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A Survey on Food Supply chain industry using Block chain Technology

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Abstract : **The global food supply chain is a complex network involving various stakeholders, from farmers and producers to distributors and consumers. Ensuring transparency, traceability, and food safety has become a paramount concern in the wake of numerous foodborne illnesses and counterfeit products. Blockchain technology has emerged as a promising solution to address these challenges by enabling a decentralized and immutable ledger system. This review paper provides a comprehensive analysis of the applications of blockchain technology in the food supply chain. It synthesizes the existing literature, surveys, and case studies to explore the potential of blockchain in enhancing food traceability, reducing fraud, improving supply chain efficiency, and empowering consumers. Moreover, the paper evaluates the challenges and limitations associated with the implementation of blockchain in the food supply chain, including data privacy, scalability, interoperability, and regulatory frameworks. It also discusses strategies used to provide security in blockchain technology and future directions in blockchain technology for the food industry. The paper begins by introducing the fundamental concepts of blockchain and its relevance to the food industry. It then examines the key features of blockchain technology, such as immutability, transparency, and decentralization, and their implications for the food supply chain. The review further delves into various blockchain-based solutions and platforms developed specifically for food traceability, supply chain management, and quality assurance. By synthesizing the existing knowledge and providing critical insights, this review paper contributes to a better understanding of the transformative potential of blockchain technology in the food supply chain. It serves as a valuable resource for researchers, practitioners, policymakers, and industry stakeholders seeking to leverage blockchain to create a safer, more transparent, and efficient food system.**

***IndexTerms*- Food Supply Chain, Block chain, Transparency**

I. Introduction

Blockchain technology has gained significant attention and recognition as a groundbreaking innovation with the potential to disrupt numerous industries. Originally introduced as the underlying technology for cryptocurrencies like Bitcoin, blockchain has evolved into a versatile solution with applications beyond digital currencies.[1] It offers a decentralized, transparent, and immutable platform for securely recording and verifying transactions. As a result[2,3], it has garnered interest from researchers, practitioners, and policymakers worldwide.

At its core, a blockchain is a distributed ledger that maintains a continuously growing list of records, called blocks, in a chronological and tamper-resistant manner. Each block contains a collection of transactions, and once a block is added to the blockchain, it becomes permanent and virtually impossible to alter. This immutability is achieved through the ingenious combination of cryptographic algorithms and distributed consensus mechanisms.[6]

The decentralized nature of blockchain eliminates the need for a central authority or intermediary to validate and authorize transactions. Instead, a network of computers, known as nodes, collaboratively participates in the consensus process to verify the integrity of transactions. This decentralized consensus mechanism enhances security, reduces the risk of fraud, and increases transparency and trust among participants.

The potential applications of blockchain span across diverse sectors. In finance, blockchain technology enables efficient and secure peer-to-peer transactions, eliminates the reliance on intermediaries, and reduces transaction costs. It also facilitates faster cross-border[6,7] payments and financial inclusion for underserved populations. Supply chain management stands to benefit from blockchain's ability to provide end-to-end traceability, provenance verification, and real-time visibility of goods, thus enhancing efficiency and mitigating counterfeit products.

Beyond finance and supply chain management, blockchain holds promise in other areas as well. Healthcare can leverage blockchain to enhance the secure sharing and interoperability of electronic health records, protect patient privacy, and streamline data management.[10,11] Governments can explore the use of blockchain for transparent voting systems, secure identity management, and efficient public service delivery. Additionally, blockchain has applications in energy, intellectual property, digital rights management, and many other domains.

While the potential benefits of blockchain are significant, there are also challenges that need to be addressed. Scalability, energy consumption, privacy, regulatory frameworks, and interoperability are among the key issues that researchers and practitioners are actively exploring.[34] Additionally, the design and implementation of effective consensus mechanisms, smart contract security, and governance models are critical for blockchain's long-term success.

This review paper aims to provide a comprehensive overview of blockchain technology, its underlying principles, and its applications across various domains. We will delve into the technical foundations of blockchain, including cryptographic techniques, consensus algorithms[5,23], and smart contracts. Furthermore, we will examine the current state of blockchain adoption, highlighting successful use cases and identifying challenges and future research directions. By synthesizing existing knowledge and analyzing the latest developments, this review paper aims to contribute to the advancement and understanding of blockchain technology and its transformative potential.

The information below provides a structured overview of the key aspects related to algorithms in blockchain, the application of blockchain in the food supply chain, a comparison of different blockchain technologies, a conclusion summarizing the potential benefits and considerations, and an exploration of the challenges and issues associated with blockchain implementation.

II. BLOCKCHAIN IN FOOD SUPPLY CHAIN

Blockchain technology has gained attention and applications in various industries, including the food supply chain. Blockchain offers a decentralized and transparent system for recording and verifying transactions, which can address several challenges in the food supply chain such as traceability, food safety, and efficiency. Here are some key aspects of blockchain in the food supply chain:

Traceability: Blockchain enables end-to-end traceability by recording every transaction or event related to the food product on a distributed ledger. Each step in the supply chain, from the farm to the consumer, can be recorded, [40]including details about the origin, processing, packaging, transportation, and storage of the food. This allows stakeholders to track the movement of products, verify authenticity, and quickly identify and resolve issues like contamination or recalls.

Food Safety and Quality: Blockchain can enhance food safety by providing a transparent and immutable record of each stage of the supply chain. It allows for real-time monitoring[14,19] and verification of various parameters such as temperature, humidity, and storage conditions. Smart contracts can be utilized to automatically trigger alerts or actions when certain conditions are not met, ensuring compliance with quality standards and reducing the risk of foodborne illnesses.

Supply Chain Efficiency: Blockchain technology streamlines supply chain processes by eliminating intermediaries, reducing paperwork, and improving data accuracy. It enables more efficient inventory management, optimized logistics, and faster settlement of payments. Smart contracts can automate and enforce contractual agreements, ensuring compliance[25] and reducing delays or disputes between stakeholders.

Authentication and Counterfeit Prevention: Counterfeit food products are a significant concern in the global market. Blockchain can help tackle this issue by providing a tamper-proof and auditable record of the product's journey from farm to fork. Each transaction is recorded on the blockchain, making it difficult for fraudsters to manipulate the data or introduce counterfeit products into the supply chain.

Consumer Trust and Transparency: Blockchain empowers consumers with access to transparent and reliable information about the food they consume. With a simple scan of a QR code or NFC tag[39], consumers can retrieve detailed information about the product's origin, ingredients, certifications, and ethical practices. This enhances trust, fosters brand loyalty, and promotes sustainable and responsible sourcing.

Collaborative Networks and Data Sharing: Blockchain facilitates secure and permissioned data sharing between different stakeholders in the food supply chain. It enables suppliers, manufacturers, distributors, retailers, regulators, and consumers to access and contribute to a shared ledger, ensuring consistent and accurate information across the network. [37] Collaborative efforts and data sharing can help address supply chain inefficiencies, reduce fraud, and improve overall industry standards.

Despite its potential, implementing blockchain in the food supply chain faces challenges such as scalability, interoperability, standardization, and the integration of existing systems. However, numerous pilot projects and initiatives are already underway globally to explore the technology's capabilities and refine its implementation in this critical industry.

III. Types of Consensus Algorithm in Block Chain

Proof of Work (PoW):

Proof of Work (PoW) is a consensus algorithm used in blockchain networks to validate and secure transactions. It requires participants, known as miners,[2] to solve a computationally intensive puzzle in order to add new blocks to the blockchain. The primary purpose of PoW is to ensure the integrity and immutability of the blockchain by making it difficult and resource-intensive to manipulate the transaction history.

However, it's important to note that the PoW algorithm is not directly related to accuracy in the traditional sense. Accuracy typically refers to the correctness or precision of a calculation, measurement, or result[5,7]. In the context of PoW, accuracy is not the main concern.

Instead, PoW focuses on the concept of "difficulty." The algorithm sets a specific difficulty level that miners must meet or exceed in order to solve the puzzle and add a new block. The difficulty is adjusted dynamically by the network to maintain a consistent block generation rate, regardless of changes in computational power.

The "accuracy" of PoW can be understood in terms of its security guarantees. The algorithm ensures the accuracy of the blockchain's transaction history by making it computationally infeasible to alter past transactions without redoing the work of the entire blockchain[23,34]. This property makes the blockchain resistant to tampering and provides a high level of security.

In summary, while the PoW algorithm does not have a direct relationship with accuracy in the traditional sense, it provides a high level of security and guarantees the accuracy and integrity of the blockchain's transaction history[7].

Proof of Stack (PoS):

Proof of Stake is a consensus algorithm used in blockchain networks to achieve distributed consensus and validate transactions[5]. It is an alternative to the more common proof of work (PoW) algorithm.

In a proof of stake system, validators are chosen to create new blocks and validate transactions based on the amount of cryptocurrency they hold and "stake" in the network. Essentially, the more cryptocurrency a validator holds and "stakes," the more likely they are to be chosen to create the next block and earn rewards[15].

In a PoS system, validators are not required to solve complex mathematical puzzles like in PoW. Instead, their chances of being chosen to validate transactions are proportional to their stake in the network. This means that validators have an economic incentive to act honestly and follow the rules of the blockchain because they have something at stake[23,7]. If a validator behaves maliciously or tries to manipulate the system, their stake can be slashed, resulting in a financial loss.

Proof of stake has several advantages over proof of work, including reduced energy consumption since it doesn't rely on intensive computational mining. It also potentially enhances the security of the network as it makes it economically impractical for an attacker to gain control of the majority of the stake. However, different PoS implementations[38] may have variations in their specific mechanisms and features.

Practical Byzantine Fault Tolerance (PBFT):

Practical Byzantine Fault Tolerance (PBFT) is a consensus algorithm designed to ensure fault tolerance in distributed systems. It was introduced by Miguel Castro and Barbara Liskov in 1999. PBFT is specifically designed to address the Byzantine fault model, where nodes in a distributed system may exhibit arbitrary and malicious behavior, including sending contradictory messages, omitting messages[40], or forging messages.

In a distributed system, consensus algorithms aim to reach an agreement among the participating nodes on a single value or outcome, even in the presence of faulty nodes. PBFT achieves this by employing a replication approach, where a distributed system is replicated across multiple nodes, called replicas[3]. These replicas communicate with each other to reach a consensus on the validity and order of transactions.

It's important to note that PBFT has certain limitations, including high message complexity (quadratic in the number of replicas) and a requirement for a known and fixed number of replicas[17,20]. However, it remains a widely studied and utilized consensus algorithm, particularly in permissioned blockchain systems and distributed databases where Byzantine fault tolerance is crucial.

IV. Most Commonly used Techniques

Internet of Things (IoT):

IoT devices, such as sensors and RFID tags, can be deployed throughout the food supply chain to collect real-time data on various parameters like temperature, humidity, location, and quality. These devices can be integrated into vehicles, storage facilities, and even individual products. For example, temperature sensors in refrigerated trucks can monitor the temperature of perishable goods during transportation[10].

Similarly, sensors in warehouses can track humidity levels to ensure the quality of sensitive food items. This data is then transmitted to a central system for analysis. By integrating IoT devices with blockchain technology, the food supply chain can benefit from enhanced traceability and transparency[12,14]. IoT sensors can collect data at each stage of the supply chain and record it on the blockchain in a secure and tamper-resistant manner.

For example, the temperature and humidity data collected by IoT devices can be recorded on the blockchain, creating an auditable trail of conditions experienced by the food products. This information can be accessed by stakeholders to ensure compliance with regulations, identify potential issues, and trace the origin of any quality or safety problems. Additionally, smart contracts, which are self-executing contracts with predefined rules, can be utilized on the blockchain to automate certain processes in the supply chain.

These smart contracts can facilitate automated payments, streamline compliance checks, and trigger actions based on predefined conditions[6]. The integration of IoT and blockchain technologies in the food supply chain can significantly improve efficiency, reduce fraud, enhance food safety, and increase consumer trust by providing transparent and reliable information about the products' journey from farm to fork.

NFC (Near Field Communication):

NFC (Near Field Communication) technology can play a significant role in enhancing the efficiency and transparency of the food supply chain. NFC is a short-range wireless communication technology[22] that allows devices in close proximity to exchange data. Here are some ways NFC can be utilized in the food supply chain:

1.Product Authentication: NFC can be used to verify the authenticity of food products. Each item can be equipped with an NFC tag that contains unique identification information[21,26]. Consumers, retailers, or inspectors can use NFC-enabled devices (such as smartphones) to scan the tags and access data about the product's origin, quality, and certifications.

2.Traceability and Tracking: NFC tags can store information about each stage of the food supply chain, including the farm or manufacturer, production date, transportation details, and storage conditions. By scanning the NFC tags at different checkpoints, stakeholders can track the product's journey and ensure compliance with regulations. This enhances transparency and enables swift identification of any issues or recalls.

3.Quality and Safety Information: NFC tags can provide consumers with real-time information about a food product's quality, safety, and nutritional content. By scanning the NFC tag, consumers can access details such as expiration dates, allergen information, storage recommendations, and any relevant recalls or warnings.

4.Temperature Monitoring: NFC-enabled temperature sensors can be integrated into packaging or containers to monitor the temperature conditions during transportation and storage. These sensors can record and transmit temperature data to NFC-enabled devices, allowing stakeholders to ensure that perishable goods are handled within the required temperature range to maintain quality and prevent spoilage[21].

5.Smart Shelves and Inventory Management: NFC can be used in retail environments to streamline inventory management. NFC-enabled shelves and tags can automatically update stock levels, trigger reordering processes, and provide real-time information about product availability[24]. This reduces manual effort and improves the accuracy of inventory management.

6.Consumer Engagement and Marketing: NFC tags can be used to engage consumers by providing them with additional information, promotions, or interactive experiences. For example, scanning an NFC tag on a product could provide recipes, nutritional facts, or suggestions for complementary products, enhancing the overall customer experience[10].

Overall, NFC technology can improve transparency, traceability, and consumer trust in the food supply chain. By leveraging NFC-enabled devices, stakeholders can access real-time data, ensure product authenticity, monitor conditions, and streamline processes, leading to more efficient and secure food systems.

RFID (Radio Frequency Identification):

RFID (Radio Frequency Identification) technology has been used in various industries, including the food supply chain, to improve efficiency, traceability, and safety. RFID involves using radio waves to identify and track objects or products equipped with RFID tags[4,5]. In the context of the food supply chain, RFID can be employed at different stages, such as production, distribution, and retail.

Here are some ways RFID is utilized in the food supply chain:

1.Inventory Management: RFID tags can be attached to individual food items, cases, or pallets, allowing for accurate and automated inventory tracking. This helps streamline supply chain operations by providing real-time data on stock levels, reducing stockouts and overstocks, and improving demand forecasting[9].

2.Traceability and Food Safety: RFID enables enhanced traceability by providing detailed information about the origin, processing, and transportation of food products. If a safety issue or recall occurs, RFID can help identify the affected products quickly, minimizing the impact on public health. By tracking temperatures, RFID also helps monitor and maintain proper food storage conditions, ensuring food safety.

3.Shelf Life Management: RFID tags can store information about the production date, expiration date, and storage requirements of food products. By monitoring this data in real-time, retailers can ensure that perishable goods are properly rotated, reducing waste and improving product quality.

4.Supply Chain Visibility: RFID technology provides increased visibility into the movement of food products throughout the supply chain. By tracking RFID-tagged items at various checkpoints, companies can identify bottlenecks, optimize logistics operations, and improve overall supply chain efficiency.

5.Counterfeit Prevention: Counterfeit food products pose a significant risk to consumer health and brand reputation. RFID can help combat this issue by providing a unique identifier for each product, making it easier to verify authenticity and detect counterfeit goods.

It's worth noting that while RFID technology offers numerous benefits, its implementation in the food supply chain can present challenges. These challenges include the cost of RFID tags, integration with existing systems[5,7,8], and ensuring interoperability across different stakeholders in the supply chain. However, as technology advances and costs decrease, RFID is becoming more accessible and widely adopted in the food industry to improve transparency and safety.

SR No	Journal Name	Data Set	Method/ Technique used
[8]	Journal of Cleaner Production	Dummy variables set designed to test the method designed with variables like H,L,M	(i)Farm management information system using IoT (ii) Agriculture sensor network WSN & WSAN (iii) RFID scanner technology
[4]	International Journal of Management Studies	NA	1. Blockchain technology adoption in the food supply chain.2. Artificial intelligence (AI) is the latest technology in supply chain analysis 3.use of RFID and other sensors and Big data and social media analytics
[11]	International Conference on Services Systems and Services Management, ICSSSM	The agri-food contains two types: fresh fruits & vegetables, and meats which include pork, mutton, chicken and beef.	The agri-food supply chain traceability system which we build in this paper mainly relies on RFTD technology to implement data acquisition.
[9]	International Conference on Information and Communication Technology(ICoICT)	Dummy Data-Sets	ZigBee, smart agriculture
[10]	IEEE International Conference on Industrial Engineering and Engineering Management	Government, Ministry of Agriculture is given the access to the record of the data. This information would provide the basis for supervision, food recall and prior warning [22].	It uses PEST Technology. PEST is an analytical model which analyzes the macro-environment location of the industry.
[2]	International Conference on Advanced Communication Technology (ICACT)	The data is collected through traditional seafood technology	Blockchain based seafood supply chain
[7]	International Seminar on Research of Information Technology and Intelligent Systems (ISRITI)	Data on the blockchain consists of the previous block hash, nonce, hash of all block transactions, and transaction list data	Blockchain based systems are divided into 4 layers of abstraction: application, data model, execution engine, and consensus.
[1]	International Journal of Information Management	The vaccine demand forecasting module is implemented by the machine learning model	Smart contracts for the vaccine supply chain
[3]	Scientific Programming	The food product's data, such as its harvesting date and price, is uploaded by the supplier and then an RFID chip is embedded in the product.	Smart contracts
[38]	International Conference on Smart Blockchain	Walmart	Wal-Mart is famous for its efficient supply chain management through large distribution, Electronic Data Interchange (EDI) and Radio frequency Identification (RFID). Smart Package system
[20]	IEEE	Collection of data from various cocoa produced regions in Ghana	The RFID technology is IoT based where it is used to sense and track the products.

[27]	Hawaii International Conference on System Sciences |	NA	Cryptocurrency Bitcoin, blockchain technology (BCT)
[12]	Modelling food supply chain traceability based on blockchain technology	Information is stored in a table of content (TOC) using IoT technology	Smart Contracts
[13]	International Journal of Information Management	Data is collected into a single product record, makes temperature compliance and humidity monitoring easier, and ensures quick and easy digital access to all data for a product	Proof of Concept (POC)
[23]	Advanced Science and Technology Letters	NA	Rice supply chain system, blockchain, centralized, decentralized and distributed.
[15]	International Journal of Production Research	T-Mining, a start-up in Antwerp (a blockchain solution for the port's container where required data for releasing a container are gathered in a database and the information is restricted to only the involved parties)	Comparison between trade and industry
[16]	International Journal of Production Research	The BOM (Bill of Materials) is recorded, along with the control parameters, the place where the control is conducted, the person responsible and the results (data, conforming/non-conforming checks) in all production phases.	Smart contracts (a multi-disciplinary research methodological framework (both SC and Information technology-oriented)
[17]	Production Planning & Control	It includes farmers; distributors; packers; processors; wholesalers; retailers; and customers, such as grocers, restaurants, traders, and end users, who jointly act and share food-related data using a blockchain consortium	Data-capture technologies include radio frequency identification (RFID), barcodes, wireless sensor network (WSN), alphanumeric cod
[18]	IEEE Access	Environmental sensors and relay nodes are installed to collect data on environmental conditions, while the collection timestamp is also recorded	Consensus mechanism, Internet of Things, sensor nodes and relay nodes
[19]	IEEE Access	NA	Consensus Protocol
[21]	IEEE INTERNET OF THINGS JOURNAL	A data block is created containing the information about the package at each valid transaction. Once the transaction is verified, the transaction of the sensorID is converted into a block of information.	A RFID based sensor at the physical layer and blockchain at the cyber layer
[25]	International Conference on Advanced Communications Technology	NA	Blockchain technology
[35]	PeerJ Computer Science	The proposed framework provides safe ,efficient , reliable and effective	Ethereum blockchain, Smart contract

		to monitor and track rice products.	
[38]	IEEE International Conference on Smart Computing (SMARTCOMP)	BRUSCHETTA leverages IoT technologies in order to interconnect sensors dedicated to EVOO quality control, and to let them operate on the blockchain.	Hyperledger Fabric, Food supply chain monitoring
[26]	International Workshop on Emerging Trends in Software Engineering for Blockchain	NA	Hyperledger Sawtooth, RFID, IoT devices and, sensors
[39]	International Conference on Smart Blockchain	ABI/Inform Complete/ProQuest; EBSCO;Web of Science; Google Scholar; IEEE Xplore etc	BCT(Blockchain Technology), Case study of WALMART
[40]	IEEE	Dummy variables set designed to test the method designed with diagrams	Ethereum, Smart Contracts

TABLE 4.1: TABLE OF COMPARISON OF DIFFERENT TECHNOLOGIES WITH DATASET

v. RESEARCH GAP

1. Traceability [2,4,7]

Traceability involves documentation (block) of crop data and linking the production, processing, and distribution chain of food products and ingredients.

2. Transparency [12,14]

Transparent systems of food production are advantageous to stakeholders and consumers.

3. Changeable or mutable data [7,8]

Immutable data will help to get accurate information about food from fark to fork.

4. Security [34,37]

The issue of supply chain security is fundamentally pertinent to the food industry as these traded products are consumed by humans, imposing significant threats to human life and our standard of living

vi. ISSUES IN THE FOOD SUPPLY CHAIN

1.Traceability: One major concern in the food industry is the lack of transparency and traceability. Blockchain can enable end-to-end traceability by recording every transaction and movement of food products on the distributed ledger. Each participant in the supply chain can add information to the blockchain, including details about the origin[40], processing, packaging, and distribution of the food. This transparency helps identify and address issues such as contamination, fraud, or illegal practices.

2.Food Safety: Contamination and foodborne illnesses are significant problems in the food industry. By using blockchain, the entire history of a food product can be recorded, including data about its quality tests, certifications, and inspections[12,14]. If a safety issue arises, blockchain can facilitate quick identification of the affected batch, allowing for targeted recalls and reducing the impact on public health.

3.Supply Chain Efficiency: The food supply chain is often complex, involving multiple intermediaries, including farmers, distributors, processors, and retailers. Blockchain can streamline and automate many processes, reducing paperwork, enhancing data accuracy, and eliminating the need for intermediaries. Smart contracts on the blockchain can automatically trigger actions, such as payments or shipments, [16]when predefined conditions are met, reducing delays and improving overall efficiency.

4.Counterfeit Products: Counterfeit food products pose risks to consumer health and brand reputation. By recording product information on the blockchain, including unique identifiers like barcodes or RFID tags, it becomes difficult to alter or replicate the records. Consumers can scan these identifiers and verify the authenticity and origin of the product, reducing the likelihood of purchasing counterfeit goods.

5.Sustainability and Ethical Practices: Blockchain can promote sustainability and ethical practices in the food supply chain by providing a transparent record of how the food is produced. For example, it can track whether products are organic, fair-trade, or produced using environmentally friendly methods[19]. This information empowers consumers to make informed choices and encourages companies to adopt sustainable and ethical practices to maintain their reputation.

While blockchain offers promising solutions[20], it's important to note that implementing it across the entire food supply chain requires collaboration and adoption by all stakeholders. Overcoming technical challenges[8], interoperability issues, and ensuring data privacy are crucial aspects to consider when implementing blockchain solutions.

vii. CONCLUSION

In conclusion, blockchain technology, with its inherent features of transparency, traceability, data integrity, digital signatures, and interoperability, has the potential to revolutionize the food supply chain. This survey paper has provided a comprehensive overview of the food supply chain, highlighting its complexity, and challenges.

The food supply chain can be successfully incorporated with blockchain technology with consensus algorithm to make immutable data that can be shared among ledgers and make system transparent. Blockchain enables end-to-end traceability by recording every step of the supply chain in a secure and tamper-resistant manner. This allows stakeholders to track the movement of products from farm to table, ensuring accountability and reducing the risk of fraud, counterfeit goods, and foodborne illnesses. Each transaction or record added to the blockchain is linked to previous records, forming a chain of blocks. Any attempt to alter previous records would require immense computational power, making it highly impractical and easily detectable. By implementing these strategies, we can work towards building a more resilient, sustainable, and inclusive food supply chain that ensures food security, minimizes waste, protects the environment, and meets the diverse needs of consumers.

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