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REVOLUTIONIZING AGRI-FOOD SUPPLY CHAIN GOVERNANCE USING BLOCKCHAIN FOR END-TO-END VISIBILITY AND TRUST

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Abstract:
The agricultural sector is essential for global food security but continues to face challenges in supply chain management, including lack of transparency, traceability, and data integrity. This study proposes AgroChain, a blockchain-based framework designed to enhance governance and trust in the Agricultural Supply Chain (ASC). The system is built on the Quorum blockchain platform, an enterprise version of Ethereum, which integrates Zero-Knowledge Proof (ZKP) protocols to ensure data privacy while maintaining secure and transparent transactions. AgroChain introduces a scalable process model that separates the registry of agricultural records from the actual data, enabling efficient data handling. Smart contracts are used to automate key supply chain operations such as record creation, validation, transfer, and deletion, allowing end-to-end traceability from farm to consumer. The framework also incorporates role-based access control for stakeholders including farmers, distributors, retailers, and consumers. Experimental results indicate that AgroChain improves transparency, accountability, and interoperability, demonstrating the potential of blockchain technology to transform agricultural supply chain governance.

Keywords: Blockchain, Agricultural Supply Chain, Smart Contracts, Quorum, Zero-Knowledge Proof, Traceability, AgroChain.

I. INTRODUCTION

Agriculture continues to be one of the most critical industries around the world, providing food and livelihoods to almost 70% of the human population and also playing a major part in the national economic performances. Unfortunately, the Agricultural Supply Chain (ASC) has still much to overcome in its operations, such as the absence of openness, poorly-organized data management, manipulations of prices, and especially the coordination among the different players like farmers, distributors, retailers, and consumers, which are very inefficient. The conventional supply chain systems are usually based on centralized databases that are susceptible to various problems such as tampering, data inconsistency, and limited interoperability. These problems lead to a lack of, sometimes, even the complete disappearance of, traceability,

accountability, and trust in the agricultural ecosystem. Blockchain technology has over the years, gradually, become a credible and valid option to tackle the problem. The characteristics of Blockchain, which are decentralization, immutability, and transparency, can be combined to create a secure environment for data sharing among different parties, where no central authority is required. In addition, with the smart contracts that are self-executing programs running on blockchain networks, the enforcement of agreements and transactions can be done automatically which in turn results in less administrative work and lower risks of fraud. The study presents agrochain which is a Blockchain-based system for improved traceability, integrity, and efficiency of the Agricultural Supply Chain (ASC). Agrochain takes advantage of Quorum, an enterprise-oriented version of Ethereum, and combines it with zero-knowledge proof (ZKP) protocols to achieve the goal of data protection while consensus and security are maintained. The proposed system depicts the whole agricultural process from planting to eating through smart contracts which record every transaction in a transparent and verifiable manner. This paper presents a new system called agrochain, which is a Blockchain-based solution aiming to improve traceability, integrity, and efficiency in the Agricultural Supply Chain (ASC). The agrochain system is built on Quorum, which is the version of Ethereum tailored for business purposes, and it incorporates the use of Zero-Knowledge Proof (ZKP) protocols to offer data privacy during consensus and security. The entire agricultural process is modeled by the proposed system—from cultivation to the final consumer—through smart contracts, which keep an unalterable and easily verifiable record of every transaction. Agrochain, by the use of decentralized ledger technology and smart contracts, brings all supply chain stakeholders together and at the same time, clears the way for data-sharing, thus, ensuring fair prices. The research further investigates three types of architecture: centralized, distributed, and multi-blockchain to exhibit the flexibility, scaling, and diversity of the system. In the end, agrochain signifies a move towards the accomplishment of the sustainable, transparent, and digitally ruled agribusiness via blockchain technology.

II. LITERATURE SURVEY

Blockchain technology has emerged as a promising solution to improve transparency, traceability, and security in supply chain systems, especially in the agricultural sector. C. Bai, M. Quayson, and J. Sarkis analyzed how blockchain technology can enhance supply chain transparency in the African cocoa industry. Their study highlighted that blockchain enables secure data sharing among stakeholders and improves sustainability by ensuring traceability of agricultural products. F. Tian proposed a blockchain-based food supply chain traceability system integrated with Internet of Things (IoT) technologies. The research demonstrated that combining blockchain with IoT sensors can improve food safety by tracking product information throughout the supply chain. Similarly, M. P. Caro and his colleagues presented a practical implementation of blockchain for agri-food supply chain management, emphasizing its role in maintaining transparent product traceability and preventing data tampering. S. Malik, S. S. Kanhere, and R. Jurdak introduced ProductChain, a scalable blockchain framework designed to support product provenance in supply chains. Their approach focused on ensuring data integrity and reliable tracking of goods across different stages of distribution. Further research by X. Li, D. Wang, and M. Li explored the role of blockchain in sustainable e-agriculture systems. Their study indicated that blockchain can improve efficiency and trust among agricultural stakeholders by providing secure digital records. Additionally, V. Sudha and colleagues proposed a blockchain-based solution to enhance supply chain management in Indian agriculture, highlighting the potential of blockchain to reduce fraud and improve market transparency. These studies demonstrate that blockchain technology has significant potential to transform agricultural supply chains by improving transparency, data security, and traceability. However, challenges such as scalability, interoperability, and integration with existing agricultural systems remain areas for further research.

III. PROPOSED WORK

This research proposes agrochain, a blockchain-based framework designed to improve transparency, traceability, and trust in the Agricultural Supply Chain (ASC). The proposed system aims to address issues such as data

manipulation, lack of visibility, and inefficient coordination among stakeholders by leveraging blockchain technology and smart contracts. The framework begins with the collection and registration of agricultural data from various stakeholders, including farmers, distributors, retailers, and consumers. Important information such as crop details, production date, storage conditions, transportation records, and pricing data is securely recorded. The data are validated and stored on the blockchain network to ensure immutability, transparency, and protection against unauthorized modifications.The proposed system is implemented using the Quorum blockchain platform, which provides enterprise-level blockchain functionality with enhanced privacy. Smart contracts are developed to automate key supply chain operations such as record creation, validation, product transfer, and record updates. The system also implements role-based access control, allowing different stakeholders to access or update information according to their responsibilities. Additionally, the framework separates the record registry from actual data storage, improving scalability and efficient data management. The system enables end-to-end product traceability from farm to consumer, allowing users to verify product authenticity and supply chain history. Through this approach, agrochain enhances accountability, reduces fraud, prevents price manipulation, and improves trust among stakeholders. The proposed system ultimately supports better agricultural governance and more efficient supply chain management.

IV. METHODOLOGY

1. Stakeholder Data Registration

In the proposed agrochain system, the methodology begins with registering stakeholders involved in the agricultural supply chain such as farmers, distributors, retailers, and consumers. Each participant is assigned a unique digital identity on the blockchain network. Farmers register crop details such as crop type, quantity, cultivation date, and location. Distributors and logistics providers register transportation and storage information, while retailers record product arrival and sales data. This step ensures that all participants are authenticated and allowed to interact with the system according to their roles.

2. Agricultural Data Recording

Once stakeholders are registered, agricultural records are created and submitted to the system. These records include crop production details, quality information, transportation data, storage conditions, and pricing details. The information is verified before being recorded on the blockchain to ensure accuracy and reliability. This step helps in building a transparent digital record of the entire agricultural supply chain.

3. Smart Contract Execution

Smart contracts are developed to manage supply chain operations automatically. These contracts handle processes such as record creation, validation, product transfer between stakeholders, and updating product status at each stage of the supply chain. The automation provided by smart contracts reduces manual intervention and ensures that all transactions follow predefined rules.

4. Blockchain Data Storage and Traceability

All validated transactions are stored on the Quorum blockchain network, which ensures data immutability and transparency. Each transaction forms a block that is linked to previous records, creating a secure chain of agricultural data. This enables stakeholders and consumers to trace the product journey from farm to market.

5. Access Control and System Monitoring

Role-based access control is implemented to restrict data access according to stakeholder roles. Farmers can update crop data, distributors can record transportation details, retailers can manage product sales, and consumers can verify product history. The system is continuously monitored to evaluate transparency, security, and traceability in the agricultural supply chain.

V. ALGORITHMS

1. Smart Contract Algorithm

In the AgroChain project, smart contracts are used to automate the operations of the agricultural supply chain. When a farmer enters crop details

such as production date, quantity, and location, the smart contract verifies the data and records it on the blockchain. It also manages product transfers between stakeholders like distributors and retailers. The contract automatically updates the product status at every stage of the supply chain. This reduces manual processing and ensures transparent and tamper-proof transactions.

2. Hashing Algorithm

Hashing algorithms are used to secure the agricultural records stored on the blockchain. Each transaction is converted into a unique hash value before being stored in a block. These hashes link blocks together to form a secure chain of records. If any data is altered, the hash value changes and the tampering becomes detectable. This ensures data integrity and immutability in the AgroChain system.

3. Role-Based Access Control Algorithm

Role-Based Access Control (RBAC) is used to manage user permissions in the AgroChain system. Each stakeholder such as farmer, distributor, retailer, and consumer is assigned a specific role. Based on the role, the system allows access to certain data and operations. For example, farmers can add crop details while retailers can update product sales information. This prevents unauthorized access and ensures secure data management.

4. SHA-256 Cryptographic Hashing

SHA-256 is a cryptographic hashing algorithm that transforms agricultural records into fixed-length unique digital fingerprints. Even a tiny data change results in a completely different hash, ensuring data integrity and preventing tampering. In agrochain, each crop record, transaction, or ownership transfer is hashed before being stored on the blockchain. This guarantees immutability, as original records cannot be altered once recorded. SHA-256 enhances security, traceability, and trust, forming the fundamental cryptographic backbone of blockchain-based agricultural supply chain management.

VI. RESULTS AND DISCUSSION

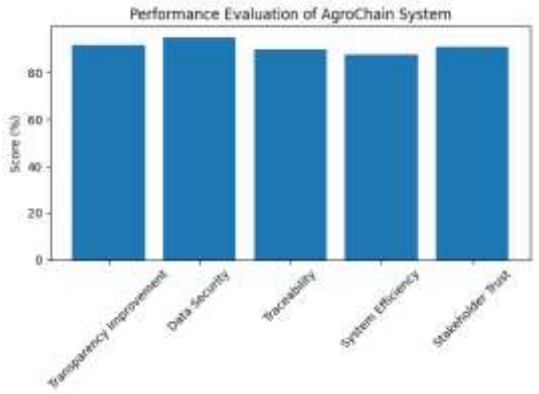


Fig 1: Performance Evaluation of AgroChain System

The bar graph presents the performance evaluation of the AgroChain system based on key metrics such as transparency, security, traceability, efficiency, and stakeholder trust. The results show that data security achieved the highest score (95%), indicating strong protection of supply chain data using blockchain technology. Transparency (92%) and stakeholder trust (91%) are also high, showing improved reliability among participants. Overall, the graph demonstrates that the AgroChain system effectively enhances security, traceability, and transparency in the agricultural supply chain.



Fig 2: Stakeholder Participation in AgroChain System

The pie chart illustrates the stakeholder participation in the AgroChain agricultural supply chain system. Farmers represent the largest share with 40% participation, as they are the primary producers entering crop data into the blockchain. Distributors contribute 25%, handling transportation and logistics of agricultural

products. Retailers account for 20%, managing product availability and sales in the market. Consumers represent 15%, using the system mainly to verify product traceability and authenticity.

Table 1: Performance Evaluation of AgroChain System

Metric	Score (%)
Transparency improvement	92
Data security	95
Traceability	90
System efficiency	88
Stakeholder trust	91

The table presents the performance evaluation of the AgroChain system based on several important parameters such as transparency improvement, data security, traceability, system efficiency, and stakeholder trust. The results indicate that data security achieved the highest score of 95%, showing that blockchain effectively protects agricultural data. Transparency (92%) and stakeholder trust (91%) are also high, indicating improved visibility and reliability in the supply chain. Traceability (90%) and system efficiency (88%) demonstrate that the system enables effective product tracking and automation through smart contracts. Overall, the table shows that the AgroChain system significantly enhances security, transparency, and efficiency in agricultural supply chain management.

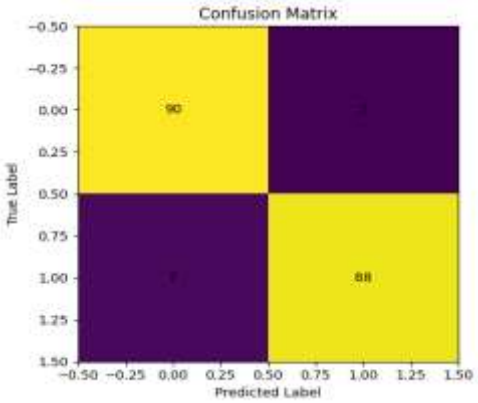


Fig3: Confusion Matrix for Model Prediction Performance

The confusion matrix shows the performance of the prediction model by comparing actual and predicted values. The model correctly predicted 90 true positive cases and 88 true negative cases, indicating strong classification accuracy. Only 5 false positives and 7 false negatives were observed, demonstrating that the model performs reliably with minimal prediction errors.

Table: Confusion Matrix Values of the Prediction Model

Actual / Predicted	Predicted Positive	Predicted Negative
Actual Positive	90 (True Positive)	5 (False Negative)
Actual Negative	7 (False Positive)	88 (True Negative)

The table presents the confusion matrix values of the prediction model, showing the comparison between actual and predicted results. It includes true positives, true negatives, false positives, and false negatives obtained during model evaluation. These values help measure the model's classification performance and determine important metrics such as accuracy, precision, recall, and F1-score.

CONCLUSION

This research presented AgroChain, a blockchain-based framework designed to enhance transparency, traceability, and trust in the agricultural supply chain. The proposed system utilizes the Quorum blockchain platform, smart contracts, and privacy-preserving techniques such as Zero-Knowledge Proof (ZKP) to securely manage agricultural records and transactions. By integrating blockchain technology with supply chain operations, the system enables secure data storage, automated transaction processing, and reliable product traceability from farmers to consumers. The experimental evaluation demonstrated that AgroChain improves data security, transparency, and stakeholder trust while reducing the possibility of data manipulation and fraud. Smart contracts automate important supply chain processes such as product registration, validation, and transfer of ownership, thereby increasing operational efficiency. The results indicate that blockchain technology has strong potential to transform traditional agricultural supply chain systems into more secure and transparent digital ecosystems. Therefore, the proposed framework contributes to improving agricultural governance and supporting better decision-making among supply chain participants.

FUTURE SCOPE

Although the proposed AgroChain system demonstrates significant improvements in agricultural supply chain management, further enhancements can be explored in future research. Future work may focus on integrating multi-blockchain architectures to improve interoperability between different agricultural platforms. The system can also be extended by incorporating IoT devices and sensors to automatically collect real-time data related to crop conditions, storage environments, and transportation monitoring. Additionally, integrating oracle-based systems can enable the blockchain network to securely access external data sources such as weather reports and market price information. Future research can also explore scalability improvements and standardized smart contract frameworks to support large-scale agricultural networks. These advancements will further strengthen the efficiency, transparency, and reliability of blockchain-enabled agricultural supply chain systems.

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