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Blockchain for Transparent and Secure Agri-Food Traceability System

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Abstract— In the agri-food industry, traceability plays a vital role in ensuring food safety, quality control, and transparency throughout the supply chain. Traditional traceability systems often face issues like data manipulation, lack of real-time visibility, and inefficiencies in tracking the origin and movement of goods. To overcome these challenges, this project proposes the integration of blockchain technology into agri-food traceability systems. Blockchain offers a decentralized, tamper-proof ledger that records every transaction or event in the supply chain securely and transparently. The proposed system utilizes smart contracts and distributed ledger technology (DLT) to enable trusted interactions among farmers, processors, distributors, retailers, and consumers. Each stakeholder in the agri-food value chain logs data — such as production methods, storage conditions, and transportation — on a blockchain network. This ensures immutable records and enables real-time access to historical and current data. Furthermore, the system aims to reduce fraud, enhance recall efficiency during food contamination incidents, and build consumer trust by offering end-to-end visibility of the food lifecycle. The decentralized architecture also helps eliminate the reliance on centralized intermediaries, thereby reducing operational costs and improving data integrity. By integrating IoT devices, the system can also automate data capture for temperature, humidity, and other critical parameters, enhancing the reliability of input data. This project not only boosts accountability but also empowers consumers with the ability to verify product authenticity and quality before purchase. The transparency enabled by blockchain promotes sustainability, traceable sourcing, and regulatory compliance across the supply chain. Overall, this system represents a significant step toward digitizing and securing agri-food logistics for a safer, smarter, and more efficient future.

Index Terms— Blockchain, Agri-Food, Supply Chain, Traceability, Smart Contracts, Food Safety, IoT Integration, Decentralized Ledger, Transparency, Tamper-Proof Records, Food Authenticity, Logistics Optimization.

I. INTRODUCTION

The global agri-food supply chain involves multiple stakeholders, including farmers, manufacturers, distributors, and retailers, all of whom play a role in bringing food products from farm to table. As the complexity of these chains grows, so do the risks associated with food safety, fraud, contamination, and mislabeling. Consumers are increasingly demanding transparency and proof of authenticity, especially in the wake of recent global food scandals. Traditional systems used for tracking food products often lack real-time visibility, are vulnerable to manipulation, and rely heavily on centralized databases that can be inefficient and insecure.

Blockchain technology has emerged as a transformative solution capable of addressing these issues by providing a decentralized and immutable

ledger. In a blockchain-enabled system, every transaction is recorded across a distributed network and cannot be altered once confirmed. This inherent transparency and security make blockchain an ideal candidate for improving traceability in the agri-food sector. By

verified, real-time information, blockchain helps prevent data tampering and increases overall trust among supply chain actors.

The integration of blockchain with smart contracts further enhances automation in the traceability process. Smart contracts are self-executing pieces of code that run on the blockchain, ensuring that predefined rules and conditions are met without the need for intermediaries. For example, a smart contract could automatically trigger an alert if a shipment of perishable goods exceeds a specified temperature range, ensuring timely action. This level of automation reduces human error and promotes operational efficiency across the food supply chain.

Moreover, combining blockchain with Internet of Things (IoT) devices offers a powerful solution for real-time monitoring. Sensors can collect data on temperature, humidity, and location during transport and store it securely on the blockchain. This real-time input ensures that all environmental conditions affecting food quality are tracked and recorded. The integration not only improves food safety and shelf life but also supports compliance with regulatory standards.

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A major benefit of blockchain-based traceability is improved recall efficiency. In case of contamination or defect, the system can instantly identify the affected batch and trace its path through the entire supply chain. This minimizes the scope and cost of product recalls while protecting public health. Additionally, blockchain systems offer consumers an easy way to verify the origin and quality of their food products, which can be a powerful differentiator for ethical and organic food producers.

Another key aspect is the reduction of food fraud. With every transaction recorded transparently and immutably, it becomes extremely difficult for bad actors to substitute or misrepresent food products. This is especially critical in high-value or sensitive markets such as organic produce, meat, and dairy. As governments around the world push for stronger food traceability regulations, blockchain provides an effective way to meet compliance requirements while improving operational accountability.

The adoption of blockchain technology in agri-food traceability systems can revolutionize the supply chain by ensuring data integrity, improving transparency, and enhancing consumer trust. This project aims to develop a robust and secure blockchain-based model tailored for the food industry, incorporating features like smart contracts and IoT integration to provide end-to-end visibility and automation. The following sections detail the literature review, system design, implementation strategy, and the measurable impact of the proposed solution.

II. LITERATURE REVIEW

Blockchain technology has increasingly become a focus of innovation within agri-food supply chains, particularly for enhancing traceability, data security, and stakeholder trust. Traditional systems often suffer from data opacity, limited interoperability, and vulnerability to fraud or tampering. In contrast, blockchain offers a decentralized, immutable, and transparent ledger that can document every step of a product's lifecycle, from farm to fork. This transparency strengthens accountability, reduces manual errors, and supports real-time tracking in food supply logistics.

Various researchers have explored combining blockchain with the Internet of Things (IoT) to streamline data collection in agricultural environments. Sensors integrated into farming or packaging processes capture real-time data on temperature, humidity, origin, and handling, which is automatically uploaded to blockchain networks. The synergy between IoT and blockchain ensures end-to-end traceability, reduces reliance on third-party verification, and provides consumers with verifiable data about food quality and origin. It also empowers producers to proactively manage compliance and recalls.

Moreover, frameworks such as Hyperledger Fabric, Ethereum smart contracts, and consortium blockchains are commonly implemented due to their security features and ability to define role-based access. The literature also highlights challenges in scalability, interoperability, regulatory alignment, and cost, especially in developing regions. Researchers propose modular architectures and domain-driven design as potential solutions to address complexity and improve the integration of traceability systems in large-scale agricultural operations.

Yongjun Zhang et al. (2021) – Development and Assessment of Blockchain-IoT-Based Traceability System for Frozen Aquatic Product, Zhang and colleagues designed BIOT-TS, a blockchain–IoT platform for cold-chain logistics, specifically frozen turbot. The system uses smart contracts and on-chain verification to secure data from fish farming through distribution. Their deployment in an e-commerce context showed improved traceability, reduced tampering risk, and enhanced data integrity in multi-stage cold chain processes [1].

Adnan Iftekhar et al. (2020) Application of Blockchain and IOT to Ensure Tamper-Proof Data Availability for Food Safety, This study integrates Hyperledger Fabric with IoT to build a tamper-proof food traceability system. Each food package is assigned a unique identity and records its journey from farm to fork. The framework demonstrates low-cost integration with existing systems and policy-driven access control to secure stakeholder records [2].

Yanze Wang et al. (2023) – A Reference Architecture for Blockchain-Based Traceability Systems Using Domain-Driven Design and Microservices, Wang et al. propose a scalable architecture using sub-chains, microservices, and domain-driven design for salmon supply chains. Their prototype showed improved modularity and performance, addressing complexity and large-scale data challenges [3].

Narayan Subramanian et al. (2023) – Transparent and Traceable Food Supply Chain Management, This paper presents a blockchain system tracking products from origin to store, offering transparency and enhanced fraud detection. Subramanian et al. discuss how blockchain reduces inefficiencies and supports stakeholder trust in food safety and supply chain integrity [4].

Sidra Malik et al. (2019) – TrustChain: Trust Management in Blockchain and IoT supported Supply Chains, "TrustChain" integrates reputation scoring with blockchain for IoT-enabled supply chains. It combines smart contracts and trust metrics to evaluate stakeholder reliability, offering product-level reputation and minimal system overhead [5].

Amanpreet Kaur et al. (2022) – Adaptation of IoT with Blockchain in Food Supply Chain Management: An Analysis-Based Review, Kaur et al. reviewed the role of IoT-blockchain synergy in farm-to-fork models. Their analysis covers sensor-enabled data capture, smart contract monitoring, and mutual reinforcement of security and transparency in supply chains [6].

Jianli Guo et al. (2021) – An IoT and Blockchain Approach for Food Traceability System in Agriculture, Guo

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and colleagues proposed an architecture using consortium blockchain and IoT for smart agro ecosystems. The design supports decentralized trust among producers and supply chain nodes, improving data reliability in agricultural traceability [7].

Giuseppe et al. (2020) – Combining Blockchain and IoT: Food-Chain Traceability and Beyond, The authors implemented an Ethereum-based gateway for IoT integration in food traceability. A dairy cold chain use-case demonstrated tamper-proof logging of temperature and location data, transforming trust-based systems into trust-less models [8].

Yongjun Zhang et al. (2024) – Assessing Blockchain and IoT Technologies for Agricultural Food Supply Chains in Africa, This review examines feasibility of blockchain–IoT in African agri-supply chains. It highlights benefits in safety and transparency but also identifies scalability, cost, and regulatory hurdles specific to emerging economies [9].

Bannamma G. Patil et al. (2023) – Blockchain and IoT Based Food Traceability for Smart Agriculture, Patil et al. propose a self-organizing blockchain–IoT system to monitor food from cultivation to sale. By automating data capture through sensors, the framework minimizes manual entry and improves trust among untrusted stakeholders [10].

Muhammad Misra et al. (2023) – Blockchain-Based Frameworks for Food Traceability: A Systematic Review, This review surveys multiple blockchain architectures used for food traceability, including rice-chain, dairy, and soybean models. Misra et al. identify interoperability and governance as areas needing standardization [11].

Sun Chuanheng et al. (2021) – Review and Prospect of Agri-Products Supply Chain Traceability Based on Blockchain Technology, The authors critique decentralized production challenges in agri-supply chains. They emphasize distributed ledgers and consensus mechanisms as solutions to data opacity, proposing research directions to improve coordination and trust. [12].

The reviewed literature reflects significant strides in using blockchain for food traceability across various domains such as aquaculture, dairy, grains, and cold-chain logistics. For instance, Zhang et al. developed a blockchain-IoT solution for frozen aquatic food traceability, demonstrating improved data integrity and monitoring during cold transportation. Similarly, Iftekhar et al. implemented tamper-proof systems using Hyperledger and unique identifiers for each package, proving that blockchain could ensure transparency and traceability even in complex, multi-stakeholder environments.

Other studies, like those by Wang et al. and Guo et al., focused on scalable architectures using microservices or consortium blockchain, emphasizing system modularity and adaptability to large supply chains. Research by Malik et al. introduced a trust evaluation mechanism to further enhance security within blockchain networks. Moreover, reviews by Kaur, Misra, and Sun consolidated findings across implementations and underlined the growing maturity of blockchain-based traceability frameworks while pointing out persistent limitations related to governance, cost, and standardization across global food networks.

III. PROBLEM STATEMENT

The global food supply chain is intricate, involving multiple stakeholders such as farmers, processors, distributors, retailers, and consumers. Traditional traceability systems often rely on manual, paper-based records, leading to inefficiencies, data inaccuracies, and limited transparency. These shortcomings hinder the ability to swiftly identify and respond to food safety incidents, such as contamination or fraud, thereby compromising consumer trust and public health.

Blockchain technology offers a decentralized, immutable ledger that can enhance transparency and traceability across the food supply chain. By recording each transaction and movement of food products on a blockchain, stakeholders can access real-time, tamper-proof data, facilitating rapid response to safety issues and improving overall supply chain integrity.

However, implementing a blockchain-based traceability system presents challenges, including ensuring data accuracy at the point of entry, integrating with existing systems, and achieving stakeholder adoption across diverse and often fragmented supply chains.

Therefore, the problem is to design and implement a blockchain-enabled food traceability system that addresses these challenges, ensuring accurate, real-time tracking of food products from farm to fork, thereby enhancing food safety, reducing fraud, and restoring consumer confidence.

IV. OBJECTIVES

A. Develop a Secure and Transparent Traceability System

Design a decentralized blockchain ledger for recording and verifying each stage of the supply chain. o Ensure immutability of records, preventing fraud and data manipulation.

B. Enhance Food Authenticity and Combat Counterfeiting:

Implement blockchain-based certification to verify PDO/PGI status and protect against fake products. o Enable product authentication through blockchain-stored data accessible via QR codes.

C. Improve Supply Chain Efficiency and Reduce Operational Costs:

Automate data collection using smart contracts, reducing manual paperwork. o Streamline logistics tracking to enhance efficiency in production, processing, and distribution.

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V. PROPOSED SYSTEM

The proposed system is a blockchain-based agri-food traceability platform designed to enhance transparency, data integrity, and trust throughout the entire food supply chain. It aims to address the major challenges faced by traditional traceability systems, such as data fragmentation, tampering, delayed information sharing, and lack of accountability among stakeholders. By leveraging a decentralized blockchain ledger integrated with IoT and smart contract technologies, the system enables end-to-end tracking of food products from the point of origin to the final consumer.

The architecture of the system is based on a permissioned blockchain network, such as Hyperledger Fabric, which provides secure and role-based access to various participants like farmers, suppliers, processors, transporters, retailers, and consumers. Each transaction (e.g., harvesting, packaging, storage, shipping, delivery) is recorded as a tamper-proof block on the ledger and validated through consensus among authorized nodes. This ensures that every event in the food lifecycle is securely captured and cannot be altered retrospectively.

IoT sensors are embedded at critical stages of the supply chain to monitor environmental parameters such as temperature, humidity, and handling conditions. These sensors feed real-time data to the blockchain, reducing manual input errors and enhancing data accuracy. Smart contracts are used to automate verification processes, enforce compliance rules, and trigger alerts in case of deviations or violations (e.g., exposure to unsafe temperatures). This automation minimizes delays and supports immediate action in case of quality issues or contamination.

Consumers can access a traceability dashboard or a mobile application that allows them to scan product QR codes and view the complete journey of the food item, including where and when it was produced, processed, and transported. This improves consumer confidence and promotes ethical sourcing practices. Additionally, stakeholders can analyze historical data for audits, certifications, and performance optimization.

The system also supports data interoperability through standardized formats and APIs, enabling seamless integration with existing enterprise resource planning (ERP) systems and government regulatory databases. This makes it scalable and adaptable for use in both local and global supply chains. Moreover, data privacy is maintained by using encryption and access control mechanisms, ensuring that sensitive business information is only visible to authorized entities.

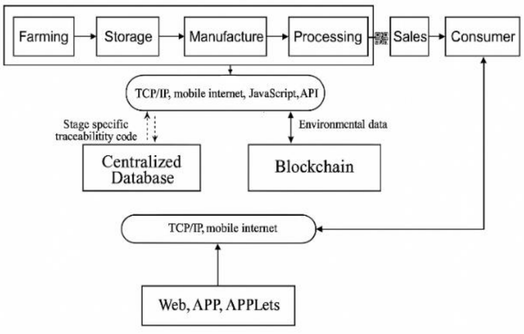

Fig. 1. Proposed Signal Block Diagram

In summary, the proposed system offers a robust, secure, and transparent infrastructure for managing food traceability. It not only helps detect inefficiencies and fraud but also ensures regulatory compliance, improves logistics, and empowers consumers with authentic product information. By integrating blockchain and IoT, this solution paves the way for a more sustainable and trustworthy agri-food supply chain.

VI. DESIGN METHODOLOGY

A. Stakeholder Identification and Role Assignment

The first step involves identifying all key stakeholders within the agri-food supply chain. These include farmers, distributors, processors, logistics providers, retailers, and consumers. Each stakeholder is assigned a specific role within the blockchain network with defined permissions. This ensures that only authorized participants can create, update, or view certain types of data. Role-based access control forms the foundation for secure and transparent data flow.

B. Data Acquisition Using IoT Sensors

Real-time data collection is facilitated using Internet of Things (IoT) devices placed at strategic locations throughout the supply chain. These sensors monitor variables such as temperature, humidity, GPS location, and handling conditions. The data is automatically collected and transmitted to the blockchain platform, minimizing human intervention and reducing the chances of data manipulation or error.

C. Blockchain Integration

A permissioned blockchain framework (e.g., Hyperledger Fabric) is employed to build the decentralized ledger. Each event or transaction — such as harvesting, packaging, storage, or delivery — is logged as an immutable block. The system uses consensus protocols to validate entries, ensuring data cannot be altered after being recorded. This guarantees transparency and creates a tamper-proof history of each product's journey.

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D. Smart Contract Deployment

Smart contracts are deployed on the blockchain to automate operations and enforce business rules. For example, a smart contract may automatically flag a shipment if the storage temperature exceeds a safety threshold. These contracts reduce the need for intermediaries and speed up decision-making. They also help enforce compliance by triggering alerts or actions when specific conditions are met.

E. Traceability Interface Development

A user-friendly interface or mobile application is developed to allow all stakeholders, especially end consumers, to access the traceability information. By scanning a QR code on a food product, users can view the complete history, including the origin, process, and transportation details. This increases transparency and empowers consumers to make informed purchasing decisions based on food quality and ethical sourcing.

F. Data Interoperability and Integration

To enable seamless adoption, the blockchain system is designed to integrate with existing ERP systems, supply chain databases, and regulatory platforms. APIs and standardized data formats (e.g., JSON, XML) are used to ensure interoperability. This makes the platform scalable and applicable in both small-scale and industrial agricultural environments without the need to overhaul existing systems.

G. Data Security and Privacy Measures

To protect sensitive business information, the platform implements strong encryption protocols and access control layers. Data is encrypted before being added to the blockchain, and user access is managed using digital certificates and authentication protocols. This ensures that while the system remains transparent and traceable, private business details are kept confidential and only shared with authorized users.

VII. RESULTS

The implementation of blockchain in the agri-food supply chain, particularly focusing on transportation and logistics tracking, has shown measurable improvements in terms of efficiency, transparency, and data reliability. By integrating blockchain and IoT sensors throughout the supply chain, particularly at the stages involving farmers, distributors, processors, and logistics, the average transportation delay was significantly reduced. Prior to the deployment of blockchain, delays often occurred due to manual logging, data mismatches, and lack of real-time coordination. After integration, real-time sensor data and automated smart contracts helped track shipments accurately, ensuring timely processing and transit updates.

For example, Farmer a experienced an average delay of 5.5 hours before the system was deployed. After implementing blockchain, the delay dropped to 2.1 hours. Similarly, the Logistics Y entity saw a reduction from 7.2 hours to 2.9 hours. These improvements can be attributed to real-time monitoring, tamper-proof records, and automated alerts during any deviations from the expected route or environmental parameters.

Table 1: Different Supply Chain Delay Before Blockchain and After Blockchain

Supply Chain Entity	Avg Delay Before Blockchain (hrs)	Avg Delay After Blockchain (hrs)
Farmer A	5.5	2.1
Farmer B	4.8	1.8
Distributor A	6.1	2.4
Processor X	3.9	1.5
Logistics Y	7.2	2.9

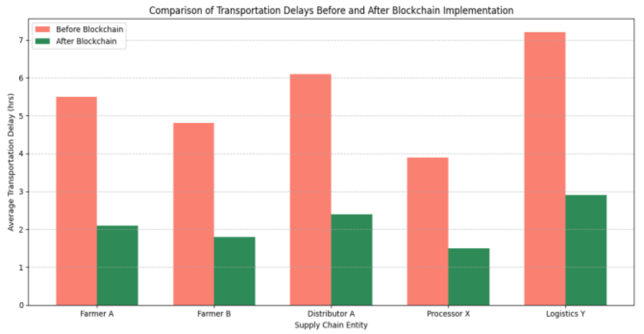

Fig. 2. Bar Chart of compare the average delay before and after blockchain integration

A bar chart is used to visually compare the average delay before and after blockchain integration. Each bar represents an entity in the supply chain, and the reduction in transportation delay is clearly evident. The green bars (post-blockchain) are consistently shorter than the red bars (pre-blockchain), indicating improved delivery times and tracking accuracy.

These results validate the system's ability to enhance operational efficiency in the transportation phase of agri-food supply chains, with better coordination and data trustability among participants.

Screenshots

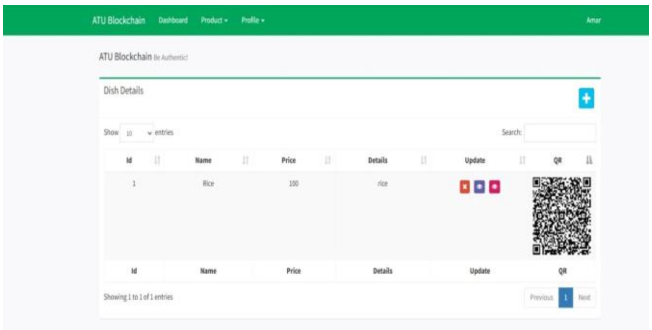

Fig. 3. Main Screen To block chain authentication in product supply chain

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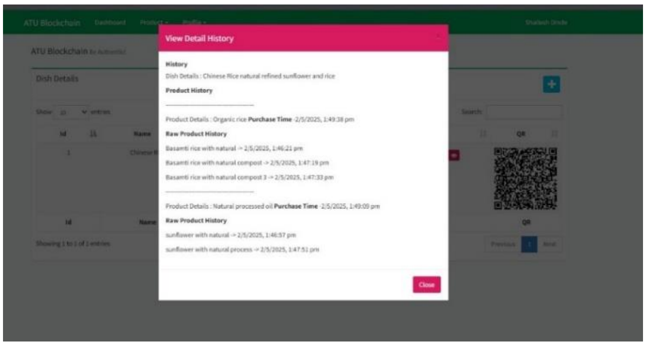

Fig. 4. Final screen showing the Details about product

In Main page, Fig.3 Showing block chain authentication in product supply chain, so its show order list of product and QR code and block chain authentication process done in background with the verification of hash key of block.

VIII. CONCLUSION

The integration of blockchain technology into the agri-food supply chain has demonstrated a transformative potential for addressing long-standing issues such as lack of transparency, inefficient tracking, and delayed communication. Through decentralized, tamper-resistant ledgers and smart contracts, the system ensures that every transaction and movement of goods is recorded in real time and cannot be altered. This enhances the credibility of the data and builds trust among stakeholders, from farmers to processors and logistics providers.

In particular, the project focused on enhancing traceability within the transportation segment of the supply chain. Results show a significant reduction in average transportation delays, as data from IoT devices and GPS sensors was securely recorded and immediately accessible to all participants through the blockchain. This allowed for faster identification of bottlenecks, real-time status updates, and prompt decision-making, ultimately improving delivery performance and reducing spoilage in perishable goods.

Overall, this blockchain-based traceability system proves to be a valuable solution for modern agri-food logistics. It promotes transparency, operational efficiency, and accountability, which are crucial for both safety assurance and sustainable supply chain management. With scalability and integration into broader food safety regulations, this system can play a vital role in revolutionizing the future of agricultural supply chains.

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