Organic Food Traceability System using Blockchain Technology

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***Abstract*— The Farm Trace Blockchain system presents a blockchain-based system of improving transparency, traceability and authenticity in the agricultural supply chain. The system was built on Solidity on the Ethereum network, a Python Flask server, and follows the products of the farms through all the stages, harvesting to sale, and guarantees the integrity of the data and trust of the stakeholders. The history of every product will be permanently stored on the blockchain, which allows secure status reporting and verifiable history of transactions. The platform also provides real time tracking of producers, distributors, retailers and consumers through the use of Web3 which creates access to the community based on roles. The two-interface nature of the system ensures that the administrators can effectively manage the supply chain operations besides the customers being able to easily validate the provenance of products. This application shows how the blockchain technology can be used to address the age-old issues of food supply chain by creating transparency, quality assurance, and efficiency, which ultimately leads to increased trust between the producers and consumers of agricultural ecosystems.**

Keywords—Blockchain, Agriculture, Supply Chain Management, Smart Contracts, Traceability, Transparency, Web3, Ethereum, Data Integrity, Flask.

I. Introduction

Agricultural supply chain is very vital in making farm products reach the consumers in a safe, efficient and transparent manner. Nonetheless, traditional supply chain systems are usually confronted with significant problems including absence of visibility, products fraud and ineffective record-keeping[4]. Such problems do not only decrease consumer confidence, but cause financial losses to farmers and distributors. The world is under pressure to improve its food safety and sustainability; hence, there is an imperative to develop new solutions that will increase traceability, accountability, and efficiency in all the stages of the agricultural value chain.

To overcome these challenges, blockchain technology has come out as a ground breaking technology to solve such challenges. Its decentralized and unchangeable quality guarantees its inability to alter any information and be easily transparent to all involved actors[6]. With the introduction of smart contracts, blockchain automates the checking and tracking steps, which is a way to remove intermediaries and minimize the possibility of a human error. In farming scenarios, this will allow real time tracking of goods since the harvesting time up to the consumer that is to bring authenticity and trust[9].

Agricultural supply chain is highly essential in ensuring that the farm products reach the consumers in a safe, efficient and transparent way. However, conventional supply chain systems are typically faced with major issues such as lack of visibility and products fraud and poor record keeping[1]. These issues not only reduce consumer confidence, but also make farmers and distributors lose their money. The world is straining to enhance its food safety and sustainability; therefore, there is a need to come up with new solutions that will enhance traceability, accountability, and efficiency in all the agricultural value chain stages.

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The results of the implementation contain considerable improvements in the effectiveness and reliability of the supply chain. Product traceability was more precise and the time for verification was cut down to almost one half when compared with manual systems previously used. Stakeholders claimed that they had a better feeling of confidence owing to the unalterable transaction records and real-time update of their status. In general, the Farm Trace Blockchain system demonstrates how blockchain technology can transform the agricultural supply chain to provide transparency, guarantee the quality of products, and establish the relationships of trust between all agents.

II. Related Works

The article by Cardwell and Lawley [1] (2025) examined both political and structural risks that impacted the supply management system in Canada, and how the system struggled to ensure regulatory consistency and stability in all the agricultural supply chains. Their results highlight the importance of effective and transparent structures to control intricate supply networks.

Erfani and Goharian [2] (2025) suggested a policy tree model of integrated water supply management in multi-purpose reservoirs. The work is applicable to agricultural supply chains since it discusses the aspects of resource allocation, efficiency, and sustainability, which is important in determining the productivity of farms and sustainability of the supply chain.

This paper by Zanon et al. [3] (2025) established the impact of system, management systems, and seasonal variations of diet on the environment efficiency and net food supply level of mountain dairy farm. Their article confirms the need of the observation of farm work and environmental conditions that can be traced with the help of blockchain-based traceability devices to track the quality and information control.

In another article, Tseng et al. [6] (2025) talked about sustainable supply chain management of coffee business in Indonesia, and the findings of the research proved the improvement of the activities by the digitalization of coffee business, as well as its information integration. The work of interest substantiates the application of smart contracts and blockchain in the context of enhancing the level of efficiency of the operations and transparency of supply chain in the agricultural industry.

Imtiaz [7] (2025) developed CattleSync, an ERP solution for cattle farm management, which provides comprehensive monitoring of livestock and operations. Such systems parallel blockchain frameworks by offering structured data management, though blockchain adds immutability and verifiability for critical supply chain events.

The article by Ho [8] (2025) represents a maturity model of assessing the sustainability of supply chains in organic agricultural co-operations with the focus on the transition to the Industry 5.0 technologies. It expresses the topicality of the further development of digital solutions, or blockchain, to reach transparency and efficiency in the activities.

The studied and followed frozen fruit and vegetable supply chain by Zhang et al. [13] (2024) shows that the use of technology will greatly enhance the traceability, demand forecasting and quality regulation. Besides, it is the joint application of the mentioned technologies with the blockchain methods that brings about an efficient, and quality-oriented supply chain management through the operation of predictive and analytical solutions.

The study by Kalirajan et al. [14] (2024) suggested an AI-driven control of water supply and pest control in agriculture with the focus on automation and real-time surveillance. The data of such environmental monitoring can be added to blockchain systems to offer records of quality available for verification.

Aspect	Limitations
Supply Management Policy	Focused on policy risks; lacks practical technological solutions for real-time tracking or data verification.
Resource & Water Management	Limited to water management; does not address end-to-end supply chain traceability or integration with stakeholders.
Environmental & Farm Efficiency	Focused on environmental and dietary impacts; lacks digital tools for immutable record-keeping or automated tracking.
Digitalization in SCM	Studied qualitatively; no implementation of decentralized or blockchain-based verification.
ERP-based Farm Management	ERP system provides monitoring but does not ensure tamper-proof or immutable data storage across the supply chain.
Supply Chain Maturity Models	Evaluates sustainability; does not provide a real-time, blockchain-enabled tracking mechanism.
AI for Predictive Analytics	Focused on prediction and analytics; lacks integration with immutable ledger for supply chain transparency.
AI-based Monitoring	Centralized monitoring; cannot provide verifiable, tamper-proof records for stakeholders.

Table 1. Comparison Table

Distinctiveness of the Proposed System

While prior studies have explored digitalization, ERP-based monitoring, and policy-driven supply chain improvements, most existing systems lack decentralized verification and immutable data storage. Unlike conventional ERP or centralized monitoring platforms, Farm Trace leverages Ethereum smart contracts to provide end-to-end, tamper-proof traceability across the agricultural supply chain. The proposed system uniquely integrates role-based Web3 access, QR-code–enabled consumer verification, and a hybrid on-chain/off-chain architecture, enabling real-time validation while maintaining scalability. These features distinguish Farm Trace from earlier blockchain traceability frameworks that are either conceptual or limited in practical deployment.

III. Framework

The Farm Trace Blockchain framework is a comprehensive solution designed to ensure transparency, traceability, and data integrity within agricultural supply chains. By leveraging Ethereum-based smart contracts combined with a Python Flask backend and responsive frontends, the system records each stage of a product's journey — from harvest to sale — in a secure and immutable manner.

Algorithm 1: Blockchain-Based Supply Chain Management

Input: Stakeholder Info, Product Data, Blockchain Network

```
Initialize Blockchain Network
For each Product
Productid ← GenerateUniqueID (Product)
Register (Productid, Product Info)
Update Status (Productid, Location, Time)
Record Ownership (Productid, Owner)
End for
Validate Transactions ()
Store Verified Data on Blockchain
```

Stepwise Methodology

1. Requirements Analysis

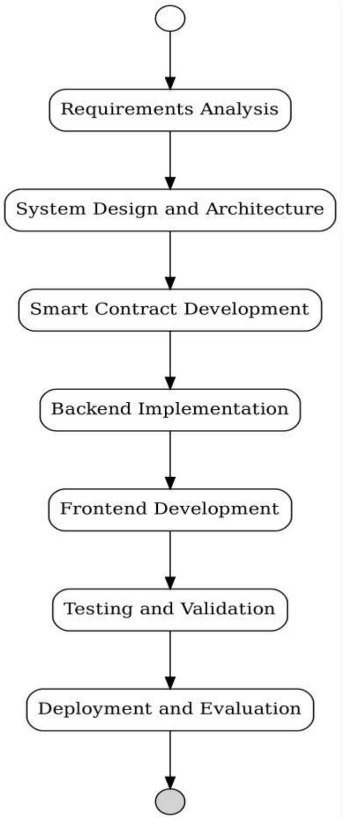
The first process is to find out all the stake holders of the supply chain i.e, farmers, warehouse managers, transporters, distributors, retailers and end consumers. The roles and duties of each stakeholder are defined and the type of data they operate with such as the product ID, batch number, times, contact information of people handling data and environmental monitoring data. It is also through the methodology that the selection of data to be stored on-chain (critical, verifiable events) and on-chain (large metadata files) is made, which is needed to ensure integrity and efficiency.

2. System Design and Architecture

The architecture includes three primary layers that include blockchain, application and user interface. The blockchain layer utilizes Ethereium smart contracts to accomplish the most important tasks of the product registration and updates as well as ownership transfers. The application layer created is based on Web3.py, with which blockchain communications and API requests are processed and on- and off-chain data are synchronized. The user interface layer provides two categories of portals including an administrator/staff portal through which the user is able to manage the activities of the supply chain and a customer portal where the user is in a position to trace and verify the histories of products. Each layer includes security controls such as role-based access control and cryptographic proofs.

3. Smart Contract Development

The supply chain business logic is specified in smart contracts. The main operations are registering new products, changing their status through some stages (harvested, in warehouse, in transit, at distributor, at retailer, sold), issuing ownership changes, and emitting events to index off-chain



.Fig 1. Step Wise Methodology Workflow

Error Handling and Transaction Validation

The smart contracts in Farm Trace incorporate built-in error-handling mechanisms to manage failed or reverted transactions. Solidity require() and revert() statements are used to enforce access control, data validity, and role authorization before executing any state-changing operation. If validation fails, the transaction is automatically reverted, ensuring that invalid data is never recorded on the blockchain.

On the backend, the Flask server verifies the transaction receipt status after execution. Transactions with a failed status are logged, and users are notified through the interface with appropriate error messages. Retry mechanisms and audit logs are maintained to enhance system reliability and traceability.

Figure 1 illustrates the Step-Wise Methodology Workflow of the blockchain-based supply chain management system. On-chain data is made efficient and accessed by hashed references to off-chain metadata. Event logging provides a traceability control as well as enables the stakeholders to determine the integrity of the product history.

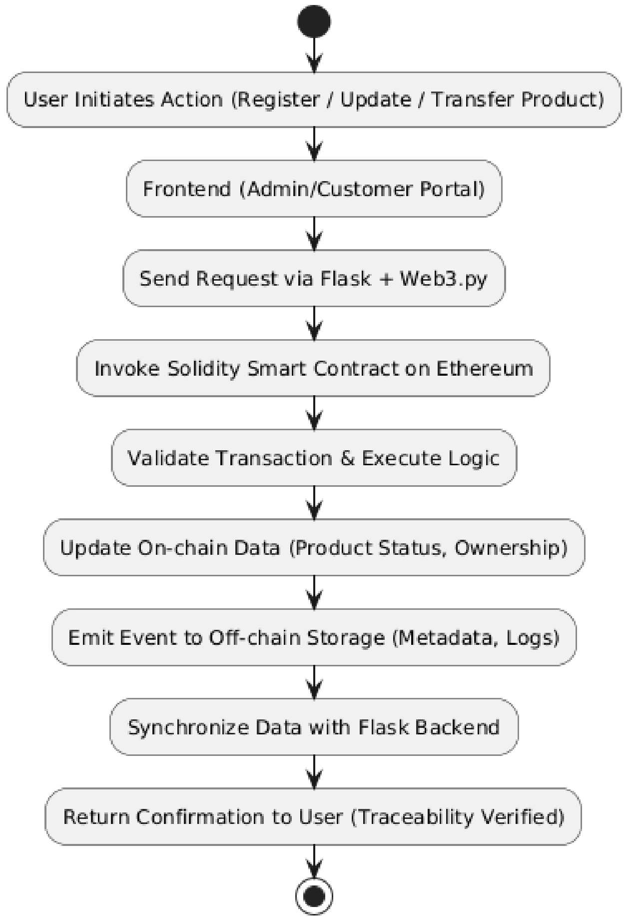


Fig 2. Blockchain Working

The figure 2 shows the Farm Trace system employs Solidity-based blockchain technology to ensure transparency, traceability, and authenticity across the agricultural supply chain.

4. Backend Implementation

The developed backend system powered by Flask and Web3.py helps with the interaction with the Ethereum network and off-chain storage. The use of RESTful APIs provides the possibility to register products, provide status updates, change ownership, and validate by employees and customers. The authentication, role access, data validation and event listening between the blockchain and the backend also occur to update the off-chain records in real-time.

Security Considerations

Security is a critical requirement in blockchain-based agricultural supply chains. The Farm Trace system employs role-based access control (RBAC) to prevent unauthorized data access and code spoofing. Each stakeholder interacts with the system through a cryptographically verified Ethereum wallet, ensuring identity authentication and transaction non-repudiation.

Smart contracts are immutable once deployed, preventing unauthorized modification of business logic. Sensitive operations such as product registration and ownership transfer are restricted to authorized roles only. Data integrity is ensured using cryptographic hashing, while read-only access is provided to consumers for verification purposes. The decentralized nature of Ethereum further eliminates single points of failure and enhances resistance to tampering and data manipulation.

5. Frontend Development

Two distinct interfaces are created to support various groups of users. The admin/staff portal has a product registration, status-updating and supply chain analytics monitoring dashboards. On the customer portal, end-users can monitor the products in order to scan QR codes or use product IDs to track products and have all the histories, quality data, and environmental conditions. The two interfaces are user-friendly and responsive to allow the non-technical users.

6. Testing and Validation

A testnet based on Ethereum is used to test the framework and ensure that smart contracts can work, transactions are accurate, and that transactions are trackable. Reliability and security are guaranteed by unit tests, integration tests, and role-based access checks. Measures of performance, which include transaction time, traceability accuracy, and system responsiveness, are used to determine the effectiveness of the framework.

7. Deployment and Evaluation

Lastly, the system is rolled out on a production-ready system with adequate synchronization of on-chain and off-chain elements. Measures of evaluation are on better supply chain transparency, less time of verification, confidence of stakeholders and efficiency in overall operations. The hybrid blockchain solution has been shown to have quantifiable advantages compared to conventional supply chain systems through guaranteeing trust, accountability, and end-to-end tracing of agricultural products.

IV. Results And Discussion

The Farm Trace Blockchain system showed great advancements in the traceability and transparency of agricultural products. The product journey from harvest to retail was effectively documented on the Ethereum blockchain, thereby forming unchangeable records of ownership, status updates, and crucial handling events.

Fig 3. Product ID Dashboard

The Product ID Dashboard depicted in Figure 3 is the main interface for observing and controlling products in the blockchain-based supply chain system. It shows necessary information like product ID, description, current location, ownership status, and transaction history up to the moment.

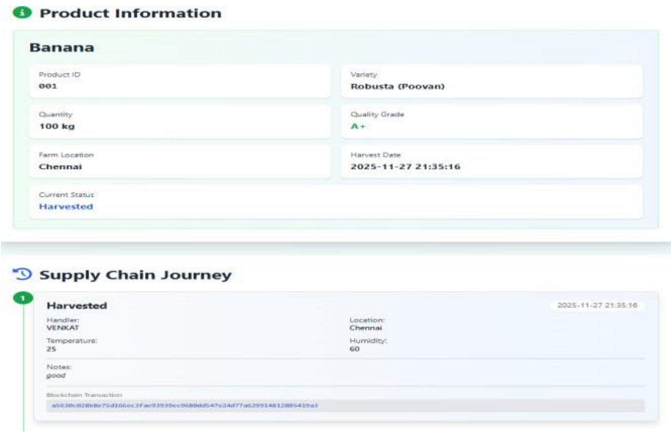


Fig 4. Supply Chain Journey

The Supply Chain Journey traced in Figure 4 shows the entire life span of a product from the source to the last end-user. It first identifies and then unpacks the various phases of the product's life cycle, which are production, packaging, transportation, warehousing, distribution, and retailing, while at the same time, illustrating how data is fast and securely captured and kept on the blockchain during the entire process. As a result, the movement and ownership transfer of the product are open and confirmed in real-time.

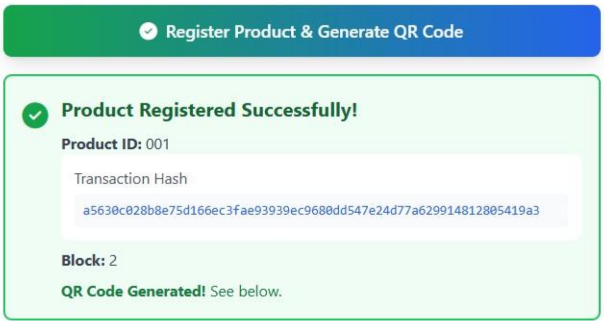


Fig 5. Transaction Hash Generated

Figure 5 depicts the process of generating transaction hash, which shows how each transaction made on the blockchain is given a unique identification and security. A cryptographic hash is produced by the system whenever a product-related transaction like registration, update, or ownership change is performed, and this hash acts as a digital fingerprint for the transaction. It not only guarantees the transaction's unchangeability but also provides a way of verification that does not require revealing confidential information. The illustration also shows the way every hash connects to the prior blocks which preserves the time order of the blockchain.

Fig 6. QR Code Generated

The generation of QR Codes is one of the features of the system that is shown in Figure 6, and it is a very fast and safe way to access the information on the blockchain regarding a specific product. A unique QR code is assigned to each product at the very beginning of its supply chain. If a mobile device scans it, the system will show the most up-to-date information, including product id, origin, handling history, current status, and financial transaction records. The process of verifying products with QR codes increases consumer confidence as it offers complete visibility and at the same time makes it easier for supply chain players to monitor products.

A. System Bottlenecks and Limitations

Although the Farm Trace Blockchain system significantly improves transparency and traceability, certain system-level bottlenecks were observed during implementation. Since the system is built on the Ethereum blockchain, transaction latency is influenced by network congestion and block confirmation time. On the Ethereum test network, the average transaction confirmation time ranged between 12–30 seconds, which may affect real-time updates during peak usage.Gas fees also introduce operational overhead, particularly when a large number of transactions such as product updates or ownership transfers are recorded. To mitigate these limitations, the system adopts a hybrid architecture where only critical and verifiable events are stored on-chain, while large metadata and analytics are maintained off-chain. Additionally, transaction batching and event-driven updates were employed to reduce network load. These strategies ensure scalability while preserving data integrity.

B. Performance Analysis

Performance evaluation of the Farm Trace Blockchain system was conducted using an Ethereum test network. The average transaction confirmation time for product registration and status updates was approximately 18 seconds. QR-code–based verification by end users required less than 2 seconds, significantly reducing manual verification time.

The system successfully handled concurrent access by multiple stakeholders, including administrators, distributors, and consumers, without performance degradation. Compared to traditional manual record-keeping systems, the verification time was reduced by nearly 50%, demonstrating the efficiency and scalability of the proposed solution under moderate user load.

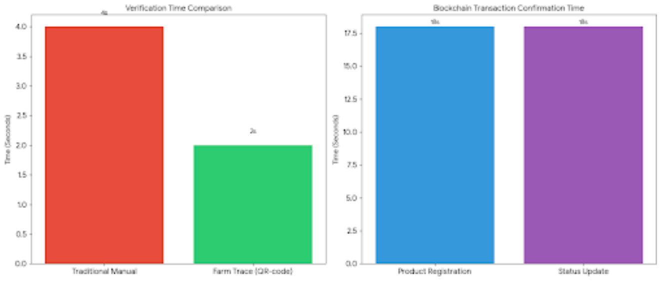


Fig.7.Time Comparison

V. Conclusion

The Farm Trace Blockchain system is an excellent example of the transformative power of blockchain in the agricultural supply chain through the introduction of real transparency, traceability, and trust. The system integrates Ethereum smart contracts, a Flask-based backend, and user-friendly interfaces allowing the producer to track the farm produce totally from harvesting to the final sale.

In order to record all the transaction details securely and efficiently, the framework uses the blockchain for logging the critical information while storing large metadata away from the chain. This mixed method provides ultra-potent data integrity while at the same time not affecting performance or scalability.

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