Enhancing Transparency In Organic Food Supply Chains Using Blockchain Technology

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Abstract

The proposed work leverages blockchain technology to ensure the authenticity and integrity of organic food products across the supply chain. The process begins with farmers recording details about their produce, including origin, cultivation methods, and certifications. These records are securely stored in the blockchain, where the decentralized structure ensures data remains immutable, safeguarding it against tampering. As the produce progresses to the processing stage, additional information is documented, such as dispatch dates, processing activities (e.g., sorting, washing, or packaging), and acquired certifications. Each update is added to the blockchain, creating a transparent, tamper-proof ledger of events. Once processing is complete, the goods are sent to distributors. Key details, including the dispatch date and distributor information, are securely recorded. To ensure end-to-end traceability, each batch of goods is assigned a unique QR code containing its full history. Scanning this QR code directs users to a secure website that provides comprehensive batch details, including its origin and processing timeline. This proposed system enhances consumer trust by offering full transparency and ensures the authenticity of organic products through blockchain's secure and immutable structure. By preventing data tampering, it sets a higher standard for verifying organic food products and maintaining supply chain integrity.

Key words: Smart contract, Supply Chain, Traceability, Blockchain, Decentralized, Ethereum, Proof of Stake

1. Introduction

Blockchain is a decentralized, distributed ledger technology designed to enable secure, transparent, and tamper-proof record-keeping. Unlike traditional centralized databases, blockchain's decentralized nature ensures that no single entity controls the data, enhancing security and trustworthiness. Initially developed as the foundation for cryptocurrencies like Bitcoin, blockchain's applications have expanded across various industries, including finance, healthcare, and supply chain management. Its ability to provide immutable records and establish trust among stakeholders makes it particularly relevant to addressing transparency issues in supply chains.

Transparency in supply chains is critical, especially in the organic food sector, where consumers demand verifiable proof of authenticity and quality. Traditional supply chains often lack efficient and reliable traceability mechanisms, leading to data tampering, inefficiencies, and mistrust among stakeholders. This lack of transparency undermines consumer confidence and creates challenges for businesses trying to validate the organic nature of their products. A robust system is required to ensure accountability, traceability, and trust throughout the supply chain.

Verifying the authenticity of organic food products presents significant challenges. Information asymmetry between stakeholders creates mistrust, while centralized storage systems are prone to tampering and unauthorized modifications. Additionally, reliance on manual paperwork increases the risk of errors and fraud, making it difficult to establish a trustworthy record of the product's journey. These challenges necessitate a decentralized, transparent solution that ensures the integrity of the data and fosters consumer trust.

The proposed system leverages Proof of Stake (PoS) as its consensus mechanism instead of Proof of Work (PoW). PoW, widely used in cryptocurrencies like Bitcoin, requires miners to solve computational puzzles, consuming significant energy and resources. In contrast, PoS selects validators based on their staked collateral, making it far more energy-efficient (99.95% less energy consumption) and cost-effective. PoS also processes transactions faster and discourages malicious activity by penalizing validators who attempt to tamper with data. These advantages make PoS an ideal choice for a sustainable and secure supply chain solution.

To address these challenges, a blockchain-based system is proposed to enhance transparency and authenticity in the organic food supply chain. The solution uses Ethereum blockchain technology with PoS consensus to record and verify transactions across the supply chain stages. Each batch of organic food is assigned a unique QR code linked to detailed product information stored on the blockchain. The Office of Food and Agriculture (OFA) validates the entries to ensure product authenticity. By providing a tamper-proof, decentralized system, the proposed solution empowers consumers with verifiable information about their purchases, fostering confidence and trust in organic certifications.

2. Related Works

[5] Patrick Burgess et al. (2024) explore rising consumer demand for transparency in sustainable food production, highlighting challenges for supply chains to address diverse stakeholder information needs. Using a mixed-methods approach, the study identifies 14 critical information requirements categorized into product quality, production processes, and sustainability. Experts prioritized product quality and safety, origin, and nutritional content as top concerns, emphasizing consumers' need for verifiable assurances. The researchers propose blockchain technology as a solution for securely capturing and sharing this information across supply chains. Blockchain's transparency and traceability can enhance data reliability, supporting informed consumer choices and advancing sustainability in food supply chains. [6] Sachin Yele et al. (2024) explores innovation measurement techniques in businesses, emphasizing the divergence between experts on analyzing mechanisms versus outcomes. It synthesizes academic and industry insights, combining empirical findings to develop a comprehensive framework for evaluating innovation. Highlighting the multifaceted nature of innovation, the research argues for broader approaches, as single metrics often fail to capture its complexity. It underscores the continuous nature of innovation, shaped by R&D, engineering practices, sustainability, and consumer needs. The study critiques existing tools' validity and proposes an inclusive framework that integrates diverse perspectives to better understand and quantify innovation within organizations for competitive advantage. [1] Claudia Cozzio et al. (2023) examines blockchain's role in enhancing food traceability and transparency. Blockchain enables consumers to verify a product's origin, boosting trust in locally sourced foods and influencing positive behaviors. However, while suppliers recognize blockchain's benefits, concerns about data sharing and intra-organizational support hinder adoption. The research combines consumer perceptions and supplier barriers, providing a comprehensive view of blockchain's potential in food supply chains. The findings suggest that businesses must align technological investments with consumer demands and address internal barriers for successful implementation. Overall, the study highlights blockchain's ability to improve trust and transparency while navigating socio-technical challenges. Shoufeng Cao et al. (2023) introduces a blockchain-based framework to enhance sustainability in food supply chains by securely communicating sustainability attributes like environmental impact and labor practices. Blockchain's traceability ensures reliable data for consumers, empowering sustainable choices while encouraging suppliers to adopt ethical practices. The proposed multi-layered architecture secures and transparently shares immutable sustainability data, surpassing traditional labeling methods. The study emphasizes blockchain's transformative potential to create transparent, sustainable supply chains, aligning consumer values with market needs. It offers a strategic model for leveraging blockchain within Industry 4.0, addressing key challenges in sustainability communication and driving ethical practices across the food industry. Mónica Martínez-Castaneda et al. (2023) explores blockchain adoption in Spain's agri-food sector under the EU's 2023 Common Agricultural Policy (CAP). Blockchain addresses transparency, traceability, and structural issues like low competitiveness. The research identifies barriers, including limited data recording, lack of standards, and integration challenges with technologies like AI and RFID. Recommendations include leveraging existing EU traceability systems, educating stakeholders, and creating legal and technical provisions. The study highlights blockchain's potential to enhance transparency and sustainability, aligned with CAP objectives. By addressing systemic challenges, the research proposes blockchain as a transformative tool for improving supply chain efficiency and competitiveness in Spain's agri-food sector. Daksh Patel et al. (2022) highlights blockchain's transformative role in agricultural supply chains, driven by rising consumer demand for transparency in food production. Blockchain enhances traceability, food safety, and quality by securely capturing and immutably storing production data. By eliminating intermediaries, blockchain fosters direct, transparent interactions and reduces financial risks. Its traceability features empower stakeholders to verify product

authenticity from farm to store shelves. The research underscores blockchain's ability to redefine trust, making agricultural supply chains more accessible and reliable. Overall, blockchain offers a secure, decentralized platform that addresses growing consumer expectations for transparency, safety, and ethical food production practices. Hana Catur Wahyuni et al. (2024) examines food safety and halal compliance challenges in the beef supply chain, proposing blockchain as a solution. Using the Failure Mode and Effects Analysis (FMEA) method, it identifies 30 risks, with the absence of halal certification ranked highest. Blockchain's transparency and tamper-proof nature mitigate risks, ensuring traceability, food safety, and halal adherence. By securely recording transactions and data, blockchain strengthens consumer trust and reinforces halal standards. The research provides a practical solution for addressing key supply chain issues, emphasizing blockchain's potential to deliver reliable product records, prevent food safety concerns, and enhance compliance in the beef industry.

3. Proposed Work

In recent years, the food industry has faced significant challenges regarding transparency, traceability, and trustworthiness within the supply chain. To address these concerns, this project proposes a blockchain-based solution that enhances food supply chain management through unique identification, real-time updates, and rigorous verification processes. The objective is to develop a transparent and tamper-proof system that tracks and verifies each food item from production to consumption, thereby building customer trust and ensuring food safety.

Each food item, sub-package, and wholesale order is assigned a unique QR code containing critical information such as material details, the supplier's name, production date, expiration date, and batch number. This QR code enables tracking and verification of the food item throughout the supply chain. At every stage—from production through to delivery—the QR code is scanned, ensuring authenticity and confirming that the food item has not been tampered with. This tracking mechanism ensures that the recorded information is consistent with blockchain records, enhancing the integrity of the supply chain.

Customers benefit from this system by scanning the QR code on their bill or food packaging to access comprehensive details about the food item, including its origin, production process, and safety standards. This level of transparency fosters customer trust, as it provides clear and accurate information about the food they are consuming. The blockchain ledger updates in real-time with each scan, maintaining a reliable and tamper-proof record of the food item's journey from farm to fork. These real-time updates provide a transparent and trustworthy history, ensuring accountability and enhancing consumer confidence.

4. Methodology

This study presents a blockchain-based framework designed to ensure a transparent and tamper-proof food supply chain using Ethereum blockchain technology. The system integrates multiple stakeholders, including Farmers, the Official Food Authority (OFA), Distributors, and Retailers, who interact through a Flutter-based user interface (UI) supported by a Spring Boot backend. The backend incorporates PostgreSQL for authentication and Web3j for blockchain interactions, ensuring secure and immutable data storage. The methodology follows a structured process, as detailed below.

4.1. Data Entry and Registration by Farmers

Farmers initiate the process by registering food products through the Flutter UI, providing essential details such as item name, quantity, production date, and farmer information. This information is transmitted via a POST API request to the Spring Boot backend, which enforces role-based authentication using PostgreSQL to ensure that only authorized farmers can submit entries. Once validated, the data is stored immutably on the Ethereum blockchain using Web3j, and a unique QR code is generated for each registered batch, linking it to the corresponding blockchain record.

4.2. Verification by the Official Food Authority (OFA)

The Official Food Authority (OFA) retrieves the recorded data via a GET API request to the backend for verification. Upon reviewing the product details, the OFA validates the information and updates the blockchain with a verification status. This step ensures that only authenticated and quality-approved products proceed further in the supply chain, preventing fraudulent or substandard goods from entering the market.

4.3. Transportation and Arrival at the Distributor

Once validated, the goods are transported to the Distributor, who scans the QR code and logs into the system via role-based authentication. The distributor records the arrival date through a POST request, updating both the PostgreSQL database and the Ethereum blockchain. This step maintains real-time traceability and ensures that all product movements are securely documented on the blockchain.

4.4. Retailer Receipt and Blockchain Update

Upon receiving the goods, the Retailer scans the QR code to access the complete transaction history. The retailer records the arrival date and confirms receipt, triggering an update to the blockchain through the Spring Boot backend. This step ensures that all supply chain activities remain securely stored on the Ethereum ledger, providing complete transparency and traceability.

4.5. Consumer Access and Final Traceability

Throughout the supply chain, blockchain updates ensure real-time, tamper-proof traceability of food products. Consumers can scan the QR code to access the entire product journey, from farm to retail, enhancing trust and transparency in the food supply chain. This methodology establishes an immutable and decentralized ledger, ensuring data integrity, authenticity, and consumer confidence.

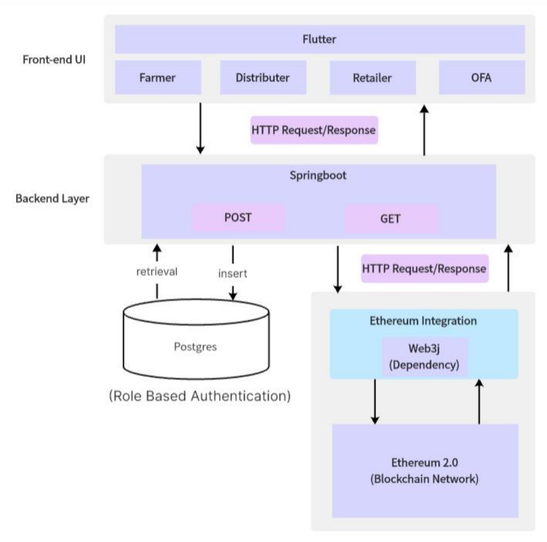

Figure 3.1 Proposed Architecture

5. Implementation

5.1. User Interface (UI) Module

The User Interface (UI) Module is designed to provide a seamless and role-specific experience for stakeholders, including Farmers, Distributors, Retailers, and the Organic Farming Association (OFA). Developed using Flutter, the application ensures cross-platform compatibility and features a role-based navigation system, directing users to interfaces tailored to their responsibilities. Farmers register goods, the OFA verifies authenticity, and distributors and retailers update arrival statuses, ensuring secure and efficient interactions within the supply chain.

Blockchain integration enables transparent and immutable record-keeping at every stage. Farmers create permanent digital records, the OFA authenticates goods, and distributors and retailers log shipments, enhancing traceability and trust. Consumers can scan QR codes to access product history, ensuring transparency. With Flutter's cross-platform capabilities, the application remains scalable and adaptable, allowing efficient updates without requiring separate iOS and Android versions. This structure supports a modern, efficient, and secure blockchain-based food supply chain system.

5.2. Role-Based Access Control (RBAC) Module

The Role-Based Access Control (RBAC) Module ensures a secure and structured framework for managing stakeholder responsibilities within the blockchain-based supply chain. Each role—Farmer, Distributor, Retailer, and the Organic Farming Association (OFA)—has clearly defined authorization rules that regulate access and prevent unauthorized modifications. Farmers are exclusively authorized to register goods on the blockchain, recording essential details such as a unique identifier and origin. This restriction ensures that only verified sources can introduce goods into the system, preserving authenticity and traceability from the point of origin. As goods progress, distributors update the blockchain upon receipt, confirming timestamped arrivals and maintaining an unbroken chain of custody.

Retailers complete the tracking process by logging the final arrival details, ensuring that consumers can verify the product's journey. The OFA acts as a validator, verifying product authenticity, ensuring compliance with organic standards, and overseeing the staking process to prevent fraudulent activity. By enforcing strict authorization rules—where only farmers can register goods, distributors and retailers update arrivals, and the OFA manages validation—the system maintains security, transparency, and data integrity. This structured approach mitigates security risks and fosters trust across the supply chain, ensuring reliable and verifiable product tracking.

5.3. Backend Module

The Backend Module serves as the middleware between the frontend interface and the Ethereum blockchain, facilitating secure and efficient communication through Spring Boot. This middleware provides RESTful APIs that enable users to interact with the blockchain without directly handling its complexities. Key operations, including goods registration, product authentication by the Organic Farming Association (OFA), arrival updates, and product data retrieval, are managed through these APIs. By maintaining a clear separation of concerns, the frontend focuses on user interactions, while the backend securely processes and executes blockchain transactions.

A critical aspect of this middleware is smart contract interaction, where predefined Ethereum smart contract functions such as registerGoods() and OFAValidateGoods() are triggered to ensure immutable and verifiable transactions. To enhance reliability, the backend incorporates comprehensive error handling, detecting failed transactions and unauthorized actions while providing real-time feedback to users. Leveraging Spring Boot's scalability and robust API management, the system ensures secure, high-performance blockchain integration, making it a reliable solution for supply chain transparency and accountability.

5.4. Smart Contract (Solidity) Module

The Smart Contract Module forms the decentralized layer of the system, leveraging the Ethereum blockchain to securely manage and store supply chain data. This layer ensures transparency and immutability, recording critical information such as goods registration, validation processes, and staking mechanisms. Built on a Proof of Stake (PoS) consensus model, the system enables the Office of Food and Agriculture (OFA) and designated validators to authenticate goods, reinforcing data integrity and reliability across the supply chain. Each product is assigned a unique identifier, allowing precise tracking from registration to distribution, while arrival updates at distributor and retailer locations are systematically recorded on the blockchain, ensuring traceability and preventing data tampering.

The OFA is authorized to verify product authenticity, ensuring only genuine and quality-approved goods enter the market. The staking mechanism incentivizes accurate validation, with rewards for trustworthy participants and penalties for malicious actions. Developed using Solidity, this module manages goods registration, staking, and validation through smart contracts deployed on Ethereum test networks like Rinkeby for optimization before mainnet deployment. MetaMask is used for transaction testing, providing an efficient interface for simulating blockchain interactions, debugging, and ensuring seamless contract execution.

Overall, this decentralized layer offers a secure, transparent, and efficient solution for managing supply chain data, validating goods, and ensuring the credibility of all participants through a well-defined staking and verification process. By incorporating Ethereum's blockchain technology and smart contract functionality, our project provides a scalable and reliable framework that supports the transparency and authenticity needs of modern supply chain systems.

6. Results And Discussions

Output Snapshots were taken on an emulated Pixel 8 on Android studio for testing the application in real world use-case scenarios from the perspective of each user namely Farmer, distributor, OFA admin and the consumer.

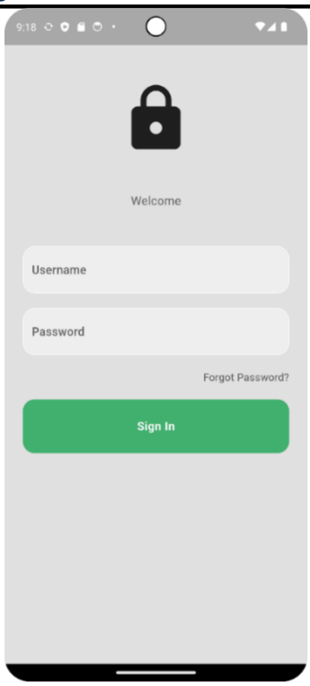

Figure 6.1 Login Page

Figure 6.1 illustrates how, using role-based access control, users such as farmers, OFA, distributors, and consumers can log in with their username and password to access role-specific pages. This ensures that each user can view only the information relevant to their role.

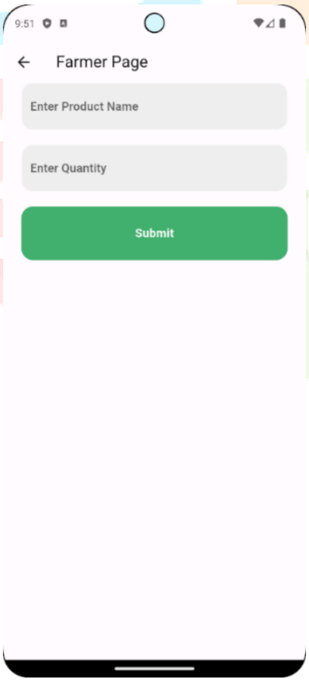

Figure 6.2 Farmer Page

Figure 6.2 shows that the farmer is the only stakeholder able to create a new block within the blockchain. Farmer enters only two pieces of information: the product name and the quantity provided to the distributor. Once the submit button is pressed, a unique UUID is generated, which is required for further processes.

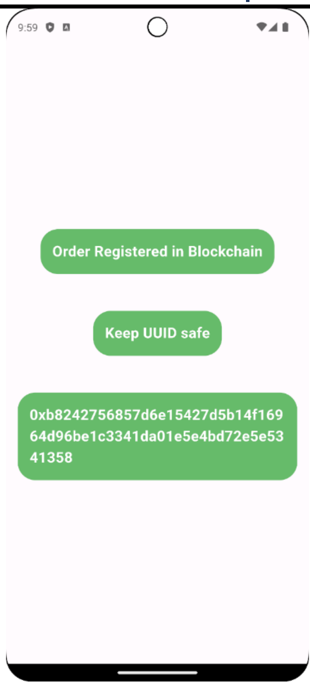

Figure 6.3 Blockchain New Block Confirmation Page

Figure 6.3 illustrates that once the farmer creates a new block within the blockchain, a confirmation is provided. The generated UUID is then shared with the OFA admin and distributor for further processing.

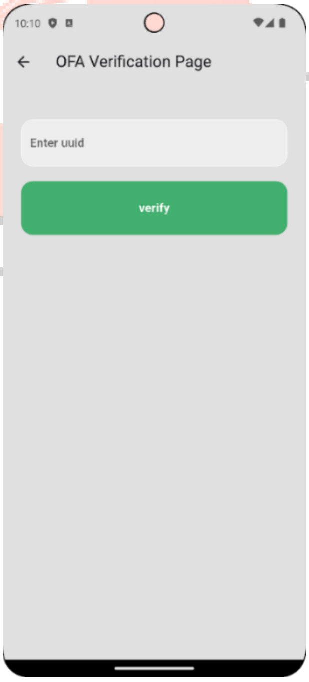

Figure 6.4 OFA Verification Page

Figure 6.4 shows that the OFA admin will approve the block only if the product and quantity in the application match those sent to the distributor. If the OFA does not approve, the distributor will be unable to update their information.

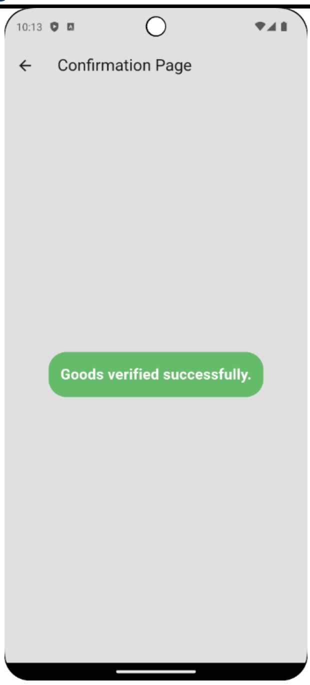

Figure 6.5 OFA Confirmation Page

Figure 6.5 illustrates that after the OFA admin verifies the goods, a confirmation page appears to indicate the success of the process. Once verification is complete, the distributor and other stakeholders can view the goods and their status.

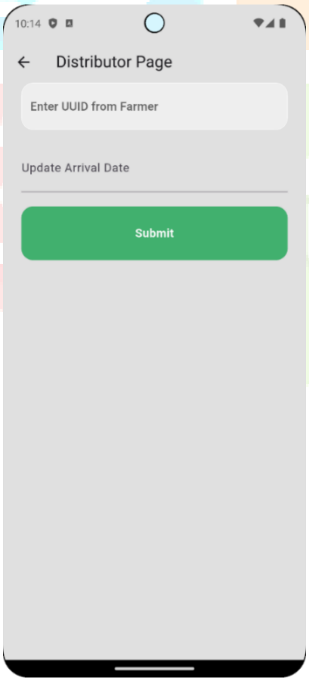

Figure 6.6 Distributor Page

Figure 6.6 shows that after the OFA verifies the goods, the distributor can use the generated UUID to update the arrival date of the goods. Once the distributor updates the arrival date, it is recorded in real-time on the blockchain for secure and transparent tracking.

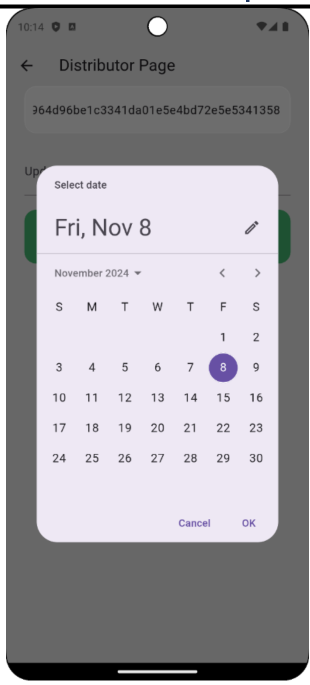

Figure 6.7 Calendar Update

Figure 6.7 illustrates that the distributor can select the goods' arrival date using a calendar and update it in the blockchain. This ensures secure and real-time tracking of arrival dates for transparency and accuracy.

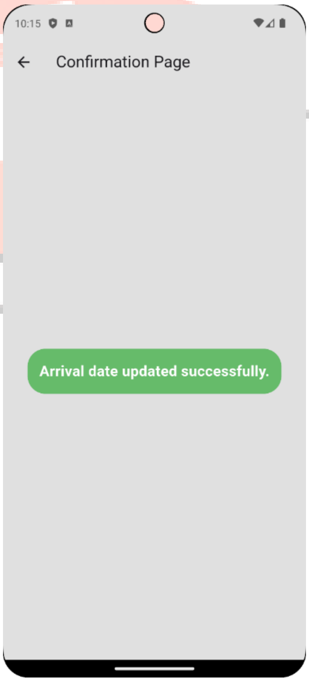

Figure 6.8 Distributor Confirmation Page

Figure 6.8 shows that after the distributor updates the arrival date, a confirmation page appears if the update is successful, confirming that the process was completed correctly. This ensures transparency and securely records the update.

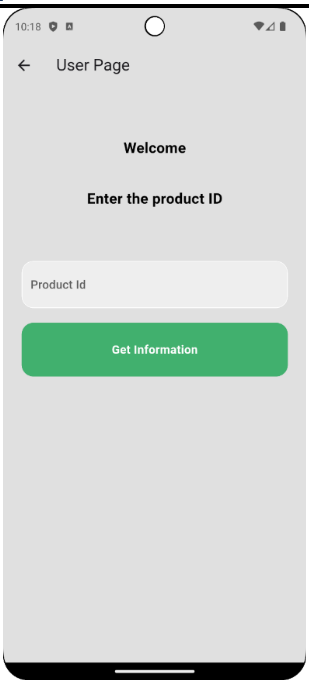

Figure 6.9 User Page

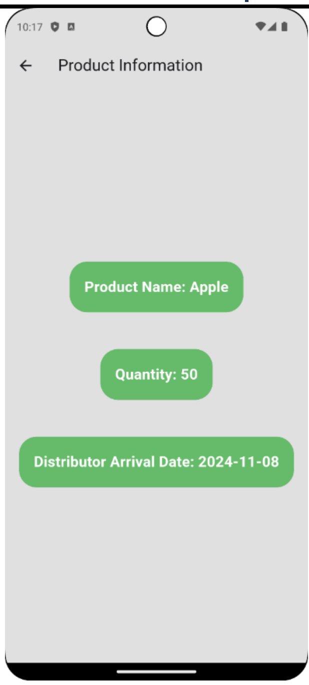

Figure 6.10 Information Display Page

Figure 6.9 illustrates how the user can enter the product ID in the text box to retrieve detailed information about the goods. This feature enables efficient searching, offering quick access to product-specific data for an enhanced user experience.

Figure 6.10 shows the product details, including the product name, quantity, and arrival date at the distributor's store, displayed for consumer verification. This feature enables consumers to confirm essential information before proceeding with their purchase decision.

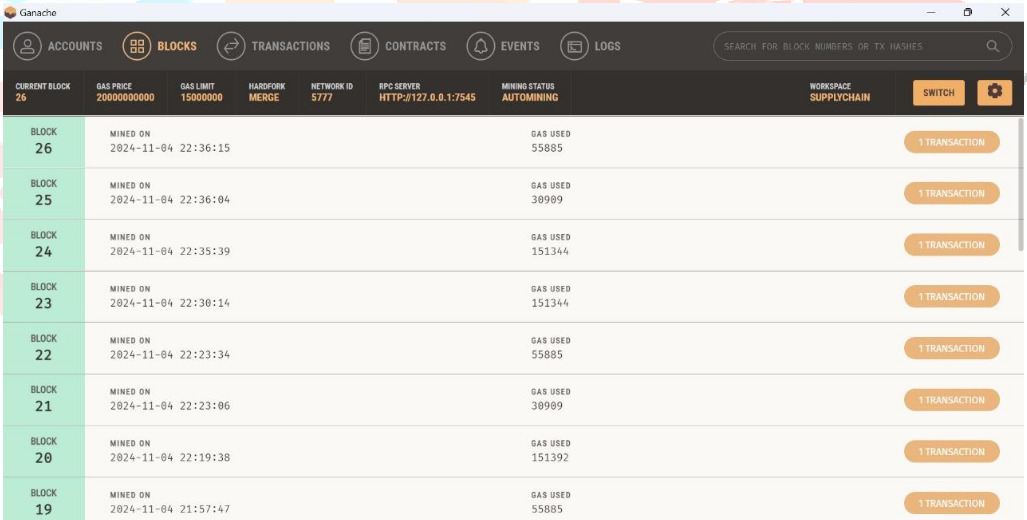

Figure 6.11 Blockchain Information

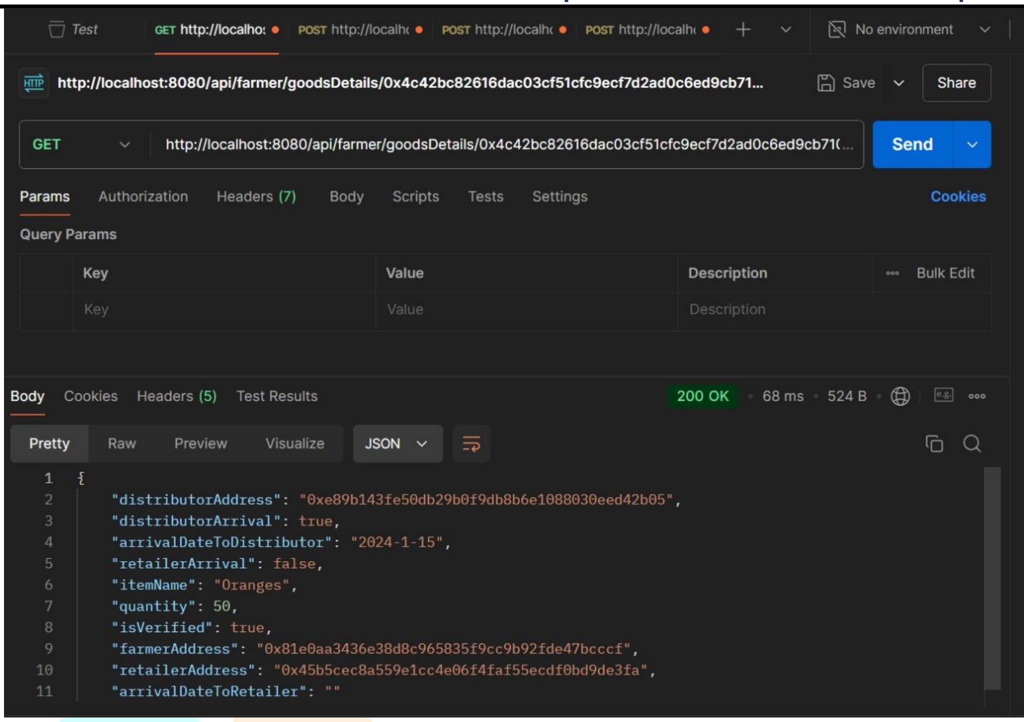

Figure 6.12 Admin View Using Postman

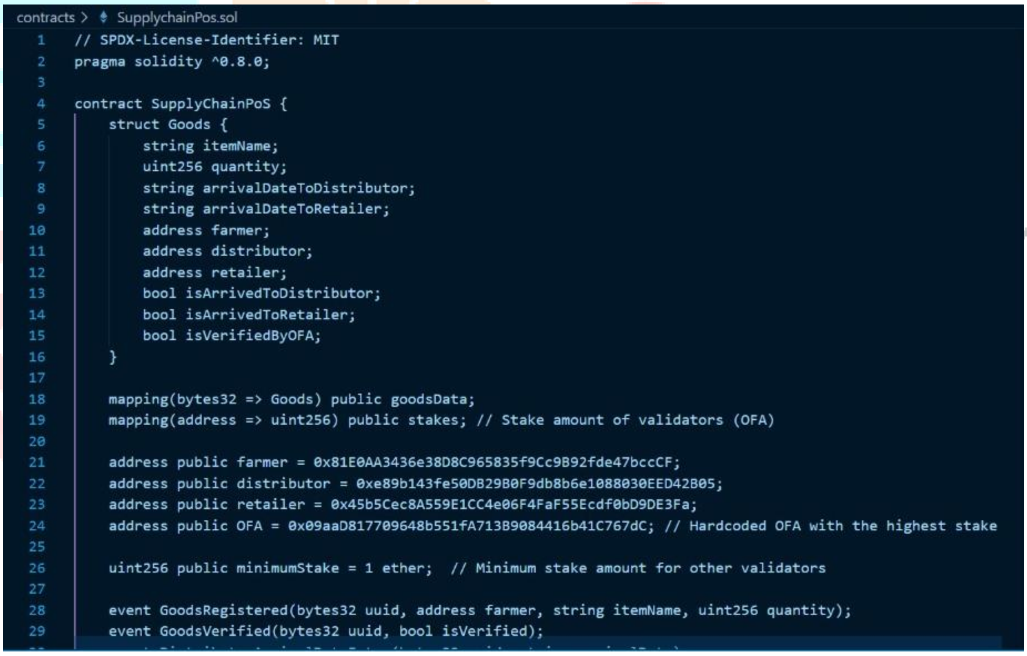

Figure 6.13 Blockchain SupplychainPos Code Snippet

Figure 6.11 displays the Ganache interface, which is used to set up a local Ethereum instance and configure 10 nodes. This setup allows for the manipulation of the blockchain, offering a controlled environment to simulate real-world blockchain interactions for testing and development.

Figure 6.12 illustrates that any admin of the system can view a specific transaction within the blockchain by entering the UUID. This feature helps maintain the integrity and security of the system by providing admins with access to crucial transaction details.

In Figure 6.13 code snippet demonstrates how blockchain functionality operates and how user access is managed. It allows for setting control levels, defining both the ability to view and modify data for each user, ensuring tailored access permissions.

Metrics	Proof of Work (PoW)	Proof of Stake (PoS)
Energy Use	Consumes **204 TWh/year** (Bitcoin alone - 2023).	Consumes **99.95% less energy** than PoW (Ethereum).
Speed	Bitcoin processes **7 transactions/second**.	Ethereum 2.0 handles **29 transactions/second** (and improving).
Cost	Mining rigs can cost **$2,000–$10,000**, with high electricity bills.	Requires staking coins (e.g., **32 ETH** for Ethereum validators).
Security	Attacks require controlling **51% of network power**, costing billions	Attacks require **51% of staked coins**, risking total loss.
Examples	Bitcoin, Litecoin.	Ethereum 2.0, Cardano.

Table 1

Table 1 highlights that Proof of Stake (PoS) offers superior efficiency by consuming 99.95% less energy than Proof of Work (PoW). It also enables faster transactions by eliminating resource-intensive mining and reduces costs by requiring only coin staking instead of expensive hardware.

7. Conclusion

This work demonstrates how blockchain enhances transparency, accountability, and trust in the organic food supply chain by creating an immutable record from farm to consumer. The system allows farmers, processors, distributors, and consumers to input and verify product details, ensuring authenticity. A user-friendly interface enables seamless access to blockchain data, with farmers logging produce details, processors recording processing data, and distributors tracking shipments. Consumers can verify authenticity through a QR code linked to the blockchain. Future improvements include mobile optimization, multilingual support, and enhanced security measures. IoT integration will enable automated data collection, such as real-time temperature monitoring. These enhancements will reduce human error and strengthen traceability. The proposed work provides a scalable framework for secure supply chain verification across industries. Blockchain's role in ensuring trust and accountability is demonstrated effectively.

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