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Research Article

Improving Traceability and Security in Food Supply Chains with Block chain

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ABSTRACT

Lack of transparency, ineffective traceability, and susceptibility to fraud and contamination are just a few of the many issues facing the global food supply chain. Blockchain technology, which provides a decentralized, transparent, and immutable ledger system, has emerged as a viable remedy for these problems. This project investigates how to improve security and traceability throughout food supply chains by integrating blockchain technology. Blockchain guarantees real-time data sharing, automates compliance checks, and improves stakeholder responsibility by utilizing distributed ledgers, smart contracts, and consensus algorithms. The proposed approach demonstrates how blockchain can provide end-to-end visibility, reducing the risks of counterfeit products and improving response times during food safety incidents. In the block chain ecosystem, the report also emphasizes the significance of incorporating artificial intelligence (AI) for predictive analytics and Internet of Things (IoT) devices for real-time data collecting. Simulations and case studies demonstrate how block chain-enabled food supply chains greatly increase productivity, customer confidence, and regulatory compliance. The revolutionary potential of block chain technology in establishing a safe, open, and sustainable food supply chain is highlighted by this study.

Keywords: Blockchain Technology, Food Supply Chain, Traceability, Food Security, Smart Contracts, Decentralized Ledger, Transparency, Internet of Things (IoT), Food Safety.

1. INTRODUCTION

Farmers, processors, distributors, retailers, and consumers are all part of the intricate network that is the food supply chain [1]. This complex system is essential to guaranteeing food safety and availability globally, but it confronts several obstacles, including a lack of transparency, ineffective traceability, and susceptibility to fraud, contamination, and counterfeiting. These challenges often result in economic losses, food safety crises, and a decline in consumer trust. To address these issues, innovative technological solutions are required to create more secure, efficient, and transparent systems.
One innovative instrument that has the potential to revolutionize the food supply system is block chain technology [2]. Blockchain is a distributed network-based digital ledger system that is decentralized and unchangeable. Because of its fundamental characteristics—security, traceability, and transparency—it is ideally positioned to handle the urgent issues in the food supply chain. Blockchain has the potential to improve food safety, product traceability, and confidence throughout the supply chain ecosystem by facilitating real-time data sharing among all stakeholders.
The capacity of block chain technology to guarantee end-to-end traceability is among its most potent uses in the food supply chain. A tamper-proof record of origin, processing, and transportation can be provided by block chain, which can follow the entire product path from farm to fork [3]. This traceability is invaluable in detecting and addressing food safety incidents, such as contamination or recalls, in a timely and efficient manner.

Additionally, smart contracts driven by block chain technology can automate adherence to legal requirements and expedite transactions, which lowers operating costs.
Blockchain's capabilities can be further increased by integrating it with complementing technologies like artificial intelligence (AI) and the Internet of Things (IoT). Real-time data collection on vital elements like temperature, humidity, and location is made possible by IoT devices, and AI can evaluate this data to anticipate and avert possible problems. Together, these technologies create a robust ecosystem for secure and transparent supply chain management.
This study investigates how block chain technology might enhance food supply networks' security and traceability. It talks about the main benefits and characteristics of block chain, the function of auxiliary technologies, and the opportunities and difficulties of putting it into practice [4]. This study intends to aid in the creation of food supply networks that are more reliable, effective, and sustainable by addressing these factors.

2. IMPROVING TRACEABILITY AND SECURITY IN FOOD SUPPLY CHAINS WITH BLOCKCHAIN

Enhancing Traceability and Security in Food Supply Chains with Blockchain: This refers to using block chain technology to improve food supply chain safety, accountability, and transparency. In order to solve common issues including lack of traceability, fraud susceptibility, contamination hazards, and inefficiencies in compliance and data management, the decentralized, immutable, and transparent characteristics of block chain technology are applied [5]. Blockchain allows end-to-end tracking of food products from the source (e.g., farms) to the final destination (e.g., consumers). The block chain ledger records every stage of the supply chain, producing an open and impenetrable record of transactions. A block chain ledger can record details like harvesting time, processing methods, transportation temperature, and retail shelf life. If contamination occurs, stakeholders can pinpoint its origin quickly and effectively.
Security
Blockchain's immutability ensures that records cannot be altered or falsified, which reduces the risks of fraud and counterfeiting. This is critical in preventing the introduction of fake or substandard food products into the supply chain [6]. Authenticity of organic food labels can be verified through block chain records, ensuring compliance with regulatory and ethical standards. On the block chain, real-time information is accessible to all parties involved, including farmers, processors, distributors, retailers, and consumers. This openness guarantees responsibility and fosters confidence. Customers' trust in the brand is increased when they scan QR codes on food packaging to see the complete product path.
Smart contracts automate key processes such as payments, compliance checks, and certifications. These self-executing contracts reduce delays, improve efficiency, and ensure regulatory compliance without manual intervention. Payments to farmers can be automatically released once the product reaches a distribution center and meets predefined quality criteria [7]. Devices connected to the Internet of Things (IoT) can gather location, temperature, and humidity data in real time while in transit. After that, the block chain stores this data, guaranteeing precise tracking and quick anomaly discovery. Artificial Intelligence can analyze historical block chain data to predict and prevent potential issues, such as contamination risks or delays in the supply chain.
Blockchain enables rapid and precise identification of contaminated or faulty products. Affected batches can be promptly identified and taken off the market in the event of a food safety problem, reducing financial losses and health hazards. Blockchain technology can pinpoint the precise lot of product that is contaminated in the event of a salmonella outbreak, avoiding needless recalls of unaffected lots [8]. Setting up a block chain infrastructure and integrating it with existing supply chain systems can be expensive. Collaboration amongst all supply chain partners is necessary for effective implementation. It might be difficult to guarantee safe access to private information while preserving openness. Blockchain systems must handle large volumes of transactions efficiently in global supply chains.

3. LITERATURE SURVEY ANALYSIS

For food safety, quality, and customer trust to be guaranteed, food supply chains must be made more traceable and secure. The decentralized, transparent, and impenetrable ledger that blockchain technology offers for transaction recording and product monitoring across the supply chain has made it a viable answer to these problems [9]. Food goods may now be tracked in real time from farm to table thanks to block chain, which lets stakeholders follow the products' path and place of origin. This capability is vital for quickly identifying sources of contamination or fraud.
Because block chain technology is decentralized, all players have access to the same information, which lessens information asymmetry and fosters stakeholder confidence. The immutable ledger of block chain technology guards against illegal data changes, guaranteeing the accuracy and dependability of data entered into the supply chain. Blockchain can improve supply chain efficiency by reducing manual interventions, lowering transaction costs, and automating processes using smart contracts [10]. It can be difficult to keep the block chain running quickly and efficiently as the volume of transactions rises.

Aligning block chain solutions with current supply chain management systems requires significant effort and can face resistance from stakeholders accustomed to traditional methods [11]. Transparency has advantages, but it also creates questions regarding the privacy of sensitive data that is released publicly. Navigating the legal landscape and ensuring compliance with varying regulations across regions can be complex when implementing block chain solutions.

The use of block chain in conjunction with other technologies to improve food supply chain management has been investigated in recent research. To further enhance traceability and quality control, for example, real-time data gathering and monitoring are made possible by integrating block chain technology with the Internet of Things (IoT) [12]. Additionally, it has been suggested that parties automate and enforce their contractual agreements by using smart contracts, which are self-executing contracts with the conditions explicitly encoded into code. This lowers the risk of fraud and ensures compliance.

There is great promise for improving efficiency, security, and traceability in food supply chains through the use of block chain technology [13]. However, successful implementation requires addressing the related issues. Ongoing research and pilot projects continue to shed light on best practices and innovative solutions to fully leverage block chain's capabilities in this sector.

4. EXISTING APPROCHES

These systems document and monitor the complete food product lifecycle, from farm to fork, using block chain technology. A transparent and unchangeable history is created on the block chain by recording each transaction (such as harvesting, processing, and shipping) as a block. IBM Food Trust: Used by companies like Walmart and Nestlé, this block chain platform ensures rapid traceability of food products. Used to track premium products like wine, ensuring authenticity and preventing counterfeiting [14]. Self-executing contracts with terms that are encoded directly into the block chain are known as smart contracts.

Automates procedures like compliance, quality assurance, and payment processing. Ensures the terms of agreements between parties are enforced without manual intervention. Smart contracts can trigger payments only after product delivery and quality verification. Blockchain technology and Internet of Things sensors work together to improve real-time data collection and monitoring. IoT devices record information while in transit, such as temperature, humidity, and location. Direct recording of this data on the block chain ensures precise and unchangeable traceability.

Sensors can monitor perishable goods (e.g., seafood, dairy) to ensure they remain within safe conditions throughout the supply chain. Companies like TE-FOOD leverage IoT and block chain to provide farm-to-table transparency. In a consortium block chain, access is limited to authorized participants, such as farmers, processors, retailers, and regulators. A permissioned block chain allows members to securely share data while maintaining privacy. Ensures faster consensus compared to public block chains.

The Food Trust Consortium includes multiple stakeholders working together to improve traceability in supply chains. Blockchain-based traceability solutions often use QR codes or RFID tags for easy data access and product tracking [15]. Each product is tagged with a unique identifier (e.g., QR code or RFID). Scanning the code retrieves the block chain-stored history of the product, providing consumers with transparency. Shoppers can scan QR codes on produce to view details such as origin, transportation, and quality checks.

Combining private and public block chains ensures scalability, privacy, and cost-efficiency. Public block chains store general information for transparency. Private block chains handle sensitive information to maintain data privacy. Frequently used for food supply chains, allowing fine-grained data access control. Blockchain records certifications (e.g., organic, fair trade) and ensures compliance with regulatory standards. Regulatory bodies or third parties upload certification details onto the block chain. Provides verifiable proof of compliance to consumers and partners.

Certifications for organic farming practices or sustainable fishing can be easily verified by scanning product information. Some block chain systems tokenize supply chain data to reward stakeholders for maintaining transparency and quality. Farmers or transporters are rewarded with tokens for meeting quality or traceability requirements. Tokens can be used for discounts, loyalty programs, or other incentives within the supply chain ecosystem. Decentralized Identity (DID) ensures secure authentication and verification of supply chain participants.

Each participant (e.g., farmer, distributor) has a unique DID on the block chain. Prevents fraud and ensures accountability. Prevents counterfeit products by ensuring only verified participants can log transactions on the block chain. Blockchain data may be analyzed by AI and ML to forecast hazards and improve supply chain efficiency. AI algorithms can detect anomalies in the supply chain (e.g., temperature deviations, delays) by analyzing block chain data. Predictive models can identify potential risks (e.g., contamination, spoilage) before they occur.

5. PROPOSED METHOD

A block chain-based approach to food supply chain traceability and security could incorporate state-of-the-art frameworks and technologies to solve present issues and boost operational effectiveness. To develop a comprehensive, scalable, and secure block chain-based system that improves food traceability, mitigates fraud,

and ensures data integrity while maintaining privacy and real-time decision-making capabilities. Stores general information for consumers, such as product origin, quality certifications, and transportation history.
Secures sensitive and proprietary information such as pricing, supplier details, and confidential contracts. Combines transparency for consumers with privacy for stakeholders, ensuring compliance with regulatory requirements. Sensors and RFID tags are examples of IoT devices that are used at critical points (farm, processing, storage, and distribution) to track variables like temperature, humidity, and location. IoT devices directly upload data to the block chain, guaranteeing immutable records and real-time traceability. Prevents spoilage and ensures that any deviations from required conditions (e.g., temperature during transport) are immediately flagged.
Use AI algorithms to analyze block chain data for anomaly detection, fraud identification, and predictive maintenance (e.g., predicting spoilage risks based on conditions and travel time). AI-powered dashboards for stakeholders provide actionable insights to optimize the supply chain. Reduces risks, identifies inefficiencies, and improves decision-making. Automate key processes, such as payments, quality checks, and regulatory compliance, using smart contracts. Payment is released to suppliers only after goods are delivered and verified as per quality standards.
Reduces manual interventions and ensures compliance with pre-defined agreements. Use Decentralized Identity (DID) to ensure that all parties involved—such as farmers, processors, and distributors—are authenticated securely and impenetrably. A distinct digital identity that is kept on the block chain is given to every supply chain member. Prevents unauthorized access and improves accountability. Products are tagged with QR codes or NFC labels containing block chain data. Consumers can scan these tags to access product information, including origin, certifications, and journey history.
Gamification or tokenized rewards can incentivize consumers to prefer products with verified traceability. Builds consumer trust and promotes responsible purchasing. Incorporate a compliance module to ensure adherence to food safety standards and regulations across regions (e.g., FDA, ISO, and HACCP). Regular audits and certifications are logged on the block chain for transparent verification. Simplifies regulatory reporting and reduces compliance costs. IoT devices capture data at various supply chain stages and send it to a block chain node.
Consumer-facing data (e.g., product origin and certifications). Confidential stakeholder data. Real-time analytics on block chain data to detect anomalies (e.g., temperature excursions) and predict risks. Trigger automated actions such as quality-based payments, regulatory reporting, or alerts for deviations. QR code/NFC scanning by consumers to view the product's blockchain-verified history. Regulators access blockchain data to verify certifications and compliance. Total openness from farm to table increases consumer trust and guarantees food safety.
The tamper-proof ledger of blockchain lowers the possibility of fraud and counterfeiting while guaranteeing data integrity. Automation via smart contracts streamlines processes and reduces manual errors. Hybrid blockchain design ensures scalability without compromising privacy or performance. Enables consumers to make informed decisions and rewards them for supporting traceable and secure supply chains. It costs a lot of money to integrate blockchain technology, IoT devices, and AI analytics.
Balancing transparency and privacy is crucial, especially when sensitive data is involved. Small suppliers and farmers may be reluctant to embrace new technologies because they lack the necessary resources or technical know-how. Blockchain, IoT, and AI are all used in this suggested approach to produce a safe, open, and effective food supply chain. It addresses existing challenges such as data integrity, fraud prevention, and traceability while empowering both stakeholders and consumers. Future studies can concentrate on creating inexpensive IoT systems and enhancing stakeholder adoption via incentives and training.

6. RESULT

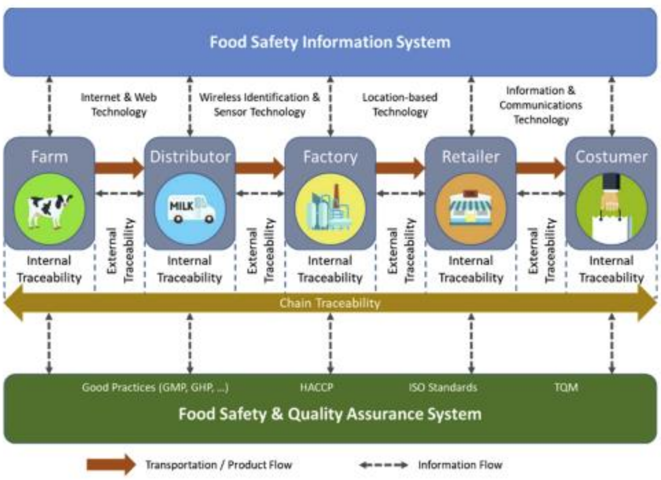

Fig. 1. Conceptual model for a food tracking system

Figure 1: The supply chain, according to their theory, is made up of several actors and explains the process from the source (raw milk from a cow on a farm) to the final product that a customer buys and consumes in a shop (baby milk powder, for example). Traceability throughout the entire chain of actors is accomplished through external traceability between the internal systems of the actors and internal traceability within them. All parties involved in the food supply chain use various forms of technology to submit and retrieve data to and from the Food Safety Information System (FSIS), which is a key component of the framework. Several types of data are included in the FSIS, which is necessary to ensure quality and transparency among the participants in the food supply chain. The FSIS is an information system that can be either centrally or decentralized controlled. It is crucial that all actors have simultaneous access to the same information. FSQAS, or the Food Safety & Quality Assurance System, provides the safety and quality standards that supply chain participants must adhere to. In the FSIS, traceability data that shows adherence to these controls is kept.

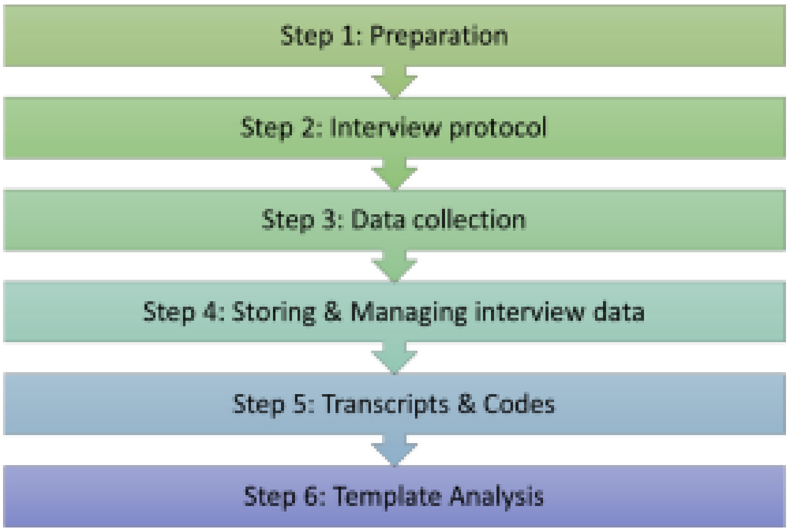

Fig. 2. The method of data collection employed in this investigation

Figure 2 For the implementation and application of traceability in the food supply chain, there isn't a widely accepted conceptual framework or theory. Furthermore, there is a dearth of scientific information currently available regarding the use of BCT in supply chains generally and supply chain technology specifically. Thus, our goal was to comprehend the BCT border conditions in supply chains. These factors influence the decision to choose a holistic multiple-case exploratory research design. Four distinct supply chains with distinctive features in the dairy product industry served as the analytical unit. The function of traceability is examined independently for every supply chain procedure.

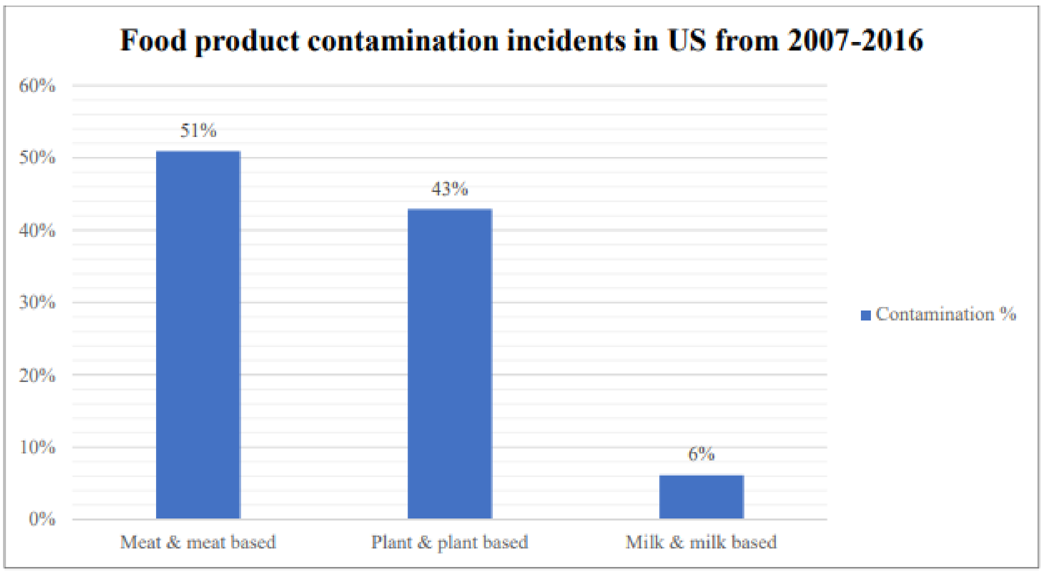

Figure 3. Food vehicle outbreaks in the United States, 2007–2016

Figure 3 illustrates that compared to plant and plant-based products, meat and meat-based products from the poultry, fish, and cattle industries are more likely to cause food contamination. Additionally, it shows that 76% of these contaminations are documented at the food processor stage, which includes banquet services, child care centers, fairs, festivals, other temporary or mobile services, hospitals, hotels, motels, assisted living facilities, long-term care facilities, nursing homes, offices, indoor workplaces, prisons, jails, places of worship, restaurants, and schools, colleges, and universities. Only 1.92% of occurrences have occurred at the retailer stage of the food chain, compared to 21.82% at the consumer level. Just 0.28% of these incidents have been documented from the food producer stage, which includes dairy farms and livestock barns.

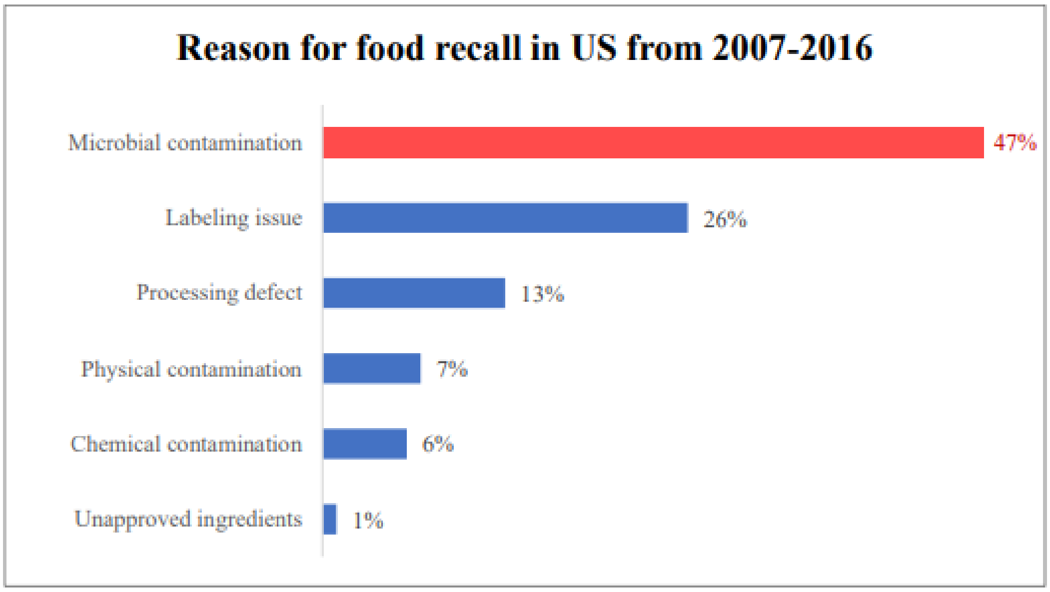

Figure 4. Causes of US food recalls between 2007 and 2016

Figure 4 Multistate outbreaks are more common than those in any one state, despite the fact that food safety laws differ greatly between jurisdictions. Furthermore, figure 4 demonstrates that between 2007 and 2016, microbiological contamination was the main cause of food recalls in the United States. Salmonella enterica, genus type Norovirus Genogroup II, has been responsible for 40.57% of all recalls. Product recalls are also caused by physical and chemical contamination along the food chain and processing flaws.
This thesis is a modest attempt to address one of the most difficult problems that FSC companies are now attempting to resolve: food provenance. In terms of food provenance and asset traceability, the main goal of this research is to develop a blockchain model that can be applied in a food supply chain and outline its advantages and disadvantages compared to conventional tracking methods.

7. CONCLUSION

Enhancing food supply chain security and traceability using blockchain technology has revolutionary potential to solve important issues with food safety, quality control, and consumer confidence. A strong framework for documenting and confirming each transaction in the supply chain is offered by block chain's decentralized, unchangeable, and transparent ledger, guaranteeing accountability and authenticity at every turn. Real-time monitoring, automated procedures, and predictive insights can be obtained by food supply chains by combining blockchain technology with complementing technologies like IoT, AI, and smart contracts. These advancements enhance operational efficiency, reduce risks, and empower consumers with the ability to verify product origins, certifications, and compliance.
Notwithstanding its advantages, issues with scalability, high implementation costs, and stakeholder adoption must be resolved before it can be widely used. To get beyond these obstacles and create uniform frameworks for blockchain integration in food supply chains, cooperation between governments, businesses, and technology companies will be crucial. To sum up, blockchain technology signifies a paradigm change toward food systems that are safer, more secure, and transparent. Its implementation will boost customer confidence, promote sustainable practices, increase transparency and security, and provide value for all parties involved in the food supply chain ecosystem.

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