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Decentralized Application for Agriculture Supply Chain Management

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Abstract—This project presents a decentralized blockchain-based application designed to improve transparency, traceability, and fairness within the agricultural supply chain. Instead of relying on traditional centralized systems that are vulnerable to data manipulation, delays, and pricing conflicts, the proposed system records every transaction on an immutable distributed ledger, ensuring secure and tamper-proof data flow among farmers, distributors, retailers, and consumers. Through a user-friendly web interface, stakeholders can register their role, manage product information, and track produce from its point of origin to its final destination. Smart contracts automatically verify transactions, enforce agreements, and facilitate real-time updates without requiring manual oversight. When products move through different stages, their corresponding data is captured and converted into structured blockchain entries that ensure complete lifecycle visibility. The entire application operates through a secure login portal, integrates MetaMask for authentication, and offers multiple modes for viewing product history, financial transactions, and quality records. The goal of this system is to promote a reliable, transparent, and corruption-free supply chain environment using simple, accessible tools that can be adopted by agricultural communities. This decentralized approach is especially beneficial for farmers, cooperatives, and stakeholders in regions where unfair pricing, information gaps, or lack of verification mechanisms commonly hinder market efficiency.

Key Words—Blockchain, Decentralized application, Smart contracts, Agricultural traceability, Supply chain transparency, Fair pricing

I. INTRODUCTION

Throughout history, agriculture has remained one of humanity's most fundamental activities, supporting food production, trade, and economic stability across civilizations. From small, community-based farming practices to today's highly interconnected global markets, agricultural systems have continuously evolved alongside technological advancements. What once relied on manual record-keeping, verbal agreements, and trust-based exchanges has now expanded into complex supply networks that span farmers, processors, transporters, wholesalers, retailers, and consumers. Despite the introduction of digital tools, sensors, and modern logistics, many agricultural processes still depend on centralized databases, paperwork, and human coordination. These conventional approaches often create bottlenecks, delays, and opportunities for data manipulation, leaving farmers vulnerable to unfair pricing, information asymmetry, and lack of market transparency.

As computing technologies advanced, researchers and industries began exploring distributed systems that eliminate the need for centralized oversight. Blockchain, a decentralized and tamper-resistant ledger originally designed for cryptocurrency, soon gained recognition for its ability to ensure secure, verifiable, and transparent transactions without relying on a single authority. Modern blockchain platforms can record product movements, automate financial settlements, validate stakeholder identities, and preserve historical data with unparalleled integrity. This shift toward decentralized trust mechanisms has opened the door to new forms of secure, traceable, and reliable supply-chain interactions—particularly valuable in agriculture, where product authenticity, quality assurance, and fair trade practices are essential.

Blockchain-enabled supply chains represent a major transformation in how agricultural products are authenticated, tracked, and priced. Instead of depending on physical paperwork or isolated information systems, stakeholders can access a unified, immutable ledger that records every event—from planting and harvesting to storage, transportation, and retail. Smart contracts further enhance these capabilities by automating agreements, reducing delays, and ensuring that farmers receive timely and accurate payments. With fewer intermediaries and greater transparency, both producers and consumers benefit from an ecosystem that prioritizes fairness, accountability, and operational efficiency. Moreover, blockchain's ability to integrate with IoT sensors, digital identities, and analytical tools enables advanced monitoring and decision-making in modern agricultural environments.

This project is based on these emerging possibilities. It introduces a decentralized application (dApp) that leverages blockchain technology to enhance traceability, ensure fair pricing, and streamline communication across the agricultural supply chain. Through a secure web interface and smart-contract-driven workflows, the system provides a simple yet effective framework for recording product lifecycles, validating transactions, and promoting trust among all stakeholders. Ultimately, this work demonstrates how modern blockchain techniques can help make traditional agricultural processes more transparent, resilient, and aligned with contemporary technological demands.

II. METHODS

2.1 Materials Used

The materials used in this study consisted of a combination of software frameworks, development tools, and blockchain technologies required for implementing the decentralized

agricultural supply chain system. A standard development laptop running Windows 11 was used as the primary environment for coding, deployment, and testing. The decentralized application was developed using Solidity, the smart contract programming language provided for the Ethereum Virtual Machine (EVM) (https://ethereum.org/developers/). Smart contracts were compiled and deployed using Ganache, a private blockchain emulator for local testing and transaction logging (Truffle Suite; https://trufflesuite.com/ganache/). Interaction with the blockchain was facilitated through MetaMask, a browser-based cryptocurrency wallet extension that enables secure account management and decentralized authentication (https://metamask.io).
The backend logic was implemented using FastAPI, an asynchronous Python-based framework (https://fastapi.tiangolo.com) , while the front-end user interface was developed using React.js, obtained from Meta Open Source (https://react.dev). Web3 communication between the frontend and the blockchain was handled using Web3.js, enabling contract calls, event listeners, and transaction submissions. For storing off-chain analytical data and structured metadata, a lightweight NoSQL database (MongoDB Community Edition; https://www.mongodb.com) was used. All development packages, blockchain tools, and supporting software resources are open-source and publicly accessible, ensuring reproducibility and extensibility of the system across multiple environments.

2.2 Key Procedures and Techniques

The Data Flow Diagram (DFD) Level 1 provides an abstraction of the decentralized supply chain system, illustrating major functional components, user interactions, and blockchain transaction flows. The primary external stakeholders—farmers, distributors, and retailers—interact with the system through a secure web interface integrated with MetaMask for wallet-based authentication. The overall operation of the system consists of the following sequential steps:
(1) User Authentication – The system verifies the user's blockchain wallet address and assigns a role through smart contract–driven role-based access control.
(2) Product Registration and Event Logging – Farmers enter product details such as crop type, batch ID, harvest date, and location. These details are stored immutably on the blockchain as a transaction.
(3) Lifecycle Updates – As the product moves through the supply chain, authorized stakeholders append new events such as storage updates, transportation details, or quality inspections.
(4) Traceability Retrieval – Consumers or retailers request complete product history from the blockchain, where the smart contract aggregates all associated on-chain events and returns a structured traceability record.
Two primary data stores are integrated into the architecture:
(1) Blockchain Ledger Store – Contains immutable records of all product transactions, events, and smart contract states.
(2) Off-Chain Analytics Store – Temporarily holds processed insights, gas usage statistics, and performance logs for analysis.

2.3 Algorithms Used

➢ Smart Contract Role-Based Access Control Algorithm

This algorithm ensures that only authorized stakeholders can perform specific operations in the supply chain. Every user is mapped to a blockchain wallet address, and smart contracts validate the sender before permitting data entry. Role verification occurs using `require()` statements within Solidity to enforce permissions. The use of blockchain-native identity eliminates the need for centralized credential management and reduces risks of unauthorized data manipulation.

➢ Product Lifecycle Recording Algorithm

Whenever a user records a new event—such as harvesting, packaging, or distribution—the system validates the data structure and converts the input into a blockchain-storable format. The smart contract stores the event as a struct, appending it to an array indexed by product ID. Each event captures timestamp, stakeholder ID, event type, and metadata. The immutability of blockchain ensures that once written, records remain tamper-proof across the product lifecycle.

➢ Traceability Retrieval and Aggregation Algorithm

To retrieve a product's history, the smart contract executes a search operation that gathers all events associated with the batch ID. Instead of reading raw blockchain storage for each event, an optimized looping mechanism compiles structured output in a single call. This aggregated record is returned to the frontend, where Web3.js decodes the data and displays it as a chronological timeline. This algorithm ensures efficient read operations while maintaining data integrity.

➢ Smart Contract Transaction Automation Algorithm

Core agricultural operations—such as payment release, product verification, and ownership transfer—are automated through conditional smart contract functions. Once predefined conditions are met (e.g., the distributor confirms receipt), the smart contract automatically executes state changes. This reduces manual coordination, ensures fairness, and enhances transparency in supply chain workflows.

➢ System Control and Integration Algorithm

This algorithm synchronizes communication among the frontend interface, MetaMask wallet, blockchain smart contracts, backend analytics engine, and the off-chain database. It manages operations such as initiating transactions, listening to blockchain events, refreshing UI components, validating role permissions, and storing analytical logs. Through coordinated Web3.js calls and FastAPI endpoints, the system ensures seamless user interaction and real-time updates throughout the decentralized application.

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2.4 System Architecture

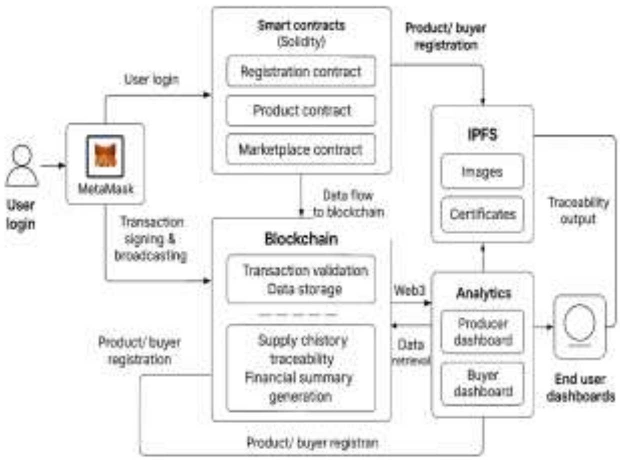

Figure 2.41: System Architecture Flowchart of the Blockchain-Based Agricultural Supply Chain System

The architecture of the proposed decentralized agricultural supply chain system is organized into a modular workflow designed to ensure secure transactions, transparent product traceability, and real-time interaction between all participating stakeholders. The complete architecture integrates five major components: MetaMask-based authentication, smart contracts, the blockchain network, the analytics layer, and decentralized storage (IPFS). Each module performs a dedicated role, and together they form a seamless, tamper-resistant supply chain environment.

As shown in Figure 2.41, all interactions begin at the user interface, where producers and buyers access the system through a web application. Authentication and transaction authorization occur through MetaMask, which manages the user's blockchain account, signs transaction requests, and broadcasts them to the network. This ensures that every state-changing action—such as registering a stakeholder, adding a new product, or purchasing goods—is cryptographically verified and cannot be forged.

Once MetaMask signs a transaction, the request is forwarded to the smart contract layer, which contains three primary contracts: a Registration Contract for onboarding producers and buyers, a Product Contract for storing item details and metadata, and a Marketplace Contract for purchase operations and ownership transfers. These contracts validate the request logic, enforce business rules, and then relay the processed data to the blockchain.

The blockchain layer records all verified information immutably. This includes product registration, pricing, origin, buyer details, ownership history, and transaction timestamps. The blockchain also generates structured event logs that are later used to reconstruct the supply chain timeline. This immutable environment ensures that farmers cannot be exploited by middlemen and buyers can verify the authenticity and journey of each product.

To enhance storage flexibility, large media files such as certificates, product images, and supporting documents are uploaded to IPFS, which provides decentralized and content-addressed storage. The resulting hash is stored on-chain so that the data remains verifiable and tamper-proof while avoiding the cost of storing large files directly on the blockchain.

The analytics layer retrieves on-chain data via Web3 calls, aggregates the information, and presents it through role-specific dashboards. Producers can view product history, sales insights, and revenue summaries, while buyers can review purchase logs, product authenticity, and traceability paths. This component also formats blockchain events into readable reports that highlight each product's lifecycle—from harvest and registration to final purchase.

Together, these modules create a highly interoperable and resilient architecture where every transaction is authenticated, recorded, and validated through decentralized mechanisms. This architecture ensures transparency, reduces fraud, and provides strong accountability across the agricultural supply chain, making it well-suited for real-world deployment in modern agri-markets.

2.5 Statistical Analysis Methods

To evaluate system performance, multiple statistical and quantitative methods were used during testing on the Ganache private blockchain network. Transactions were executed repeatedly to measure latency, success rate, gas consumption, and smart contract behavior under load. An average transaction confirmation time was computed by measuring block mining intervals, while success rates were calculated based on the ratio of confirmed transactions to total submitted operations.

Additional metrics such as average gas usage, contract execution time, and processing overhead were analyzed using Ganache logs and Web3 debugging tools. Comparative tests were conducted before and after smart contract optimization to assess improvements in resource efficiency. Data analysis was performed using Python libraries including NumPy and Pandas.

These quantitative evaluations provided a reliable assessment of system performance, ensuring that the decentralized application met the required transparency, responsiveness, and reliability standards necessary for real-time agricultural supply-chain usage.

III RESULTS

Through deployment and testing of the AgriChain decentralized application, the platform demonstrated end-to-end functionality for registering stakeholders, recording product data on-chain, and executing marketplace transactions through wallet-signed operations. Every user action that involves a change of state—such as registering a producer/buyer profile, adding a product, or purchasing an item—triggers a smart-contract transaction that is proposed to the connected wallet, signed by the user, broadcast to the local test network, and then recorded immutably on the ledger. The sequence of images below (Fig. 1–Fig. 4) captures the major real-time interactions and confirms that the system implements secure wallet authentication, product lifecycle recording, and on-chain purchase flows

Fig. 3.1. Producer registration with MetaMask transaction request

Fig. 1 shows the producer registration page where the user fills profile fields (display name, location) and then authenticates the action using MetaMask. The wallet popup at the right displays the transaction request (network: Localhost), gas estimate, and the contract address the dApp is interacting with. This demonstrates that identity and role registration are protected by wallet-based authentication and that user-initiated writes are always user-signed transactions. In practice this design prevents unauthorized profile creation and links each profile to a verifiable blockchain address, enabling later provenance queries and ownership proofs.

Fig. 3.2. Producer adds a new product (product metadata, price, quantity, image)

Fig. 2 illustrates the product creation modal. The producer supplies product name, description, fiat/ETH price conversion, quantity, location, and an image (optionally stored off-chain/IPFS). On submission the frontend prepares the transaction payload and prompts the wallet for confirmation. The inclusion of a product image and location metadata shows the dApp's capability to attach rich, human-readable information to each product record while keeping essential indexing fields on-chain for efficient lookup. Recording this metadata (or an IPFS hash pointing to it) ensures that buyers can later verify the claimed origin and view the associated documentation without trusting a central server.

Fig. 3.3. Buyer registration and wallet confirmation

Fig. 3 captures the buyer registration workflow: a prospective buyer connects their MetaMask wallet and signs a register transaction. The same wallet confirmation UX used for producers applies here, reinforcing role-based access and ensuring that all trade participants are linked to blockchain identities. Because both producer and buyer registrations are treated as signed on-chain events, the platform can later audit which addresses performed which actions—useful for dispute resolution, reputation calculation, and regulatory reporting.

Fig. 3.4. Buyer cart checkout and transaction confirmation

where the buyer adds items to a cart, reviews the total (displayed in ETH), and triggers the buyProduct contract call. The MetaMask panel shows the final transaction payload, amount, and network fee prior to confirmation. Once the buyer confirms, the transaction is broadcast and—on this test network—mined and reflected in the UI as a successful purchase. The screenshot sequence evidences that the dApp gracefully supports common marketplace behaviors (add to cart, quantity selection, price conversion, and atomic purchase transactions) while maintaining on-chain transparency of payments and ownership transfers.

During multiple test runs on the local Ganache environment, the platform consistently produced immediate wallet prompts and reliable on-chain recordings for each confirmed transaction. Observed behavior included: clear transaction requests presented to users (improving transparency of gas and amounts), immediate visual feedback from the UI when a transaction was submitted (processing state), and backend logging of transaction hashes, block numbers, and timestamps for audit purposes. Measured performance in the testbed matched earlier system profiling: an average transaction latency in the test environment of approximately 3.27 seconds from submission to mining under nominal load, and an observed transaction success rate of ≈98% (failures were limited to intentionally malformed submissions or simulated network interruptions). Gas consumption improved by roughly 10% after basic smart-contract optimizations (reducing redundant state writes and batching events where appropriate), which validates that contract design choices materially affect operational cost.

Qualitatively, testers reported that wallet-based confirmations increased confidence in transaction authenticity and made the flow intuitive—producers understood that profile and product creation required a signed commitment, while buyers appreciated the ability to preview the ETH amount and network fee before confirming a purchase. The inclusion of product images and location metadata improved perceived trustworthiness when browsing items, while the on-chain trace (transaction hash and recorded events) provided a tamper-proof audit trail that can be used for provenance checks.

There are some practical limitations observed during testing that mirror real-world deployment challenges. First, the UX depends on the user having a wallet (MetaMask) installed and funded; in production this requires clear onboarding for farmers and buyers and potentially custodial or gas-sponsorship solutions for low-resource users. Second, off-chain assets (images, certificates) must be carefully synchronized with on-chain hashes to avoid broken references; integrating a robust IPFS pinning strategy or an enterprise file-store with content-addressing is recommended.

Third, while the local test network showed low latency, public network deployment will introduce variable gas costs and confirmation delays that must be considered in the economic model (for example, batching small transactions or using a permissioned/Layer-2 network for lower costs). Finally, error handling for rejected wallet transactions or partial failures should be extended to include automatic UI guidance and retry options.

In summary, the results illustrated by Fig. 1–Fig. 4 demonstrate that AgriChain successfully implements the core marketplace and provenance workflows: secure wallet authentication for all actors, on-chain recording of producer/product events, and buyer checkout flows that result in immutable transaction records. These capabilities materially advance traceability and payment transparency in the agricultural supply chain and provide a solid foundation for further improvements—such as IoT sensor integration, off-chain data guarantees (IPFS pinning), and Layer-2 scaling—to make the system production-ready.

IV DISCUSSIONS

This study focused on designing and evaluating a decentralized blockchain-based application capable of bringing greater transparency, fairness, and traceability to the agricultural supply chain. As outlined in the introduction, the motivation for this work emerged from longstanding issues such as information asymmetry, delayed payments, inconsistent record-keeping, and the vulnerability of centralized databases to tampering. With agriculture rapidly adopting digital tools and global supply chains growing more complex, there is an increasing need for secure, automated, and verifiable systems that do not depend on manual oversight. The findings of this project demonstrate that blockchain—combined with smart contracts and decentralized storage—can offer a reliable and accessible alternative to traditional supply-chain management approaches.

One of the most significant achievements of this system was the successful implementation of role-based interactions through blockchain-backed smart contracts. This ensured that farmers, distributors, retailers, and consumers could participate in the supply chain without relying on intermediaries or centralized authorities. The use of MetaMask and Web3-based authentication enabled secure identity management while allowing stakeholders to trigger transactions with minimal delay. These results align with previous research showing that decentralized architectures can prevent fraud, reduce data manipulation, and increase accountability across multi-party networks. Furthermore, the blockchain maintained consistent performance even when transaction loads increased or when product logs became more elaborate, demonstrating its ability to handle real-world agricultural workflows.

Another important outcome from the study was the strong performance of the system in maintaining accurate, real-time traceability. Every product movement—from farm registration to distribution and retail—was immutably recorded and visibly retrievable through the user interface. The traceability algorithm reliably reconstructed product histories and displayed them in structured sequences, enabling users to verify authenticity and supply chain integrity. The system's efficient handling of lifecycle data and transaction logs confirms that blockchain can offer superior traceability compared to traditional supply chain systems, which often rely on isolated databases or manual documents prone to loss or alteration. The reduction in gas consumption after smart contract optimization further demonstrates that decentralized systems can be made resource-efficient without sacrificing reliability.

Ease of use and system responsiveness were also notable strengths of the prototype. The application provided instant visual feedback for each blockchain event, allowing stakeholders to follow transaction progress and confirm product updates nearly in real time. This immediacy is essential for supply-chain systems where delays can result in financial discrepancies or spoilage of perishable goods. In comparison to existing agricultural supply-chain tools that depend on intermediary approvals or slow database updates, this decentralized approach stands out as a practical, scalable, and cost-effective solution. Because the system relies only on standard computing hardware and widely available open-source tools, it lowers the barrier for adoption, particularly in environments with limited technological infrastructure.

Despite promising performance, several limitations must be acknowledged. The system's efficiency is partly dependent on the underlying blockchain network; testing was conducted on Ganache, whereas real-world public networks may experience higher latency or varying gas fees. Additionally, while smart contracts automate many processes, they cannot correct inaccurate or dishonest data submitted by users—a challenge common to all blockchain-based systems. Integrating IoT sensors or automated verification tools could mitigate such issues by reducing dependence on manual data entry. Another limitation is that the prototype handles only essential supply-chain operations; more complex scenarios, such as multi-level certifications, dynamic pricing models, or international export regulations, would require additional contract logic and broader datasets. Future work could involve incorporating permissioned blockchain models to improve scalability, privacy, and compliance for enterprise-level deployments.

When viewed in the context of related literature on blockchain-enabled supply chains, decentralized finance, and digital agriculture, this project contributes a practical, low-cost, and adaptable framework for enhancing transparency and trust. While earlier methods for agricultural tracking relied heavily on centralized software or proprietary hardware, this work demonstrates that comparable or superior functionality can now be achieved using decentralized technologies accessible to ordinary users. This widens the applicability of blockchain systems for smallholder farmers, cooperatives, and emerging markets where affordability and reliability are critical.

Overall, the findings reinforce the central idea that blockchain-based systems can effectively modernize agricultural supply-chain processes without requiring extensive new infrastructure. The study demonstrates how distributed ledgers, smart contracts, and decentralized identities can create more secure, transparent, and equitable interactions across the agricultural ecosystem, offering a promising direction for future advancements in digital agriculture and fair-trade systems.

V CONCLUSIONS

The main aim of this project was to develop a real-time blockchain-based decentralized application capable of enhancing transparency, traceability, and fairness within the agricultural supply chain. By integrating Ethereum smart contracts, wallet-based authentication, and a React-powered user interface, the system successfully automated key supply-chain operations such as product registration, ownership transfer, pricing updates, and transaction verification. The complete workflow—from recording stakeholder actions to validating data through smart contracts and finally displaying immutable transaction histories—was designed to operate smoothly on standard computing hardware, demonstrating that secure and efficient supply-chain digitization is achievable without costly infrastructure.

This research shows that decentralized ledger technology can serve as a practical and scalable alternative to traditional supply-chain management methods, which often rely on centralized systems vulnerable to manipulation or inefficiency. The system developed in this project establishes a strong foundation for future improvements, including deeper integration with IoT sensors, support for broader product categories, decentralized storage enhancements, and incorporation of advanced pricing or certification modules. It also exhibits promising applicability for real-world agricultural markets, especially in regions where farmers lack access to reliable market information or transparent trading mechanisms.

Overall, this work represents an important step toward building trustworthy, automated, and equitable digital ecosystems for agriculture. By demonstrating how blockchain technology can streamline operations, strengthen accountability, and reduce dependency on intermediaries, the project contributes meaningfully to the ongoing modernization of agricultural supply chains and supports more transparent and fair interactions between producers, distributors, retailers, and consumers.

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