or repository that records transactions. Blockchain employs a decentralized ledger, allowing all participants (or nodes) in the network to share it. Copies of the ledger, including consensus (including new transactions), must be verified by the network. This decentralized approach reduces the need for intermediaries and provides transparency, as all participants can see changes instantly.

Blocks and chains: A blockchain is made up of a series of blocks. Each block consists of a process of identification and recording. When a block is completed and linked to the one before it by a hash value, a chain of blocks is formed as seen in Figure *2*. This link guarantees that data inserted into the blockchain cannot be altered without modifying each block that comes after it.

This immutability is one of the main benefits of blockchain technology. Each block contains three key components [2]:

• Transaction Profile: Contains transaction information such as sender, recipient, and amount.

• Hash: A cryptographic representation of a block of data. It is like a fingerprint pointing to the block.

• Previous Block Hash: The hash of the prior block that links the blocks together in a chain.

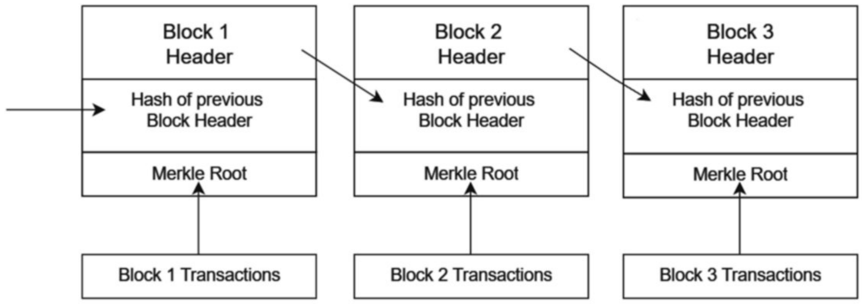

FIGURE 2: Blockchain architecture

Smart contracts: Self-executing contracts, or smart contracts, are written directly into program code. Once the preconditions are met, the contract automatically executes, and there is no need for any intermediary trees. Smart contracts are a crucial component of blockchain technology because they can automate tasks, reduce human error, and speed up processes.

Cryptography: Cryptography is the foundation of blockchain security [3]. Blockchain uses encryption technology to protect transactions and ensure data integrity [9]. The two types of encryption used in blockchain are as follows:

• Hashing: Hashing is an operation that takes an input (like exchanging data) and creates a constant length string. A huge difference in hash value can be seen for small change in input.

• Public and Private Keys: The user's private key is used to sign transactions, while the public key is used to validate the signature. This makes sure that only the rightful owner of the private key is able to start a transaction.

Types of Blockchains

Now that we understand the basics, it is important to examine the different types of blockchain networks. Each type has its own characteristics and is suited to different uses.

Public blockchain: A public blockchain is a shared system that anyone can join without permission. The most famous examples are Bitcoin and Ethereum. These blockchains are public, allowing anyone to read, write, or verify transactions. They are decentralized, with no single point of control.

Private blockchain: A private blockchain is a closed network that restricts participation. Only authorized individuals or organizations can join the network, and blockchains are often managed by an organization or consortium. This type of blockchain is typically faster and more efficient than public blockchains.

Consortium chain: A consortium chain, also known as a federated blockchain, is a collaborative system where a group of organizations jointly manage the blockchain. This type of blockchain combines the functionality of public and private blockchains, facilitating coordination between organizations while maintaining a decentralized structure.

Hybrid blockchain: A hybrid blockchain is a combination of public and private blockchain elements. It allows for the ability to change who can participate in the network and what information can be made public.

Algorithms

Secured Hashing Algorithm-256: The US National Security Agency created the cryptographic hash function known as Secure Hash Algorithm 256 bit. In particular, this algorithm is crucial to the protection of transactions and the maintenance of the blockchain's integrity in blockchain technology. SHA-256 gets input and generates a result of 256 bits (32 bytes). Regardless of its size (a character or an entire book), the output size remains the same. These features are important for verifying the accuracy of the data, maintaining the integrity of transactions in the blockchain, and protecting sensitive data. This ensures that any changes to the block of data will affect all subsequent blocks in the blockchain.

The blockchain is made up of blocks, each of which has the hash of the one before it. By ensuring that the hash value changes if the block is modified, SHA-256 helps to reduce the likelihood of error [10].

Consensus algorithm: A consensus algorithm is a strategy used in blockchain networks to reach the consensus on the validity of transactions and the state of the blockchain. They ensure that all the participants come together and agree on one of the facts. Below are various types of consensus algorithms [11]:

a) Proof of Work (PoW): The first miner to solve a challenging cryptographic problem adds a new element to the blockchain. Miners battle to solve these riddles.

Security Level: PoW provides a high level of defence.

Disadvantages: Its substantial energy usage leads to environmental harm because of the considerable carbon emissions linked to mining operations.

b) Proof of Stake (PoS): Validators are not miners but are elected to create new blocks based on the number of tokens they hold and are willing to “stake” as collateral [12]. PoS is more powerful than PoW because it does not require intensive computational work.

Disadvantages: The illusion of wealth because those with more tokens have more influence.

c) Delegated Proof of Stake: A variant of PoS where participants appoint delegates (or witnesses) to implement changes and create new delegated blocks. The turnaround time is faster because the client spends less time on calculations.

Disadvantages: Possible centralization because a few large stakeholders can dominate the voting process.

d) Practical Byzantine Fault Tolerance (PBFT): Designed to operate in an environment where nodes can fail or become malicious. By having nodes communicate across several rounds, it achieves consensus on the blockchain's current state. PBFT is resistant to bad actors, as it requires a supermajority to reach consensus. It should not be weak.

e) Proof of Authority: In Proof of Authority, a small number of nodes (validators) have the authority to generate new blocks based on their reputation. This model allows for high transaction speed and efficiency due to the trusted validators.

f) Hybrid Confirmation Model: Provides multiple confirmations to give the blockchain its full advantage. For example, use PoW to create the first block and PoS for subsequent verification.

This model allows for flexible transitions between different networks, although conflicts may arise.

Methodology

Search Strategy

Research related to the topic was conducted using a systematic method and clear objectives. A rigorous peer-review process was employed to ensure the inclusion of high-quality results. The databases and repositories utilized in this review include IEEE Access, ResearchGate, IJRSCT, IEEE Xplore, scholar.archive.org, The Grenze, arXiv.org, and IJRT (International Journal of Recent Technology).

These platforms were selected based on their reputation for publishing research articles relevant to blockchain technology and food supply network. This review provides an overview of existing literature across various sources, focusing on topics such as "Blockchain in Food," "Food Supply Chain Transparency," "Blockchain for Organic Food Traceability," and "Utilizing Blockchain for Supply Chain Security".

Inclusion Criteria

To ensure the relevance and appropriateness of the content, the following criteria were established for selecting studies:

• Time Period (2018-2024): Studies published between 2018 and 2024 were included. This period was chosen to focus on the latest developments in blockchain technology for food supply chains. The rise in blockchain research beyond financial sectors into food and agriculture also makes this period significant.

• Research Areas: The studies needed to analyze key aspects of blockchain technology, including its infrastructure, cryptographic algorithms, and smart contracts used within the food industry. Topics such as decentralized ledger technology (DLT), cryptography (e.g., SHA-256), and consensus mechanisms were particularly relevant for providing depth of analysis.

Exclusion Criteria

To maintain focus and efficiency in the analysis, the following exclusion criteria were applied:

• Non-Food Studies: Papers discussing the application of blockchain in sectors outside of food, such as healthcare, finance, or transportation, were excluded unless their findings had a direct impact on food product studies, particularly regarding transparency or traceability.

• Theoretical Research: Studies that focused solely on blockchain theory without practical applications in the food industry were excluded. The review was anchored in rigorous peer-reviewed research to ensure practical relevance.

Study Selection and Assessment

The selection and assessment of studies followed a careful process to ensure that only the most important and useful studies were included:

• Preliminary Screening: A initial screening was conducted based on the paper titles and abstracts. Studies that did not clearly align with the inclusion criteria were excluded at this stage. This initial step ensured that only those studies directly associated to blockchain applications inside the food sector were selected.

• Detailed Analysis: Each selected paper underwent a thorough analysis of its methodology, results, and conclusions. The contribution of blockchain to the integration of the food supply chain was further evaluated based on the type of blockchain used (public, private, or consortium), the encryption method (e.g., SHA-256), and use cases such as food tracking and supply chain optimization.

Research Classification

To provide a clear structure for analysis, the selected research was categorized into three main perspectives:

• Technical Perspective: This category includes research focused on blockchain technology aspects such as DLT, encryption methods (e.g., SHA-256), and consensus processes. This research investigates how blockchain technology can address critical challenges related to food traceability, safety, and efficiency, particularly in compliance with data privacy laws like the General Data Protection Regulation (GDPR).

• Regulatory Compliance: Studies within this category explore how blockchain can support regulatory compliance through an enhanced transparency and data integrity. They examine the factors influencing consumer adoption of blockchain in food supply chains and how it can increase consumer trust in food safeness and detectable.

• Consumer Faith: The use of blockchain technology in the food industry and consumer impressions are the subjects of this research category. Studies analyze how blockchain can enhance communication among stakeholders, leading to improved supply chain efficiency.

Quality Assessment

Each study was assessed to ensure credibility and relevance for the review. The assessment criteria included:

• Implications for Blockchain and Food Products: Studies were evaluated based on their direct application of blockchain technology to food product development.

• Objectives and Methods: Articles that presented clear research questions and employed rigorous methodologies such as empirical evidence, case studies, or validated models were favored.

• Research Outcomes: Studies that demonstrated strong results and contributions to the field were prioritized. Those scoring lower on these criteria were excluded to maintain high quality and relevance in the review.

Issues of blockchain in food supply network mechanism

Scalability Issues

Problem: A significant scaling challenge in the organic food supply chain when using blockchain technology is the enormous volume of data produced by the many parties involved, including farmers, distributors, retailers, and consumers. Blockchain's inherent decentralized nature requires that every transaction or data entry be validated and recorded across the entire network, which can lead to slow processing times and high computational costs, especially as the network grows. This can make real-time tracking and transparency, crucial for organic food certification, less efficient and delay operations [9].

Solution: A solution to this scalability issue is such as side chains or off-chain protocols, which manage a large number of transactions outside the main blockchain before finalizing them in batches. This minimizes the load on the main blockchain and increases transaction speed and throughput. Additionally, permissioned blockchain networks can be adopted, where only a selected number of trusted participants validate transactions, thereby reducing the network's size and improving efficiency without compromising data integrity [3,13].

Data Privacy and Security Concern

Problem: In the organic food supply chain, data privacy and security are major concerns when using blockchain technology [14]. Blockchain, while transparent and immutable, can inadvertently expose sensitive data, such as proprietary business information [15], consumer details, and supplier identities. This openness makes it vulnerable to breaches and unauthorized access if not properly secured [16]. Furthermore, some data, like the exact location of farms or proprietary farming techniques, may be misused or exploited by competitors or malicious entities. In addition, because blockchain records are immutable, once information is stored in the ledger, it cannot be easily modified. This raises concerns about the long-term protection of private data [17].

Solution: To solve this issue in blockchain, organizations can implement encryption techniques to protect sensitive data before it is added to the blockchain. For example, zero-knowledge proofs can be used to verify the authenticity of transactions without revealing confidential details. Private or permissioned blockchains can also be used to limited access to certified parties only. Ensuring adherence to data protection laws like the GDPR is another way, where sensitive information is stored off-chain, with the blockchain serving as a verification layer [18]. Combining these methods helps maintain data privacy and security while preserving the transparency [19].

Interoperability Issue

Problem: Interoperability in the organic food supply chain, when integrated with blockchain technology, faces several challenges. One major problem is the lack of standardization across different blockchain platforms used by various stakeholders, such as farmers, suppliers, and retailer, leading to difficulties in data sharing and communication. Each participant might use different systems for recording transactions, making it hard to achieve seamless integration and transparency across the entire chain [20]. This fragmentation hinders the traceability and authenticity of organic certifications, which are crucial for consumer trust [2,10].

Solution: A potential solution is the adoption of cross-chain communication protocols or middleware that can enable interoperability between different blockchain platforms. These protocols allow data and smart contracts from one blockchain to be read and validated on another, ensuring that the entire supply chain can communicate effectively regardless of the underlying technology. Additionally, industry-wide business models and governance systems can help coordinate these efforts, promote collaboration and transparency, and ultimately guarantee the value and safety of organic food items [2].

High Implementation Cost Issue

Problem: The high implementation cost in integrating blockchain technology into the organic food supply chain arises from several factors [3]. First, blockchain requires sophisticated hardware, software, and expertise, which lead to high upfront expenses. Small-scale farmers and suppliers in the organic food industry may not have the resources to adopt this technology. Furthermore, integrating blockchain with an already-existing supply chain system can be difficult and expensive, requiring a large initial investment as well as continuing maintenance and training for IT infrastructure [3].

Solution: To address these challenges, one solution is the adoption of blockchain as a service platforms. These platforms allow businesses to implement blockchain without building the technology from scratch, reducing upfront costs. Governments or industry bodies could also offer subsidies or incentives to small-scale organic producers to help offset the initial costs. Moreover, collaboration among stakeholders can lead to shared investment in blockchain infrastructure, dividing the cost while maintaining the organic food supply network's traceability and transparency [14,1].

Energy Consumption and Environmental Impact

Problem: The incorporation of blockchain technology into the supply network for organic food has the capacity to improve consumer confidence, traceability, and transparency [21]. However, one of the main problems is that blockchain networks, especially those that use PoW consensus techniques, use a lot of energy. High processing power requirements in organic farming practices undermine the environmental advantages usually associated with these systems, increasing carbon emissions. This disparity poses a problem for companies trying to keep the entire supply chain sustainable [3].

Solution: Swapping the energy-intensive PoW consensus methods for more environmentally friendly ones like PoS or other energy saving options could help resolve this problem. PoS reduces the need for massive computational resources, thereby decreasing energy consumption and mitigating environmental harm. Additionally, integrating blockchain with renewable energy sources for its operations can further align the organic food supply chain with eco-friendly principles. These measures would allow blockchain to support the organic food industry without contradicting its environmental goals [22].

Resistance to Change and Adoption Barrier

Problem: Stakeholders, including farmers, distributors, and retailers, are often hesitant to adopt new technology due to lack of familiarity, fear of disruption in traditional processes, and the cost of transitioning from conventional systems [23]. Many small-scale organic farmers may also lack the technical expertise or infrastructure required to integrate blockchain solutions effectively. Additionally, the complexity of blockchain systems can create confusion about its benefits, leading to slow adoption rates [21].

Solution: To address these issues, solutions need to focus on education, financial support, and simplified systems. Training programs tailored to stakeholders at all levels of the supply chain can demystify the technology, showcasing its benefits like improved traceability, transparency, and reduced fraud [24]. Financial incentives or subsidies could encourage smaller players to adopt blockchain technology without feeling burdened by costs. Furthermore, blockchain platforms should be user-friendly, enabling stakeholders to use them without requiring deep technical knowledge. By reducing the perceived risks and emphasizing on long-term benefits, the adoption of blockchain in the organic food supply network can be accelerated [2].

Latest Research Progress

Recent research on the use of blockchain technologies in supply network administration reveals several insights and trends:

Benefits and Challenges

A substantial benefits of blockchain in supply chains, including improved security, traceability, transparency, data integrity, efficiency, accountability, and trust, are highlighted in a research study that was published in 2024. However, challenges persist, including scalability issues, high implementation costs, regulatory concerns, interoperability issues, lack of standardization, energy consumption, and difficulties in integrating with existing systems.

AI and Blockchain Synergy

Another ongoing research trend explores the combined use of AI and blockchain in supply networks, particularly focusing on durability and data monetization [13]. This approach can provide improved transparency, traceability, and efficiency, especially in sectors like the seafood industry [25]. These technologies can help in monitoring compliance with regulations, reducing illegal activities, and ensuring sustainability [11].

Data Monetization and Traceability

Research also suggests that AI and blockchain can enable "data monetization," where supply chain participants can profit from data by enhancing transparency and traceability. When it comes to items having a traceable supply chain, consumers who are aware of traceability are frequently willing to pay more [26].

Quantum-Resistant Blockchain for Supply Chains

With the increasing advancement of quantum computing, researchers are exploring quantum-resistant blockchain algorithms to ensure long-term data security in supply chains. These algorithms aim to protect transaction records from potential future threats posed by quantum decryption capabilities [26].

Blockchain and IoT Integration for Real-Time Tracking

The integration of blockchain with the Internet of Things (IoT) is gaining traction in supply chain management. IoT sensors embedded in products allow real-time tracking of environmental conditions such as temperature, humidity, and location, ensuring product integrity during transit. The recorded data are stored on the blockchain, making it tamper-proof and verifiable [16].

Decentralized Identity Verification in Supply Networks

To enhance transparency and prevent counterfeiting, decentralized identity solutions are being integrated with blockchain-based supply chain systems. This enables each participant, including manufacturers, distributors, and retailers, to have a verifiable and immutable digital identity, reducing the risks of fraud and unauthorized modifications [1].

Smart Contracts for Automated Compliance and Auditing

Researchers are also focusing on utilizing smart contracts for automating compliance checks and audits in supply chains. By embedding regulatory requirements into blockchain-based contracts, supply chain participants can ensure that standards are met without the need for manual verification, reducing delays and administrative overhead [24].

These emerging advancements highlight the continuous evolution of blockchain technology in supply chain management, offering more secure, transparent, and efficient solutions to address industry challenges.

Different research trends and open issues on blockchain technology in the food supply chain

Categorized based on various perspectives:

Technology Perspective

Technology development: The need for additional technologies such as IoT devices and radio-frequency identification is essential to ensure the reliability of packaging and instant tracking with blockchain [4,16,27,28].

System requirements: Developing a more robust tracking system than QR codes, which can be easily damaged or tampered with, is essential for packaging development [7,13]. This will help improve logistics and ensure that packages reach customers safely [23,29].

Project Overview

Systematics: Creating industry-wide standards for the use of blockchain can help ensure consistency and trust in how data are recorded and shared on equipment. Collaboration between suppliers, vendors, retailers, and customers can increase the efficiency of blockchain applications and speed up the process. Education programs throughout the supply chain are needed to overcome technological barriers and encourage adoption [12,30,31].

Regulatory Perspective

Framework development: It is critical to establish a clear regulatory framework for the use of blockchain in the food and agriculture industry in order to give stakeholders direction and ensure compliance. One of the most important challenges that needs to be addressed is supply chain compliance with data privacy rules like GDPR while retaining transparency.

Consumer Perspectives

Trust and transparency: Building consumer trust in blockchain systems requires effective communication about how data are collected, stored, and used to ensure food safety. Understanding the benefits and limitations of blockchain systems to track food can increase their confidence and willingness to use blockchain systems. Consumer-driven adoption of blockchain technology can help boost its integration into the food chain [4].

Logistics Perspective

Last-mile delivery challenge: Solving the complex logistics issues of last-mile delivery remains an open challenge, as ensuring safe and timely delivery to the actual customer is important to maintaining food quality and safety.

Monitoring package integrity: Implementing an effective system to track the physical condition of packages across of the supply chain is essential as blockchain by itself cannot ensure the preservation of package integrity.

Participants in the food supply network can work to effectively integrate blockchain technology to increase efficiency, transparency, and security while reducing restrictions [17].

Conclusions

The food supply chain is essential to maintain global food security, but it has many obstacles to overcome, such as opaqueness, inefficiency, and worries about food safety. Limited traceability, fragmented data management, and logistical problems with package integrity and end-to-end client delivery exacerbate these difficulties. Blockchain technology offers a novel solution for tracking food products along the whole supply chain in a decentralized, transparent, and immutable manner. By eliminating middlemen, ensuring product authenticity, and providing real-time visibility, its integration improves process dependability and efficiency from farm to table. In this paper, we have explored the potential of blockchain technology in addressing key food supply chain issues. The methodology involved existing research on blockchain fundamentals, its applications in the food industry, and the challenges of implementation, such as high costs, scalability, data privacy, and interoperability. Despite these challenges, blockchain has proven effective in improving food traceability, enhancing safety measures, and increasing consumer trust. However, there are still open issues, particularly in logistics. While blockchain ensures transparency and traceability, it does not directly solve the problem of package integrity during transportation, nor can it guarantee safe and timely last-mile delivery. These logistical challenges, essential to maintaining food quality and safety, require integration with IoT devices and other monitoring technologies to track package conditions in real time. Addressing these concerns alongside blockchain will be crucial for fully safeguarding the food supply network. The most recent research trends emphasize how blockchain, AI, and IoT can improve data management and traceability, further revolutionizing the food supply chain. To fully realize blockchain's potential to enhance the transparency, efficiency, and security of food supply chains, research must continue to address integration issues and explore new approaches.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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Disclosures

Conflicts of interest: In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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