Communications on Applied Nonlinear Analysis
ISSN: 1074-133X
Vol 32 No. 9s (2025)

An Automated Framework Blockchain-Based Agriculture Supply Chain

Ankita K. Tiwari[1], Dr. Seema Mahajan[2]

[1]Research scholar–Indus University,[2]Head of Department–Indus University

Article History:

Received: 12-01-2025

Revised: 15-02-2025

Accepted: 01-03-2025

Abstract:

The agricultural supply chain plays a crucial role in ensuring food security and sustainability. However, traditional supply chains face challenges such as lack of transparency, inefficiencies, and limited traceability, leading to fraud, food wastage, and delays. Blockchain technology has emerged as a promising solution to address these issues by providing a decentralized, immutable, and transparent ledger system. This paper explores the key attributes essential for an efficient agricultural supply chain, such as traceability, transparency, data integrity, and operational efficiency. A comprehensive survey of existing research is conducted to analyze blockchain-based solutions implemented in the agriculture sector. Various techniques, including different consensus mechanisms (such as Proof-of-Work, Proof-of-Stake, and PBFT), smart contract applications, and scalability solutions, are compared based on performance, cost, and adoption challenges. Despite its potential, blockchain faces limitations such as high transaction costs, interoperability issues, and resistance to adoption by stakeholders. Identifying these research gaps helps in refining future studies to develop a more effective and scalable blockchain framework for agricultural supply chains. This paper presents a novel perspective on blockchain-driven supply chain frameworks, highlighting their role in optimizing logistics, reducing fraud, and ensuring sustainability in global commerce. The future of blockchain-based supply chain management lies in its integration with emerging technologies such as Artificial Intelligence (AI), Internet of Things (IoT), and Big Data analytics. AI-powered analytics can enhance predictive decision-making, while IoT sensors can provide real-time monitoring of goods, improving accuracy and efficiency.

Keywords**:** Food Supply Chain, Block chain, Transparency, Interoperability

INTRODUCTION

Blockchain technology has gained significant attention and recognition as a groundbreaking innovation with the potential to disrupt numerous industries. Originally introduced as the primary 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 tampersecurity, 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 many challenges that need to be defined. 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 extensive 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 provocations and future research directions. By synthesizing existing knowledge and analyzing the latest developments, this review paper aims to come up with 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.

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 industry 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 incorporation 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.

TYPES OF CONSENSUS ALGORITHM IN BLOCK CHAIN

A. Proof of Work (PoW):

Proof of Work (PoW), 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].

B. Proof of Stack (PoS):

Proof of Stake, 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.

C. 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.

MOST COMMONLY USED TECHNIQUES

A. 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.

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.

B. 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].

C. 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.

D. Smart Contracts:

A smart contract is a sort of program that encodes business logic and operates on a dedicated virtual machine embedded in a blockchain or other distributed ledger.

Step 1: Business teams collaborate with developers to define their criteria for the smart contract's desired behavior in response to certain events or circumstances.

Step 2: Conditions such as payment authorization, shipment receipt, or a utility meter reading threshold are examples of simple events.

Step 3: More complex operations, such as determining the value of a derivative financial instrument, or automatically releasing an insurance payment, might be encoded using more sophisticated logic.

Step 4: The developers then use a smart contract writing platform to create and test the logic. After the application is written, it is sent to a separate team for security testing.

Step 5: An internal expert or a company that specializes in vetting smart contract security could be used.

Step 6: The contract is then deployed on an existing blockchain or other distributed ledger infrastructure once it has been authorized.

Step 7: The smart contract is configured to listen for event updates from an "oracle," which is effectively a cryptographically secure streaming data source, once it has been deployed.

Step 8: Once it obtains the necessary combination of events from one or more oracles, the smart contract executes.

COMPARATIVE ANALYSIS OF METHODS WITH DATA IN BLOCKCHAIN TECHNOLOGY

TABLE 1: TABLE OF COMPARISON OF DIFFERENT TECHNOLOGIES WITH DATASET

SR No	Method/Technique	Advantages	Research gaps
[8]	Agriculture sensor with RFID scanner technology, Cloud	P2P network, Transaction ownership, Coordination between modules	i) Trust ii) Traceability iii) Confidentiality
[4]	Blockchain technology Artificial intelligence (AI) RFID and other sensors and Big data analytics	Transparency, Data Governance and policies	i) Traceability ii) Mutability iii) Security
[11]	RFID, Sensors	Reducing the cost because the data are stored in different layer of blockchain , Privacy Leakage Issues, benefits of RFID	i) High cost of RFID ii) Mutability iii) Confidentiality
[9]	ZigBee, smart agriculture, IoT	Live Tracking, Accuracy in data	i) Trust ii) Mutability
[10]	Pest Analysis	Blockchain technology replaces traditional system	i) Traceability ii) Reliability iii) Security

[2]	IOT, Blockchain technology	It provides security and sustainability of resource.	i) Lack of flexibility ii) Lack of visibility
[7]	Blockchain Consensus Theorem, Smart Contract	The evaluation shows that FoodTrail Blockchain fulfilled the distributed, verified, and immutable aspect.	i) Lack of Trust ii) Lack of Security
[1]	Smart Contract, Blockchain Technology and Machine Learning	A reliable information management and traceability system, effective trust mechanisms between institutions and customers in supply chains.	i) Lack of Safety ii) Lack of Trust
[3]	Smart Contracts, Centralized Supply Chain	(i) Overall management of the system. (ii) System errors. (iii) Product delay.	i) Trust ii) Transparency iii) Security
[38]	Smart Agriculture, Hyperledger Fabric, IoT	Temper Proof copy of the product, Securing data with encryption	i) Trust ii) Reliability iii) Security
[20]	RFID, Blockchain Technology, IoT	Global Traceability Platform, Supply Chain Intelligence and Visibility	i) Accuracy ii) Reliability
[27]	Blockchain Technology, Supply Chain Management	Quantitative Analysis, Model of data Ownership	i) Validity ii) Reliability
[12]	Blockchain Technology, Smart Contracts	FSC traceability model provides visibility and security.	i) Trust ii) Validity iii) Reliability
[13]	Blockchain Consensus Theorem, Hyperledger Sawtooth	Consumer demand and the need for improved traceability is adopted	i) Authenticity ii) Tracking Method iii) Reliability
[23]	Rice supply chain, Blockchain with distributed and decentralized	Safety in production and planning	i) Traceability ii) Quality

[15]	Blockchain Technology, Types of blockchain	Cargo integrity and security, Supply chain digitization, trust and stake holder management	i) Security ii) Feasibility
[16]	Blockchain technology, Smart contracts with solidity	Improved trust, efficiency, quality and resilience	i) Large amount of data ii) Scalability
[17]	Blockchain technology and IoT with sensors	Food Tracking ,Data capture	i) Customization ERP implementation ii) Traceability
[18]	Blockchain, Consensus Mechanism, IoT	IoT monitoring module, cloud database, Fuzzy food quality module	i) Integration of flows in supply chain ii) Quality Management
[19]	Blockchain technology, Ethereum	Merkle tree technique, Smart farming through IoT sensors	i) Security and privacy ii) Scalability
[21]	RFID, Blockchain technology, IoT	Sensing Modality, Tracking and Quality monitoring	i) Security ii) Scalability
[25]	Blockchain, RFID, Peer to Peer network	Distributed ledger provides security and trust.	i) Security ii) Smart sensors
[35]	Rice grain supply chain, Ethereum in Blockchain technology	Secure and Traceable Rice Supply Chain Framework	i) Privacy ii) Credibility
[36]	Blockchain, IoT, Cloud computing	Blockchain and smart contracts are used to track and trace supply chain	i) Scalability ii) Privacy iii) Security
[26]	Blockchain, Hyperledger Sawtooth, Smart contract	Elimination of centralization between modules, trust between modules	i) Scalability ii) Quality control
[39]	Blockchain technology	Thematic analysis, Case study of WALMART	i) Scalability ii) Security
[40]	Agriculture Supply Chain, Blockchain Barriers	Model provides limited interpretative logic	i) Food Safety ii) Security

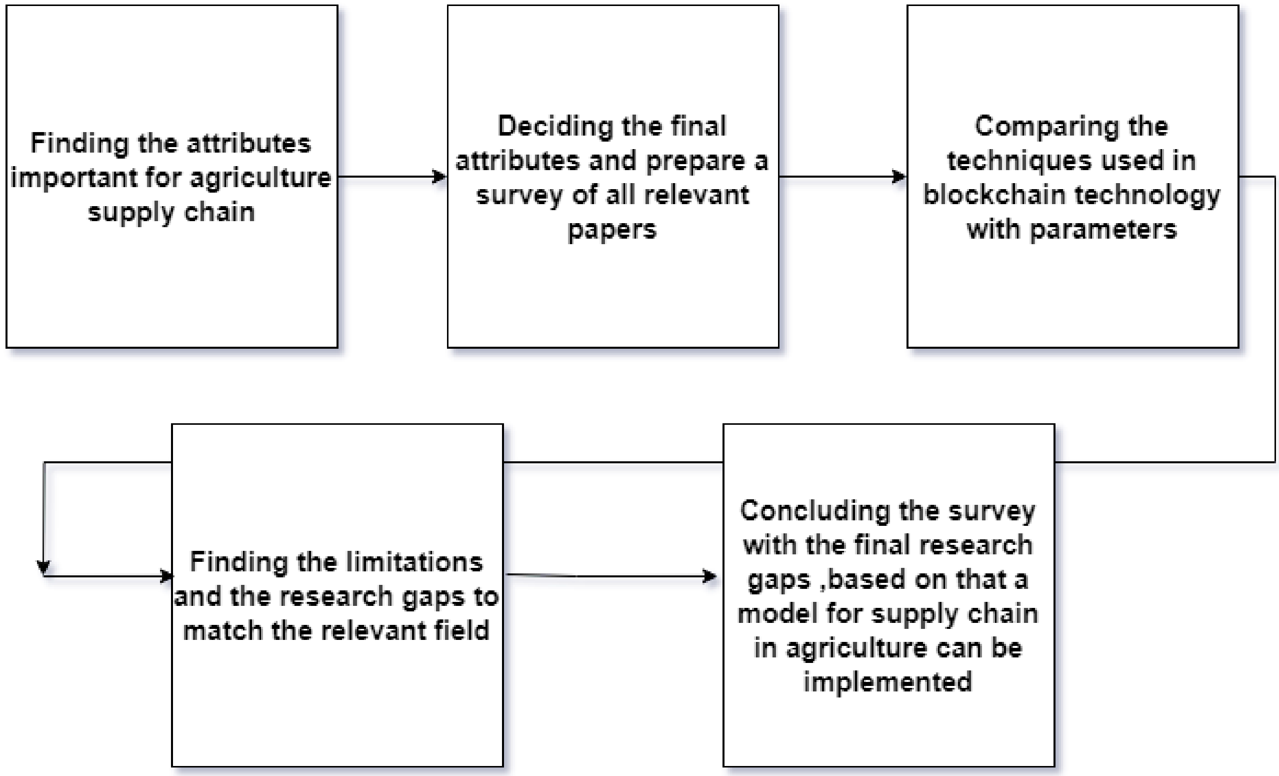

FIGURE 1: FLOWCHART SHOWING LITERATURE SURVEY

The diagram outlines a structured approach to analyzing and improving the agricultural supply chain using blockchain technology. The first step involves **identifying the key attributes** that are crucial for an efficient agricultural supply chain, such as traceability, transparency, data integrity, and efficiency. Once these attributes are identified, the next step is to **finalize the most relevant attributes and conduct a comprehensive survey** of existing research papers related to blockchain applications in the agricultural sector. This survey helps in understanding various techniques and methodologies that have been proposed or implemented in this domain.

Following the literature review, the next step is **comparing different blockchain-based techniques** based on predefined parameters. These parameters may include the type of consensus mechanisms used (e.g., Proof-of-Work, Proof-of-Stake), the role of smart contracts, scalability issues, and cost-performance trade-offs. A comparative analysis helps in identifying strengths and weaknesses of existing approaches and how they align with the identified attributes of the agricultural supply chain.

Once the comparison is complete, the next step is **identifying limitations and research gaps** in the existing studies. This step is crucial as it highlights the areas where current blockchain implementations fall short, such as high transaction costs, lack of interoperability, and challenges in large-scale adoption. Based on these findings, the final step is to **conclude the survey by summarizing the research gaps and proposing a model** that can address these shortcomings. This model will serve as a potential framework for implementing blockchain in the agricultural supply chain, ensuring improved efficiency, security, and transparency. The cycle may also revisit earlier stages to refine the attributes and address newly discovered challenges, ensuring a continuous improvement approach toward blockchain integration in agriculture.

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

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.

PRACTICAL STEPS IN BLOCKCHAIN-BASED AGRICULTURAL SUPPLY CHAIN

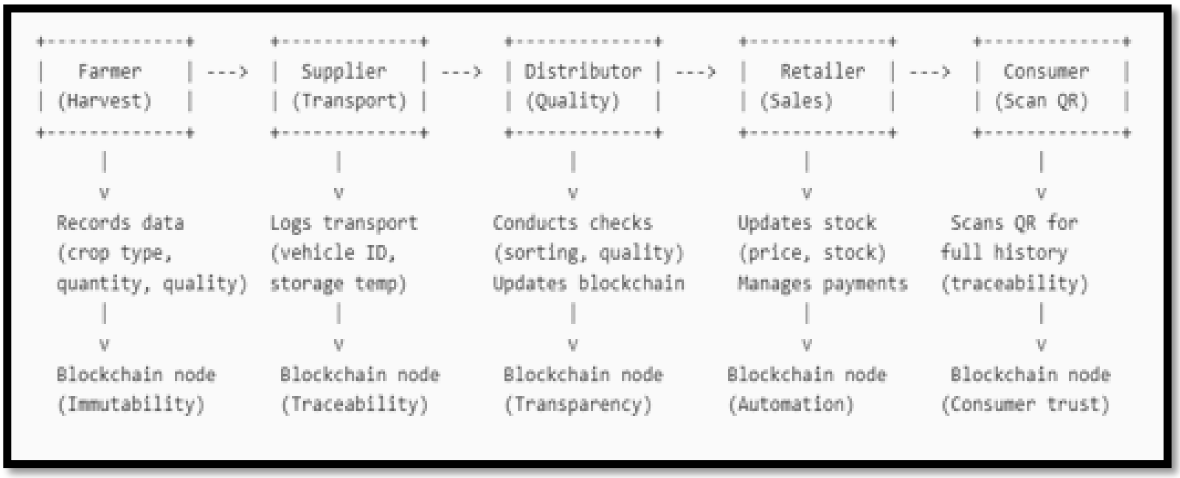

FIGURE 2: FLOWCHART SHOWING BLOCKCHAIN-BASED AGRICULTURAL SUPPLY CHAIN[8]

1. Farmer (Production Stage)

- Harvests crops and records essential data:
  - **Crop type, quantity, quality, harvesting date**
- Data is stored on the **blockchain ledger** for transparency.
- **Smart contracts** verify authenticity and ensure compliance with agricultural standards.

2. Supplier (Transportation & Storage Stage)

- Collects harvested produce and **updates storage conditions** (temperature, humidity).
- Records **transportation details** (vehicle ID, route tracking).
- Ensures that **logistics information** is immutably recorded on the blockchain.

3. Distributor (Quality Inspection & Processing Stage)

- **Performs quality checks** and logs inspection results.
- Records details on **sorting, packaging, and processing** before shipment.
- Ensures compliance with regulatory standards using **blockchain verification**.

4. Retailer (Market Distribution Stage)

- Updates **product pricing, stock availability, and inventory changes** on the blockchain.

- Uses **smart contracts** to manage automated payments and streamline supply-demand processes.
- Ensures traceability so consumers can access the **entire product history**.

5. Consumer (End-User Transparency)

- Scans a **QR code** on the product packaging.
- Gains access to **real-time supply chain history**, including:
  - **Origin details** (farm location, crop quality).
  - **Storage & transportation conditions** (temperature logs, route tracking).
  - **Quality inspection results** (certifications, freshness levels).
- Ensures trust in the agricultural supply chain.

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.

REFERENCES

[1] Yong, Binbin, et al. "An intelligent blockchain-based system for safe vaccine supply and supervision." International Journal of Information Management 52 (2020): 102024.

[2] Aich, Satyabrata, et al. "A review on benefits of IoT integrated blockchain based supply chain management implementations across different sectors with case study." *2019 21st international conference on advanced communication technology (ICACT)*. IEEE, 2019.

[3] Ehsan, Ibtisam, et al. "A conceptual model for blockchain-based agriculture food supply chain system." Scientific Programming 2022 (2022): 1-15.

[4] Behnke, Kay, and M. F. W. H. A. Janssen. "Boundary conditions for traceability in food supply chains using blockchain technology." *International Journal of Information Management* 52 (2020): 101969.

[5] Tian, Feng. "An agri-food supply chain traceability system for China based on RFID & blockchain technology." 2016 13th international conference on service systems and service management (ICSSSM). IEEE, 2016.

[6] Tian, Feng. "A supply chain traceability system for food safety based on HACCP, blockchain & Internet of things." 2017 International conference on service systems and service management. IEEE, 2017.

[7] Hayati, Hashri, and I. Gusti Bagus Baskara Nugraha. "Blockchain based traceability system in food supply chain." *2018 International Seminar on Research of Information Technology and Intelligent Systems (ISRITI)*. IEEE, 2018.

[8] Saurabh, Samant, and Kushankur Dey. "Blockchain technology adoption, architecture, and sustainable agri-food supply chains." *Journal of Cleaner Production* 284 (2021): 124731.

[9] Hidayat, Taufik, Rahutomo Mahardiko, and Franky D. Sianturi Tigor. "Method of systematic literature review for internet of things in zigbee smart agriculture." 2020 8th International Conference on Information and Communication Technology (ICoICT). IEEE, 2020.

[10] Tse, Daniel, et al. "Blockchain application in food supply information security." *2017 IEEE international conference on industrial engineering and engineering management (IEEM)*. IEEE, 2017.

[11] Zhao, Guoqing, et al. "Blockchain technology in agri-food value chain management: A synthesis of applications, challenges and future research directions." *Computers in industry* 109 (2019): 83-99.

[12] Casino, Fran, et al. "Modeling food supply chain traceability based on blockchain technology." Ifac-Papersonline 52.13 (2019): 2728-2733.

[13] Bumblauskas, Daniel, et al. "A blockchain use case in food distribution: Do you know where your food has been?." *International Journal of Information Management* 52 (2020): 102008.

[14] Yadav, Vinay Surendra, et al. "Blockchain technology adoption barriers in the Indian agricultural supply chain: an integrated approach." *Resources, conservation and recycling* 161 (2020): 104877.

[15] Chang, Yanling, Eleftherios Iakovou, and Weidong Shi. "Blockchain in global supply chains and cross border trade: a critical synthesis of the state-of-the-art, challenges and opportunities." International Journal of Production Research 58.7 (2020): 2082-2099.

[16] Casino, Fran, et al. "Blockchain-based food supply chain traceability: a case study in the dairy sector." *International journal of production research* 59.19 (2021): 5758-5770.

[17] Kayikci, Yaşanur, et al. "Food supply chain in the era of Industry 4.0: Blockchain technology implementation opportunities and impediments from the perspective of people, process, performance, and technology." *Production planning & control* 33.2-3 (2022): 301-321.

[18] Tsang, Yung Po, et al. "Blockchain-driven IoT for food traceability with an integrated consensus mechanism." *IEEE access* 7 (2019): 129000-129017.

[19] Lin, Weijun, et al. "Blockchain technology in current agricultural systems: from techniques to applications." *IEEE Access* 8 (2020): 143920-143937.

[20] Musah, Salisu, Tunç Durmuş Medeni, and Demet Soylu. "Assessment of role of innovative technology through blockchain technology in Ghana’s Cocoa beans food supply chains." 2019 3rd International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT). IEEE, 2019.

[21] Mondal, Saikat, et al. "Blockchain inspired RFID-based information architecture for food supply chain." *IEEE Internet of Things Journal* 6.3 (2019): 5803-5813.

[22] Shingh, Shuvam, et al. "Dairy supply chain system based on blockchain technology." *Asian Journal of Economics, Business and Accounting* 14.2 (2020): 13-19.

[23] Kumar, M. Vinod, and N. C. S. Iyengar. "A framework for Blockchain technology in rice supply chain management." *Adv. Sci. Technol. Lett* 146 (2017): 125-130.

[24] Bhat, Showkat Ahmad, et al. "Agriculture-food supply chain management based on blockchain and IoT: a narrative on enterprise blockchain interoperability." *Agriculture* 12.1 (2021): 40.

[25] Ahamed, N. Nasurudeen, et al. "Sea food supply chain management using blockchain." 2020 6th International Conference on Advanced Computing and Communication Systems (ICACCS). IEEE, 2020.

[26] Baralla, Gavina, Andrea Pinna, and Giacomo Corrias. "Ensure traceability in European food supply chain by using a blockchain system." *2019 IEEE/ACM 2nd International Workshop on Emerging Trends in Software Engineering for Blockchain (WETSEB)*. IEEE, 2019.

[27] Blossey, Gregor, Jannick Eisenhardt, and Gerd Hahn. "Blockchain technology in supply chain management: An application perspective." (2019).

[28] Caro, Miguel Pincheira, et al. "Blockchain-based traceability in Agri-Food supply chain management: A practical implementation." *2018 IoT Vertical and Topical Summit on Agriculture-Tuscany (IOT Tuscany)*. IEEE, 2018.

[29] Ronaghi, Mohammad Hossein. "A blockchain maturity model in agricultural supply chain." *Information Processing in Agriculture* 8.3 (2021): 398-408.

[30] Tsoukas, Vasileios, et al. "Enhancing food supply chain security through the use of blockchain and TinyML." *Information* 13.5 (2022): 213.

[31] Leng, Kaijun, et al. "Research on agricultural supply chain system with double chain architecture based on blockchain technology." Future Generation Computer Systems 86 (2018): 641-649.

[32] Madumidha, S., et al. "Transparency and traceability: In food supply chain system using blockchain technology with internet of things." *2019 3rd International Conference on Trends in Electronics and Informatics (ICOEI)*. IEEE, 2019.

[33] Ray, Papri, et al. "Incorporating block chain technology in food supply chain." *International Journal of Management Studies* 6.1 (2019): 5.

[34] Park, A., and H. Li. "The Effect of Blockchain Technology on Supply Chain Sustainability Performances. Sustainability 2021, 13, 1726." (2021).

[35] Yakubu, Bello Musa, et al. "RiceChain: secure and traceable rice supply chain framework using blockchain technology." *PeerJ Computer Science* 8 (2022): e801.

[36] Kaur, Amanpreet, et al. "Adaptation of IoT with blockchain in Food Supply Chain Management: An analysis-based review in development, benefits and potential applications." Sensors 22.21 (2022): 8174.

[37] Dey, Somdip, et al. "FoodSQRBlock: Digitizing food production and the supply chain with blockchain and QR code in the cloud." *Sustainability* 13.6 (2021): 3486.

[38] Arena, Antonio, et al. "BRUSCHETTA: An IoT blockchain-based framework for certifying extra virgin olive oil supply chain." *2019 IEEE International Conference on Smart Computing (SMARTCOMP)*. IEEE, 2019.

[39] Tan, Bowen, et al. "The impact of blockchain on food supply chain: The case of walmart." *Smart Blockchain: First International Conference, SmartBlock 2018, Tokyo, Japan, December 10–12, 2018, Proceedings 1*. Springer International Publishing, 2018.

[40] Yadav, Arun, et al. "Online food court payment system using blockchain technolgy." 2018 5th IEEE Uttar Pradesh Section International Conference on Electrical, Electronics and Computer Engineering (UPCON). IEEE, 2018.