International Journal of
DATA SCIENCE AND IOT MANAGEMENT SYSTEM
Peer Reviewed, Referred & Indexed Journal
ISSN: 3068-272X www.ijdim.com Original Research Paper

Decentralized Framework for Food Safety Monitoring in Supply Chains Using Blockchain Technology

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Abstract - Accurate Food safety and traceability in the agricultural supply chain are critical challenges, particularly for perishable products such as crops and vegetables. Traditional centralized tracking systems often suffer from lack of transparency, data manipulation risks, and delays in identifying contamination sources. To address these issues, this study proposes a blockchain-based framework for enhancing food safety and traceability in crop and vegetable supply chains. The system utilizes a decentralized ledger to record every stage of the product lifecycle, starting from harvesting by farmers to distribution and final retail delivery. Each batch of crops or vegetables is assigned a Unique Batch Identity Number (UBIN) and attached with a physical tracking tag that enables secure identification and monitoring across supply chain participants. Smart contracts automate verification processes, ensuring that only authorized stakeholders can update supply chain records and that compliance with predefined safety standards is maintained. In addition, integration with Internet of Things (IoT) sensors allows real-time monitoring of environmental conditions such as temperature and humidity during transportation and storage. The proposed system improves transparency, prevents data tampering, and enables rapid identification of contaminated or compromised food batches. As a result, the framework enhances consumer trust, supports regulatory compliance, and improves the efficiency of agricultural supply chain management. This approach demonstrates how blockchain technology can be effectively applied to ensure safe, transparent, and traceable distribution of crops and vegetables from farm to consumer.

Keywords— Blockchain, Food Safety, Food Traceability, Agricultural Supply Chain, Crops and Vegetables Tracking, Smart Contracts, Internet of Things (IoT), Unique Batch Identity Number (UBIN), Tag-Based Identification, Supply Chain Transparency

I. INTRODUCTION

Food safety and traceability have become major concerns in modern agricultural supply chains, particularly for perishable products such as crops and vegetables. As these products move through multiple stages including harvesting, packaging, transportation, storage, and retail distribution, maintaining accurate records of their origin and handling conditions becomes essential. Traditional food tracking systems are typically centralized and rely on manual documentation, which can lead to data inconsistencies, lack of transparency, and increased risk of fraud or contamination. In many cases, identifying the source of contaminated food products becomes time-consuming, resulting in delayed recalls and potential health risks for consumers.

Recent advancements in digital technologies have created opportunities to address these challenges by improving transparency and accountability across supply chains. One such technology is Blockchain, which provides a decentralized and tamper-resistant platform for recording transactions among multiple stakeholders. By storing information in an immutable ledger shared across the network, blockchain enables secure data sharing and ensures that once information is recorded it cannot be modified or deleted without consensus from authorized participants.

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In the context of agricultural supply chains, blockchain can be used to record important information such as farm origin, harvest date, batch details, transportation records, and storage conditions. Each batch of crops or vegetables can be assigned a unique batch identity number and linked with a physical identification tag, allowing the product to be tracked throughout the entire supply chain. Furthermore, the integration of Internet of Things devices enables real-time monitoring of environmental conditions such as temperature and humidity during storage and transportation, ensuring that food safety standards are maintained.

Another important feature of blockchain systems is the use of smart contracts, which are automated programs that enforce predefined rules and conditions within the network. Smart contracts can verify supply chain transactions, ensure regulatory compliance, and automatically trigger alerts if abnormal conditions or safety violations occur. This automation reduces the need for manual verification and improves the efficiency of supply chain management.

The proposed system focuses on enhancing the safety and traceability of crops and vegetables by implementing a blockchain-based supply chain framework. The system assigns a Unique Batch Identity Number (UBIN) to each batch of agricultural produce and uses tag-based identification to track the product across all supply chain stages, from farmers to distributors, retailers, and consumers. By providing a transparent and tamper-proof record of product movement, the system helps stakeholders verify authenticity, quickly identify contamination sources, and improve consumer confidence in food products.

This research aims to demonstrate how blockchain technology can transform traditional agricultural supply chains into more transparent, secure, and efficient systems capable of ensuring food safety and reliable traceability from farm to consumer.

II. LITERATURE REVIEW

Food safety and traceability in agricultural supply chains have been widely studied in recent years, particularly with the emergence of digital technologies such as blockchain, Internet of Things (IoT), and RFID systems. Researchers have explored different technological approaches to ensure transparency, authenticity, and secure data management in food supply chains, especially for perishable agricultural products such as crops and vegetables.

Feng Tian (2016) proposed one of the earliest blockchain-based traceability systems for the agri-food sector. The system integrates blockchain with RFID technology to monitor food products across the supply chain from production to consumption. The approach ensures that all stakeholders can access transaction records related to a particular product, improving transparency and trust in the food supply chain. The study highlighted that blockchain can effectively record and verify supply chain data, ensuring that food safety information cannot be manipulated. ()

Kim (2016) introduced an ontology-driven blockchain traceability model that organizes supply chain information using structured data frameworks. In this model, smart contracts are used to automate traceability processes and validate supply chain transactions. The research demonstrated that blockchain combined with semantic technologies can improve information sharing between supply chain stakeholders and enhance the efficiency of traceability systems. ()

Kamilaris, Fonts, and Prenafeta-Boldú (2019) reviewed the application of blockchain technology in agriculture and food supply chains. Their study highlighted that blockchain systems provide a decentralized and immutable data storage platform that can record production, processing, storage, and transportation activities. The authors also discussed several pilot projects that use blockchain and IoT technologies to improve transparency and trust between producers, distributors, and consumers. ()

Caro et al. (2018) proposed a blockchain-based food traceability system integrated with IoT devices. Their research demonstrated that IoT sensors could capture real-time environmental data such as temperature and humidity during food transportation and storage. The collected data are stored on the blockchain to ensure data integrity and prevent tampering. This approach significantly improves monitoring of food quality and reduces the risk of spoilage or contamination. ()

Li et al. (2024) developed an agricultural product traceability system that combines blockchain with RFID technology. Their system records detailed traceability information of agricultural products on the blockchain, ensuring that supply chain data remain secure and immutable. The study also introduced cryptographic techniques to improve the efficiency of data processing and ensure reliable storage of agricultural product information. ()

Recent systematic reviews of blockchain-based food

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ISSN: 3068-272X www.ijdim.com Original Research Paper

supply chains indicate that blockchain technology primarily enhances transparency, product traceability, and information sharing across supply chain participants. However, challenges such as high implementation costs, infrastructure requirements, and scalability issues still limit the widespread adoption of blockchain-based food traceability systems. ()

Overall, the existing literature demonstrates that blockchain technology has strong potential to improve food safety and traceability in agricultural supply chains. By integrating technologies such as RFID, IoT sensors, and smart contracts, blockchain-based systems can provide secure, transparent, and tamper-resistant monitoring of food products from farms to consumers. However, many existing studies focus on conceptual frameworks or limited implementations. Therefore, further research is required to develop integrated and practical blockchain-based traceability systems specifically designed for crops and vegetable supply chains.

III. RELATED WORK

Several studies have explored the use of emerging technologies to improve food safety and traceability within supply chains. Researchers have particularly focused on integrating blockchain technology with IoT devices and smart contracts to enhance transparency and prevent data manipulation.

Feng Tian (2016) proposed a blockchain-based agricultural food supply chain system integrated with RFID technology to record production and distribution data securely. The study demonstrated that a distributed ledger can maintain data integrity and provide reliable traceability across all stages of the food supply chain.

Aung and Chang (2014) emphasized the importance of traceability systems in maintaining food safety and quality standards across global supply chains. Their work highlighted how effective tracking mechanisms help identify contamination sources and improve regulatory compliance.

Kamilaris, Fonts, and Prenafeta-Boldú (2019) reviewed various blockchain applications in agriculture and concluded that blockchain significantly improves transparency, accountability, and trust among supply chain participants.

Caro et al. (2018) developed a blockchain-based traceability framework integrated with IoT sensors to monitor environmental conditions such as temperature and humidity during food transportation and storage. The system ensured secure storage of sensor data and improved monitoring of perishable food products.

Xu et al. (2021) introduced a blockchain-enabled food safety tracking system using smart contracts to automatically detect violations of safety regulations and trigger alerts. Their research demonstrated the effectiveness of automated compliance mechanisms in maintaining food safety standards.

Although these studies demonstrate the potential of blockchain for supply chain transparency and food safety, most existing solutions focus on general food supply chains. The present work specifically addresses traceability for crops and vegetables by introducing a tag-based identification mechanism combined with a Unique Batch Identity Number (UBIN) to track agricultural produce from farms to consumers.

IV. METHODOLOGY

The proposed methodology aims to develop a blockchain-based food safety and traceability system specifically designed for crops and vegetables. The system ensures that every batch of agricultural produce can be securely tracked from the farm to the final consumer. The methodology combines blockchain technology, tag-based identification, smart contracts, and supply chain transaction recording to create a transparent and tamper-resistant monitoring framework.

The overall methodology is divided into several stages that correspond to the key operations of the agricultural supply chain.

1. Batch Registration at Farm Level

The process begins when farmers harvest crops or vegetables and prepare them for packaging. Each batch of harvested produce is registered in the blockchain network by entering essential information such as farmer identification, farm location, crop type, harvest date, batch quantity, and packaging details. After registration, the system generates a Unique Batch Identity Number (UBIN) that uniquely represents the batch of agricultural produce.

A physical tracking tag containing the UBIN is attached to the container or package of crops or vegetables. This tag serves as the identification mechanism that will be used throughout the supply chain to track the batch.

2. Blockchain Transaction Recording

As the agricultural batch moves through different stages of the supply chain, the tracking tag is scanned by authorized participants. Each scan creates a new

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transaction in the blockchain network. The transaction records important information including the sender, receiver, location, timestamp, and the corresponding batch identity number. These transactions form a continuous digital record that documents the complete journey of the agricultural produce from the farmer to the retailer.

3. Smart Contract Validation

Smart contracts are deployed on the blockchain network to automatically verify the validity of each transaction. The smart contract ensures that only authorized supply chain participants can update the product information. It also checks whether the batch identity number is valid and confirms that the transaction follows predefined supply chain rules. If any unauthorized activity or irregular data entry is detected, the smart contract automatically rejects the transaction and generates an alert for system administrators.

4. Supply Chain Monitoring

The system continuously monitors the movement of crops and vegetables through the blockchain ledger. Each participant in the network has access to verified information about the batch status and supply chain history. This decentralized monitoring mechanism improves transparency and allows regulatory authorities to track agricultural products efficiently.

5. Consumer Verification and Traceability

At the retail stage, consumers and regulatory authorities can verify the authenticity of crops or vegetables using the batch identity number recorded on the tag. By querying the blockchain network, the system retrieves the entire history of the product, including its farm origin, harvesting details, transportation stages, and distribution path. This traceability mechanism helps identify the source of contamination quickly and ensures that consumers receive safe and authentic agricultural products.

Through this methodology, the proposed system enhances transparency, prevents data tampering, and provides a reliable mechanism for monitoring crops and vegetables throughout the agricultural supply chain.

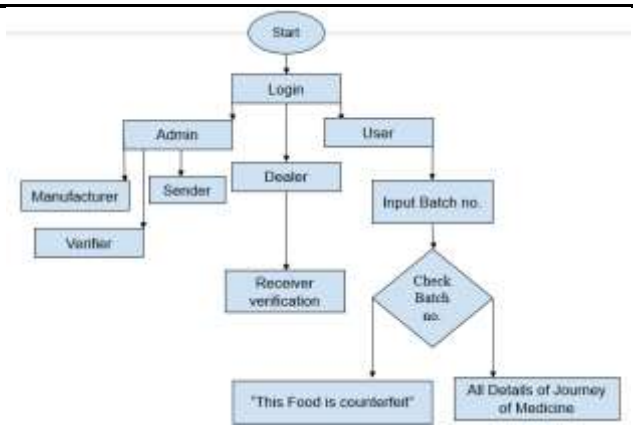
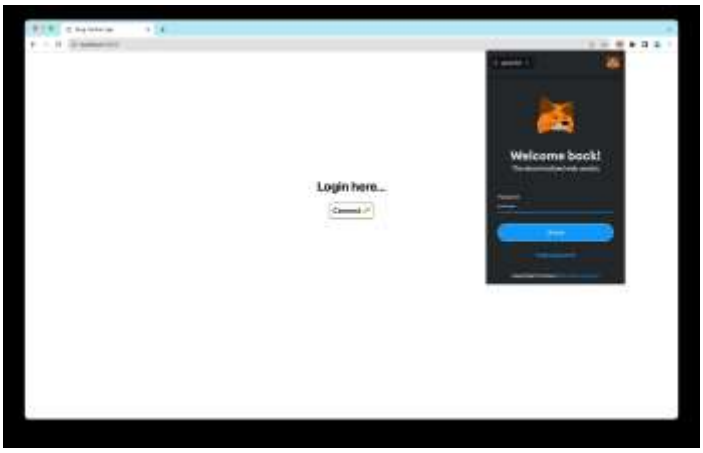


Fig.1: Flow chart

V. EXPERIMENTAL RESULTS

When we open the application on a local server it will allow us to log in with a unique ID that is registered



already or can be registered if required.

Fig.**2:** Login Page

Dealer registration is authorized by Manufacturer and Admin only so that only verified dealers can access the information of receiving Batches of particular medicine.
Blockchain technology, with its inherent characteristics of immutability, transparency, and decentralized consensus, offers a robust framework to create a secure and Trustworthy.

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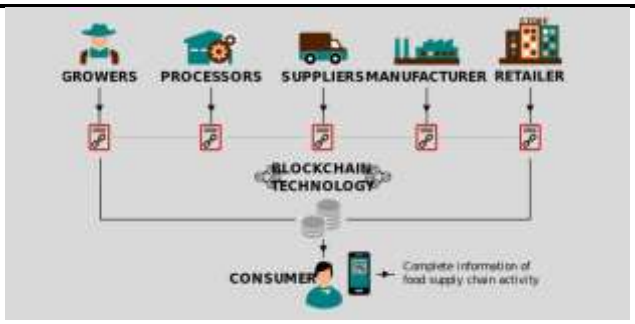

Fig.3: Chain of manufactures

After receiving medicine, the dealer will complete the checkbox of the manufacturer that the batch is received.

Fig.4: Detection of Counterfeit Food

The new user defines the role Admin / Manufacturer has the key to allow the unverified user/Dealer into a verified user or dealer.

Fig.5: Counterfeit Food

Whenever wrong input or fake medicine having batch no. received to consumer or Dealer. They can check for confirmation and if no History of Food is found in the blockchain then it will show above fig.

Blockchain technology is highly capable of keeping track of the Food history throughout the pharmaceutical supply chain. Two important aspects that make Blockchain data secure and safe are that the blocks are time stamped and immutable making tampering of information impossible. Organizations can have either a public blockchain or a private one. The organizations will share a distributed ledger between the parties involved in the manufacture and distribution of the Food on these blockchains. Moreover, in these blockchains only limited access is provided which depends on the data sharing contract among the two parties. With Blockchain we can keep complete track of the foods beginning from manufacturers to end consumers. Every time the Food travels from one entity to another, the data is stored on the block supply chain. This makes the traceability of Foods an easy task and thus helps in combating counterfeits from the industry. To overcome these challenges Blockchain is being adopted.

Sr. No.	Name	Issue discussed	Trajectory prediction estimation method	Parameters	Features
1.	S. Seven, G. Yao, A. Soran, A. Onen[6]	Improved supply chain management based on hybrid demand forecasts	The latter problem refers to the risk of successfully spending the digital currency more than once.	As such, blockchain is a perfect solution to the key issues faced by ITSs	The application's front end, where they must enter their credentials to access the blockchain network. The administrator enrolls everyone in the network and then provides each user with their login information and an enrolment certificate.
2.	Y. Yuan and F. Wang[10]	A survey on retail sales forecasting and prediction in fashion	"Bitcoin: a peer-to-peer electronic cash system"	The key advantages of blockchain models can be summarized	Blockchain, widely known as one of the disruptive technologies emerged in recent years,

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		markets.		decentralization, trust, security, chronological data.	is experiencing rapid development and has the full potential of revolutionizing the increasingly centralized intelligent transportation systems (ITS) in applications.
3.	A. Hasselgren, K. Kralevska, D. Gligoroski, S. A. Pedersen, and A. Faxvaag, "Blockchain in healthcare and health sciences—Asc[22]	"Curriculum In Cardiology Statistics."	A structured literature search on the topic was conducted in October 2018 relevant bibliographic databases.	It is valuable to investigate if the current research meets the expectations to blockchain technology within healthcare, health sciences and health education	The technology of blockchain, with inherited characteristics such as decentralization, transparency and anonymization, was introduced in the cryptocurrency Bitcoin
4.	A. Dwivedi, G. Srivastava, S. Dhar, and R. Singh[24]	"A Decentralized Privacy-Preserving Healthcare Blockchain for IoT	Using blockchain technology in the health domain are increasing exponentially	A key attribute of blockchain is decentralization; no central authority	The purpose of this study was to systematically review, assess and synthesize peer-reviewed publications utilizing/proposing to utilize blockchain to improve processes and services in healthcare, health sciences and health education.

TABLE I. OVERVIEW OF VARIOUS TRAJECTORY PREDICTION METHODS

Recently it is seen that the employment of block-chain technology in the medical and healthcare services is increasing at a rapid rate. Block-chain with its secured nature has been adopted in various e-health sectors such as data access management among medical entities and secure sharing of electronic health records [5]- [6]. In the case of block-chain there is no central point of failure as the data is distributed and is stored in blocks. Blockchain technology helps in overcoming the problems in healthcare. Features which make blockchain reliable for use in combating counterfeit Foods are: -

• Peer-to-Peer Transmission

• Distributed Database

• Computational Logic

• Transparency with Pseudonymity

• Irreversibility of Records

VI. CONCLUSION

Ensuring food safety and traceability in the agricultural supply chain is essential for protecting public health and maintaining consumer trust. Traditional centralized tracking systems often face challenges such as lack of transparency, delayed detection of contaminated products, and vulnerability to data manipulation. These limitations highlight the need for a more reliable and secure system for monitoring the movement of crops and vegetables throughout the supply chain.

This research presented a blockchain-based framework designed to enhance food safety and traceability for crops and vegetables. The proposed system assigns a Unique Batch Identity Number (UBIN) to each batch of agricultural produce and uses tag-based identification to track the batch across different stages of the supply chain, including farming, distribution, and retail. By recording each transaction on a decentralized blockchain ledger, the system ensures that supply chain data remain transparent, secure, and tamper-resistant.

Smart contracts are used to automate transaction validation, enforce compliance rules, and verify authorized participation within the network. This automation reduces manual errors and improves the efficiency of supply chain operations. Additionally, the traceability mechanism enables consumers and regulatory authorities to verify the origin and handling history of agricultural products, thereby increasing accountability and trust among stakeholders.

Overall, the proposed blockchain-based system provides an effective solution for improving transparency, authenticity verification, and traceability in crop and vegetable supply chains. By leveraging decentralized technologies, the framework contributes to safer food

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ISSN: 3068-272X www.ijdim.com Original Research Paper

distribution and more reliable agricultural supply chain management.

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