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Full Length Article

Blockchain-Based Supply Chain Transparency For Agricultural Produce

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Abstract
Agricultural supply chains face significant challenges related to transparency, traceability, data security, and stakeholder trust. Traditional supply chain systems often rely on centralized databases and manual record-keeping processes, which can lead to information asymmetry, food fraud, inefficient logistics, and reduced profitability for farmers. To address these limitations, this paper presents a Blockchain-Based Supply Chain Transparency System for Agricultural Produce that leverages decentralized ledger technology to ensure secure, transparent, and tamper-resistant management of supply chain information.
The proposed system records and tracks agricultural products throughout their lifecycle, including cultivation, harvesting, processing, transportation, storage, and retail distribution. By utilizing blockchain technology, every transaction is permanently recorded, time-stamped, and verified, ensuring data integrity and preventing unauthorized modifications. The framework incorporates Hyperledger Fabric, MongoDB, QR code technology, and smart contracts to facilitate secure data sharing and automated transaction processing among farmers, distributors, retailers, and consumers.
Each product batch is assigned a unique QR code linked to its blockchain record, enabling consumers to instantly access verified information regarding product origin, quality, freshness, and supply chain history. Smart contracts further enhance efficiency by automating business processes and ensuring transparent and fair transactions between stakeholders. The proposed system improves product traceability, reduces dependency on intermediaries, minimizes fraud, and strengthens consumer confidence in agricultural products.
Furthermore, the solution promotes sustainable agricultural practices, operational efficiency, and accountability across the supply chain ecosystem. Future enhancements may include integration with Internet of Things (IoT) devices for real-time environmental monitoring and mobile-based platforms for improved accessibility and stakeholder engagement. The proposed framework demonstrates the potential of blockchain technology in transforming conventional agricultural supply chains into secure, transparent, and trustworthy systems.

Keywords: *Blockchain Technology, Agricultural Supply Chain, Supply Chain Transparency, Traceability, Hyperledger Fabric, Smart Contracts, QR Code, Food Safety, Decentralized Ledger, Data Integrity, Sustainable Agriculture.*

Introduction

Blockchain-Based Supply Chain Transparency for Agricultural Produce Blockchain-based supply chain transparency for agricultural produce is an innovative approach that utilizes blockchain technology to establish a secure, decentralized, and tamper-resistant framework for tracking agricultural products throughout their lifecycle. Traditional agricultural supply chains often suffer from a lack of visibility, inefficient record management, and limited traceability, making it difficult to verify product authenticity and quality. The adoption of blockchain technology addresses these issues by maintaining an immutable ledger in which every transaction and movement of a product is permanently recorded. Information related to cultivation, harvesting, transportation, storage, and retailing can be securely shared among stakeholders, ensuring accountability and trust. By enabling transparent access to product information, blockchain enhances consumer confidence, improves food safety, reduces fraud, and streamlines supply chain operations. Consequently, this technology has emerged as a promising solution for building a more efficient and trustworthy agricultural ecosystem.

Existing System

The existing agricultural supply chain primarily operates through traditional and centralized management systems involving multiple intermediaries such as agents, wholesalers, distributors, and retailers. Farmers often rely on these intermediaries to market and sell their produce, which frequently results in reduced profits and limited control over pricing. Information regarding product origin, quality, and movement is typically maintained through manual documentation or isolated databases that are not interconnected. Such methods increase the likelihood of errors, delays, and inconsistencies in data management. Although certain digital solutions have been introduced to improve record keeping, they generally provide limited visibility across the entire supply chain and fail to ensure comprehensive traceability. Furthermore, centralized systems remain vulnerable to data manipulation, unauthorized modifications, and operational inefficiencies. As a result, the existing system struggles to establish transparency, trust, and accountability among supply chain participants.

Proposed System

The proposed Blockchain-Based Supply Chain Transparency System introduces a decentralized platform that records and manages agricultural supply chain data using blockchain technology. In this system, farmers register product-related information such as crop type, quantity, harvesting date, and cultivation practices onto a blockchain network. The recorded information is stored in an immutable manner, ensuring that it cannot be altered or deleted without authorization. As products move through different stages of the supply chain, distributors and retailers update transportation, storage, and handling details on the blockchain. Each product batch is assigned a unique QR code that acts as a digital identifier linked to its blockchain record. Consumers can scan the QR code to access verified information regarding the product's origin, quality, freshness, and movement history. Through real-time tracking and secure information sharing, the system enhances traceability, reduces dependence on intermediaries, minimizes post-harvest losses, and promotes fair trade practices. Ultimately, the proposed framework establishes a transparent and trustworthy agricultural supply chain ecosystem.

Requirement Analysis

Requirement analysis is a critical phase in system development that identifies and defines the functionalities, quality attributes, and resource requirements necessary for successful implementation. The Blockchain-Based Supply Chain Transparency System requires a combination of functional and non-functional requirements to ensure effective operation and user satisfaction.

Computational Resource Requirements

The successful deployment of the proposed system requires adequate hardware, software, and network resources. The recommended hardware configuration includes a modern Intel Core i5 processor or higher, 16 GB of RAM, and a minimum of 500 GB storage capacity to support blockchain operations and database management. Devices such as desktops, laptops, and smartphones can be used to access the platform, while an HD camera is necessary for QR code scanning. The software environment includes Windows 11, Visual Studio Code, Hyperledger Fabric, MongoDB, HTML, CSS, JavaScript, and backend technologies for application development and blockchain integration. A reliable internet connection with secure communication protocols such as HTTPS is required to facilitate real-time synchronization, transaction processing, and data exchange across the network.

Life Cycle Model

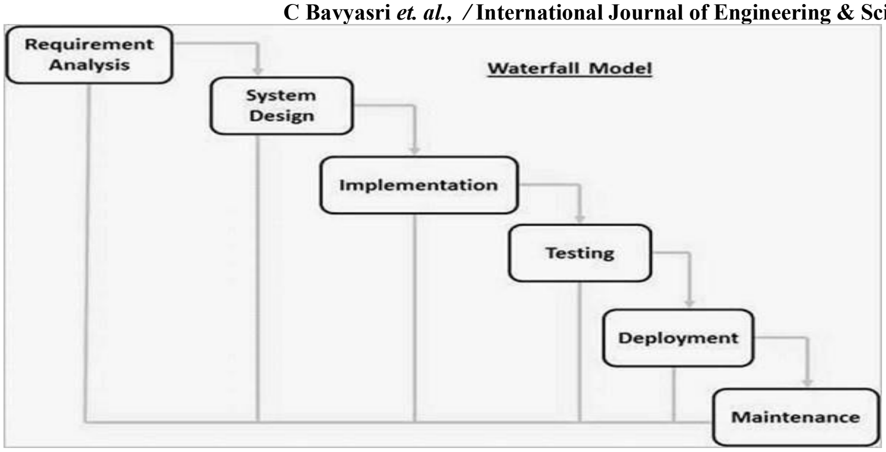


Fig 1 Waterfall Model

The development of the Blockchain-Based Supply Chain Transparency System follows the Waterfall Software Development Life Cycle model, which provides a structured and sequential approach to system construction. The process begins with requirement analysis, where user needs and system objectives are identified and documented. During the design phase, the system architecture, database schema, user interfaces, and blockchain integration mechanisms are planned in detail. The implementation phase involves coding and integrating frontend, backend, database, and blockchain components into a unified platform. Comprehensive testing is conducted to verify functionality, security, performance, and reliability while identifying and correcting defects. Following successful testing, the system is deployed in the target environment and made available to users. The maintenance phase focuses on monitoring system performance, resolving issues, applying updates, and incorporating enhancements to ensure long-term effectiveness and adaptability.

Design

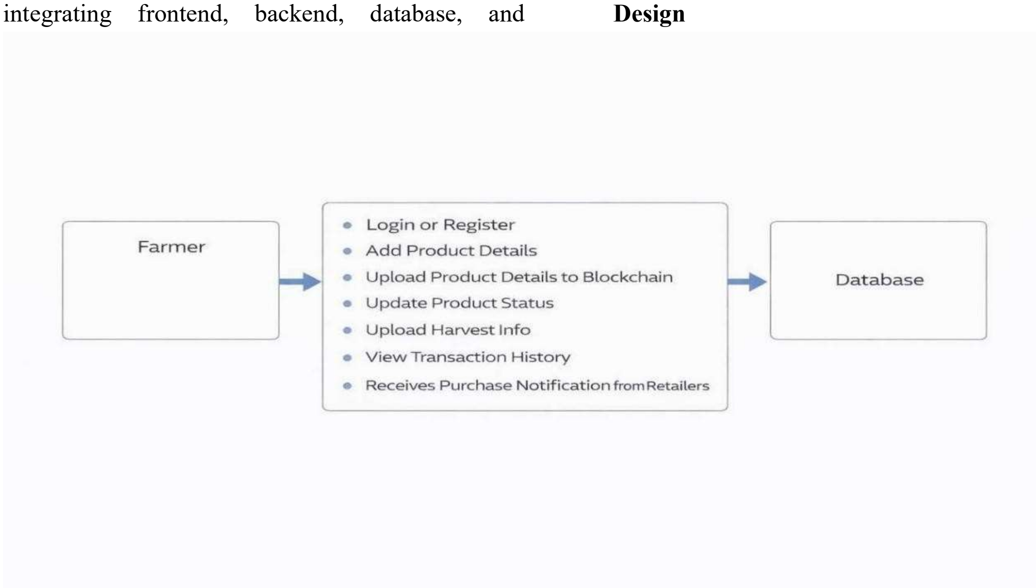


Fig 2 Software Architecture for Farmer

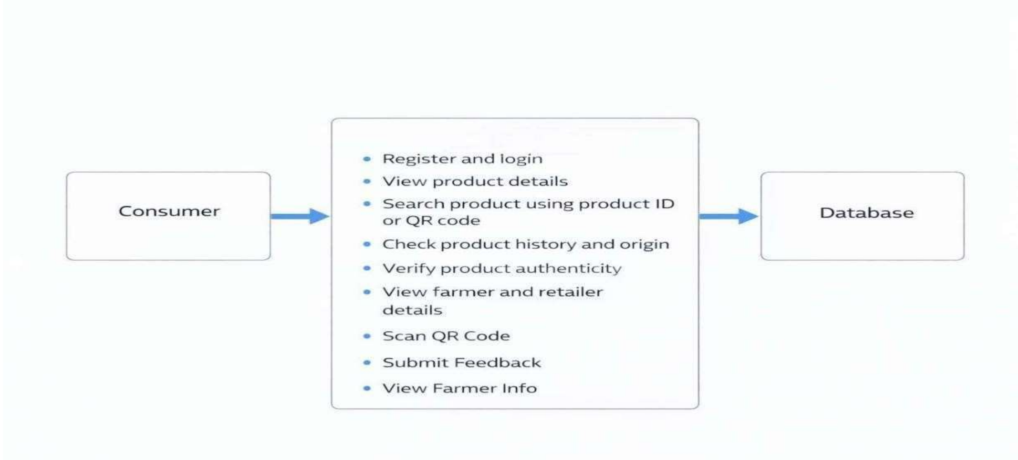


Fig 3; Software Architecture for Consumer

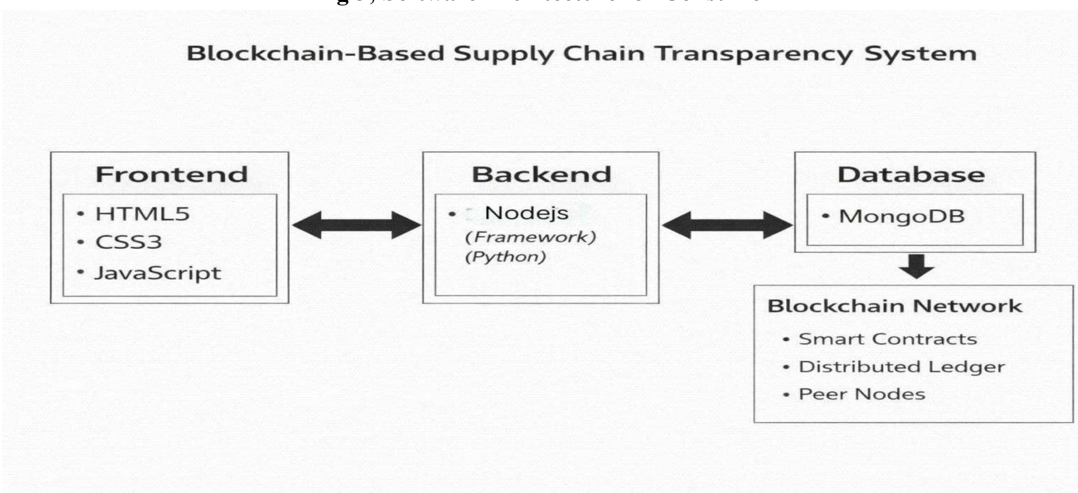


Fig 4; Technical Architecture

The design phase establishes the overall structure and operational workflow of the Blockchain-Based Supply Chain Transparency System. It defines how users interact with the platform and how information flows among various components. The architecture integrates a web-based user interface, backend services, a MongoDB database, and a Hyperledger Fabric blockchain network to create a secure and transparent ecosystem for agricultural supply chain management. Farmers, distributors, retailers, consumers, and administrators interact with the application through dedicated dashboards designed according to their roles and responsibilities. Product information and transaction records are processed by the backend layer and stored within both the database and blockchain network. Hyperledger Fabric ensures secure transaction validation and immutable record keeping, while MongoDB supports efficient storage and retrieval of application data. QR code technology provides a convenient mechanism for linking physical products to their digital records, enabling consumers to verify product authenticity and traceability. Through the coordinated interaction of these components, the system delivers transparency, accountability, and operational efficiency throughout the agricultural supply chain.

Implementation

The implementation phase focuses on the actual development of the Blockchain-Based Supply Chain Transparency System by integrating blockchain technology, web development frameworks, and database management systems. This stage transforms the proposed design into a fully functional application that ensures secure, transparent, and traceable management of agricultural supply chain data. The system is developed to support multiple stakeholders, including farmers, distributors, retailers, and consumers, by enabling real-time data sharing and tamper-proof record keeping. Each module is designed to interact seamlessly with the blockchain network, ensuring that every transaction is securely recorded and verifiable.

The frontend of the system is developed using HTML, CSS, and JavaScript, which collectively provide an interactive and user-friendly interface for different categories of users. This interface enables stakeholders to perform activities such as registration, login, product management, and order tracking efficiently. The backend is implemented using Node.js, which handles server-side logic, API communication, and integration between the frontend, database, and blockchain components. MongoDB is used as the primary database to store structured application data such as user profiles, crop information, and order records, ensuring efficient data retrieval and management.

Blockchain technology forms the core of the system by ensuring data immutability, transparency, and security. All critical transactions, including crop registration, transportation updates, and order processing, are recorded on a decentralized ledger. This prevents unauthorized modifications and enhances trust among stakeholders. Security mechanisms such as authentication and role-based access control are implemented to ensure that only authorized users can access or modify system data based on their assigned roles.

The system workflow begins with environment initialization, where server configurations, database connections, and blockchain network access are established. Required modules such as authentication, crop management, order processing, and blockchain interaction are loaded before the application starts. During user registration, input validation is performed, passwords are securely hashed, and user data is stored in the database. For login functionality, credentials are verified, and authentication tokens are generated upon successful validation.

Farmers can add crop details such as crop type, quantity, harvest date, location, and agricultural inputs. Once validated, this information is stored in the database and simultaneously recorded on the blockchain through smart contract execution. Each product batch is assigned a unique QR code linked to its blockchain record, enabling transparent tracking across the supply chain. Similarly, consumers can place orders, and each transaction is securely stored in both the database and blockchain network, ensuring consistency and traceability.

Testing

Software testing is a crucial phase that ensures the correctness, reliability, and security of the developed Blockchain-Based Supply Chain Transparency System. The primary objective of testing is to verify that all components of the system function as intended and that agricultural supply chain data is accurately recorded, securely stored, and reliably retrieved through the blockchain network. Since the system handles critical information related to food supply chains, rigorous testing is essential to maintain data integrity, transparency, and user trust.

Testing ensures that crop data, transactions, and supply chain updates are correctly processed without errors. It also validates the immutability of blockchain records, ensuring that no unauthorized modifications can be made once data is stored. Additionally, it verifies that QR code-based tracking provides accurate and complete product information to end users, including farmers, retailers, and consumers. The system is evaluated for performance, security, usability, and reliability under different operational conditions.

The testing process is carried out at multiple levels, including unit, integration, system, and acceptance testing. At the unit level, individual modules such as user registration, crop management, QR code generation, and blockchain transaction functions are tested independently to ensure correct functionality. Integration testing focuses on verifying the interaction between frontend, backend, database, and blockchain components, ensuring seamless data flow across the system.

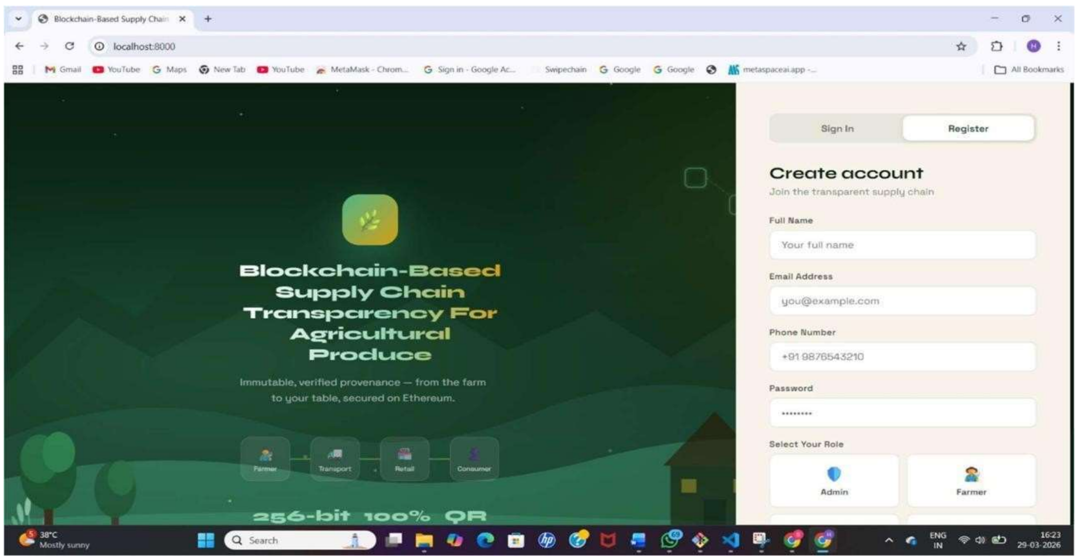
System testing evaluates the complete application as a unified platform by simulating real-world scenarios such as product registration, supply chain tracking, and QR-based product verification. Acceptance testing is performed by end users to confirm that the system meets functional requirements and provides an intuitive and transparent user experience.

Different testing techniques are applied to ensure comprehensive validation of the system. Functional testing verifies that all features work according to specifications, while usability testing ensures that the system is easy to use for all stakeholders. Performance testing evaluates system responsiveness under high transaction loads, and security testing ensures that data stored on the blockchain remains protected from tampering or unauthorized access. Both manual and automated testing approaches are used to validate system behavior in realistic scenarios.

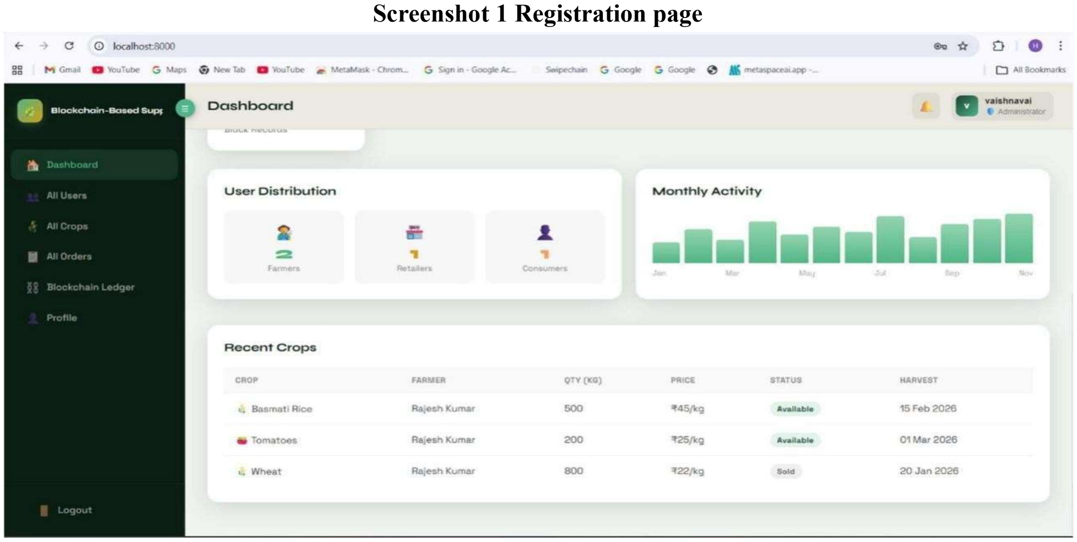
Further classification of testing includes black box and white box testing methods. Black box testing focuses on validating system outputs based on input data without considering internal implementation details, ensuring that users receive correct supply chain information. White box testing examines internal logic, including smart contract execution and blockchain transaction processing, using coverage techniques such as statement, branch, and path testing to ensure code reliability.

A set of test cases is executed to validate key functionalities of the system, including user registration, login, product addition, QR code generation, blockchain storage, supply chain tracking, and order management. The system is also tested for invalid inputs, QR code errors, data tampering attempts, and performance under multiple simultaneous transactions. The results confirm that all modules function correctly, blockchain records remain immutable, and the system performs efficiently under expected workloads.

Screenshots



Screenshot 1 Registration page



Screenshot 2 Admin dashboard

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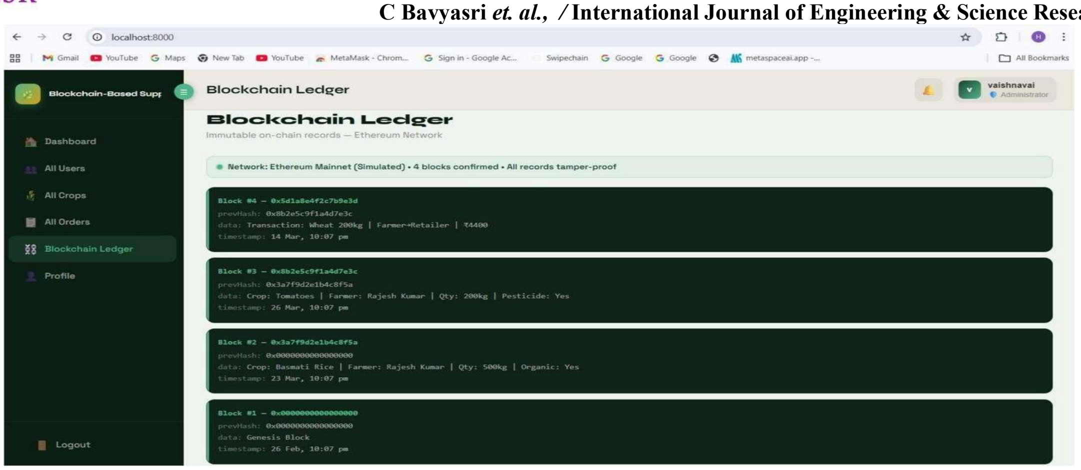
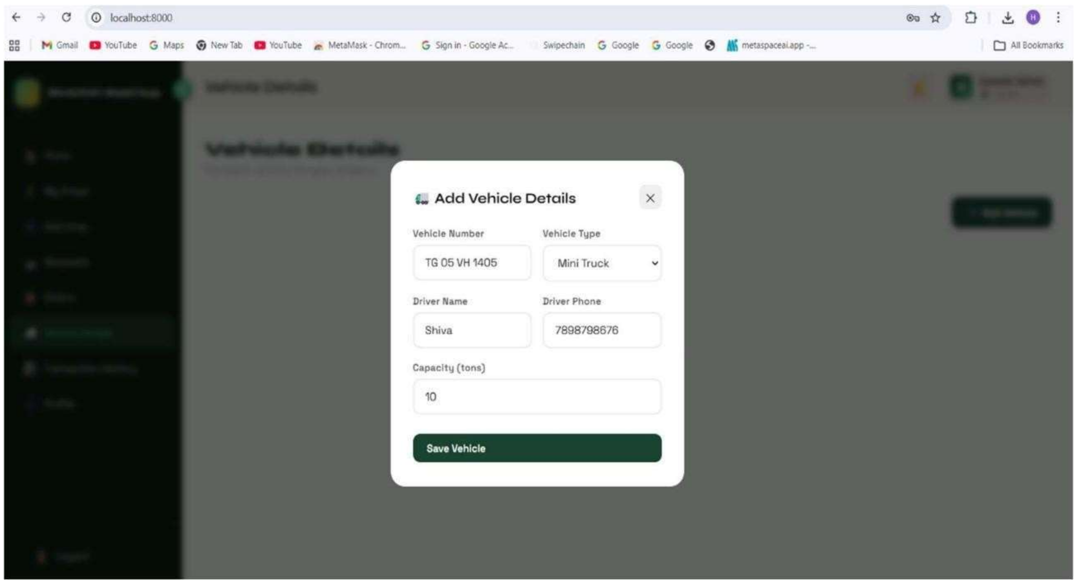
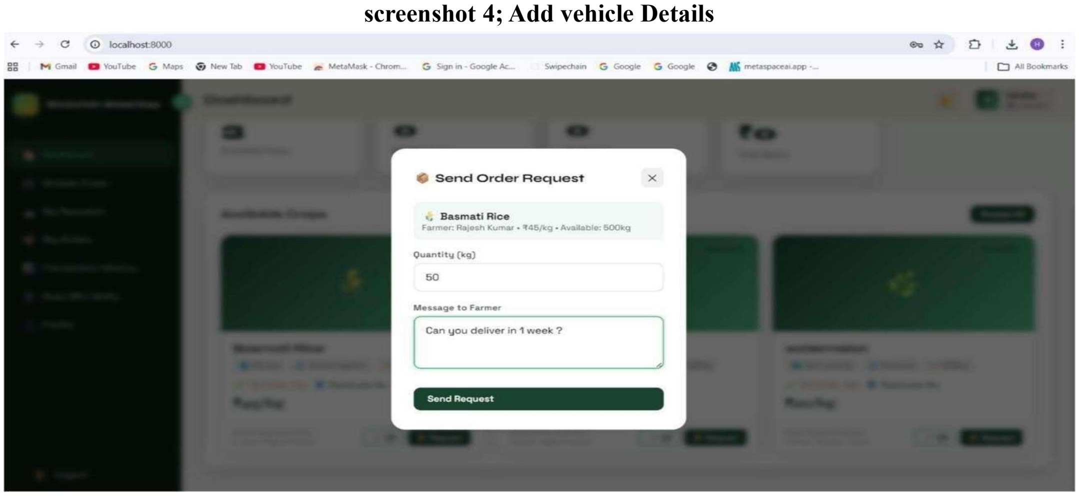


Screenshot 3 blockchain ledger

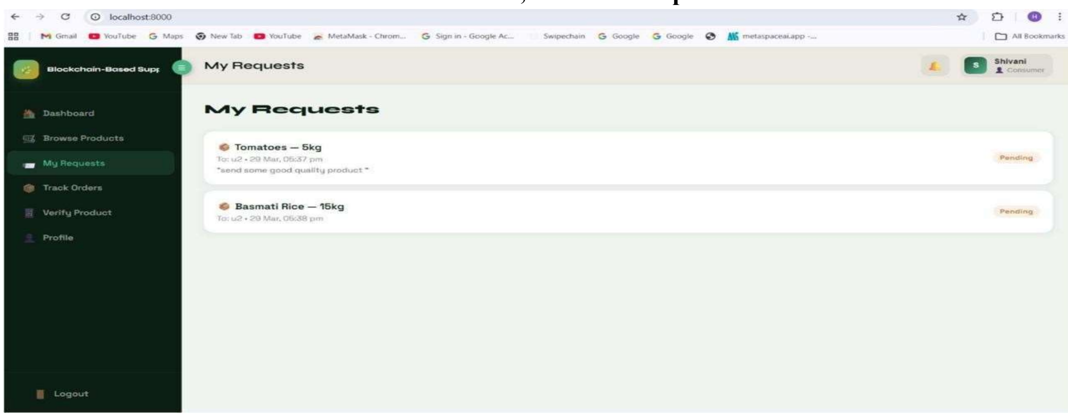


screenshot 4; Add vehicle Details

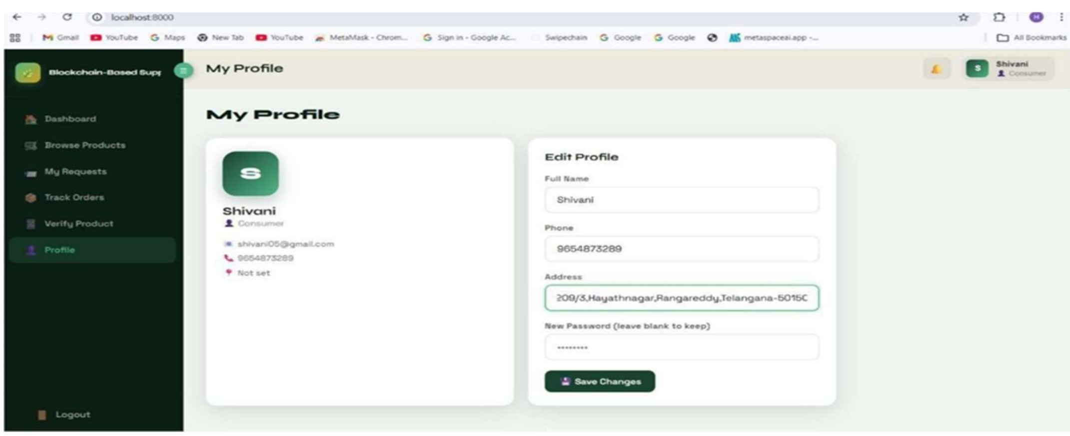


Screenshot 5; request to farmer

Screenshot 6; Available crops



Screenshot 7; My Request dashboard



Screenshot 8; Consumer Profile

Conclusion

The Blockchain-Based Supply Chain Transparency System for agricultural produce has been successfully designed and developed to address critical challenges related to traceability, transparency, and trust within conventional agricultural supply chains. By leveraging blockchain technology, the proposed system ensures that all transactions and product movements are recorded in a decentralized, secure, and immutable ledger. This enables all stakeholders, including farmers, distributors, retailers, and consumers, to access accurate and tamper-resistant information regarding the origin, quality, and complete journey of agricultural products. As a result, issues such as data manipulation, product fraud, and lack of accountability are significantly reduced, leading to improved efficiency and reliability across the supply chain.

A significant feature of the system is the integration of QR code technology, where each agricultural product is assigned a unique identifier linked to its blockchain record. By scanning the QR code, consumers can retrieve detailed and verified information about crop origin, cultivation practices, harvesting details, and farmer identity. This capability enhances product transparency and empowers consumers to make informed purchasing decisions based on authentic data. Additionally, the incorporation of real-time tracking and immutable record-keeping strengthens operational efficiency, minimizes post-harvest losses, and enhances trust among all stakeholders in the agricultural ecosystem. Overall, the system demonstrates the practical applicability of blockchain technology in improving agricultural supply chain management and ensuring a more transparent and trustworthy food distribution network.

Future Scope

The proposed system offers significant opportunities for further enhancement and expansion. One of the primary improvements involves the development of a mobile-based application to increase accessibility and usability, particularly for users in rural and remote regions. A mobile platform would simplify QR code scanning, product tracking, and real-time information access, thereby improving user engagement and convenience.

Future enhancements may also include the integration of Internet of Things (IoT) devices to capture real-time environmental parameters such as temperature, humidity, and storage conditions during transportation and storage. This would further improve product quality monitoring and enable more precise supply chain control. The incorporation of smart contracts can automate various processes, including payments, order validation, and transaction verification, thereby reducing manual intervention and improving system efficiency.

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