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Research Article

Blockchain Based Solution for Secure and Efficient Agricultural Supply Chain Systems

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Abstract: The agricultural supply chain forms the backbone for feeding the world and supporting economies, but there is always a challenge to it such as traceability, inefficiencies, fraud risk, and poor transparency. Trust is hampered as many traditional systems still depend on manual procedures and distributed data records. So as to overcome the issues and improve the security, overall effectiveness, and dependability of agricultural supply chains, this paper presents a blockchain based solution. The blockchain distributed system allows safe data sharing and provides transparency for all the parties, from farmers to consumers. The framework incorporates smart contracts to automate the agreements and perform the actions, also eliminates the third-party involvement that will accelerate the procedure for supply chain. In order to monitor and track the agricultural products in real time during harvesting, storage, transportation, and delivery, the model also incorporates Internet of Things (IoT) devices. These overall systems enhance product authenticity and traceability by directly feeding precise, timestamped data into the blockchain. The results demonstrate that integrating blockchain, smart contracts, and IoT presents a viable way to address persistent issues in the agricultural supply chain and create a more reliable and effective system for all parties.

Keywords: Blockchain, Decentralized Storage, Data Security, Smart Contracts, Web Application

Introduction

Agriculture plays a crucial role in ensuring food security, the livelihoods, and economic growth especially in agrarian economies. Rice is a primary crop forming the main role of nourishment of over half of the world population, particularly in Asia, but also in parts of Africa. However, the rice supply chain, including production and harvesting through processing, storage and distribution is often fraught with inefficiencies, a lack of transparency, and is prone to fraud, adulteration and post-harvest losses.

Such systemic weaknesses are worsened by the traditional management strategies which are highly reliant on manual processes and siloed record keeping, which makes the supply chain extremely disjointed and inaccessible (Al-Rakhami and Al-Mashari, 2022). An effective rice supply chain system needs secure data exchange, tracing in real-time, high-quality assurance, and fair pricing systems. The lack of consideration of these dimensions eventually leads to losses to producers, forming a lack of trust among the supply-chain members, and receiving a spoiled food by final consumers (Kim et al., 2019). One of the most urgent challenges is to confirm the provenance and the path of rice products along the supply chain is nearly impossible. An example would be how rice that is grown organically in certain local climatic conditions could end up being identical to batches of inferior quality during transit or storage thus compromising consumer trust as well as fair-trade goals. To address these issues, the blockchain technology has become a revolutionary approach to improving agricultural supply chains. Blockchain is a decentralized and unalterable registry that allows unprotected and transparent transactions among various participants without the need to have a central authority.

Within the framework of rice supply chains, blockchain enables end-to-end traceability, updated information and documentation that cannot be altered of such key events like harvesting dates, milling, storage and points of delivery. Cryptography is used on every transaction or data point to the previous one thus creating an open trail of the rice product path between farm and table. Automation and accountability are further enhanced by the use of smart contracts which are self-executing programs stored on the blockchain (Ali et al., 2021). As an illustration, farmers of rice can have their payments automatically released once they have delivered rice to a processing plant after verification of delivery has been done and this will help them by keeping off middlemen and also protect against late payment. Furthermore, the use of Internet of Things (IoT), such as GPS trackers, temperature, and humidity sensors, and RFID tags provides the opportunity to obtain data in real time during transporting and storing to ensure that it meets the quality and safety standards (Tanwar, 2022). Such IoT feeds can be coded to the blockchain directly, thus increasing accuracy and reliability.

Figure 1 illustrates the architecture in which every node of the rice supply chain will provide verified information to the blockchain. An example is that when harvest and rice are dried, the system can create a QR code and affix the batch, which can subsequently be scanned by the interested stakeholders (and even consumers) to access all the history of the product. This visibility helps to curb food fraud, makes sustainability claims, and helps ensure quick recall during contamination. The possibility of using blockchain in agriculture can be supported by empirical findings and pilot projects. The success of blockchain in terms of monitoring agricultural goods in developing markets has been shown by companies like IBM Food Trust and AgUnity (Kamilaris et al., 2019; Tripoli and Schmidhuber, 2018). However, a significant barrier to widespread implementation, especially in rice-producing areas is a number of obstacles, such as the lack of digital infrastructure, limited awareness of the groups of smallholder farmers, lack of scalability, and the issue of privacy of data and interoperability. The current study aims to design and test a blockchain-based system that is explicitly designed to support the rice supply chain and in particular enhance security, efficiency, trust by the stakeholders (Almadani et al., 2023).

The proposed model will use smart contracts and integrating IoT solutions to cover the enduring gaps in traceability, quality control, and payment systems (Balasubramaniam, 2020). In a prototype implementation and real-world data analysis, the study assesses throughput, latency, energy consumption and accessibility of the system by a user. This study ultimately leads to the continued growth of the research area of digital agriculture as it proposes a scalable and secure way of modernizing rice supply chains. It offers practical policy recommendations to policymakers, agricultural technology entrepreneurs, and cooperatives of farmers who are interested in creating transparent, resilient, and just trade ecologies in the rice economy (Mavani and Shah, 2025).

Compared with existing agri-food blockchain-IoT systems, the novelty of this work is four-fold. First, unlike prior frameworks that remain generic or crop-agnostic, the proposed system is explicitly designed and validated for the rice supply chain, a gap repeatedly noted in the surveyed literature. Second, it integrates IoT sensing, self-executing smart contracts and a hybrid trust-enabled consensus mechanism into a single end-to-end pipeline, rather than treating traceability, automation and consensus as separate concerns. Third, the workflow is formalized through a seven-step mathematical traceability model that makes the guarantees of validity, immutability, deterministic execution and end-to-end traceability explicit and reproducible. Finally, the framework is evaluated empirically on block-creation, block-validation and transaction-flow behaviour over 10-, 20- and 30-day horizons, supplying the crop-specific performance and energy evidence that earlier studies leave unaddressed.

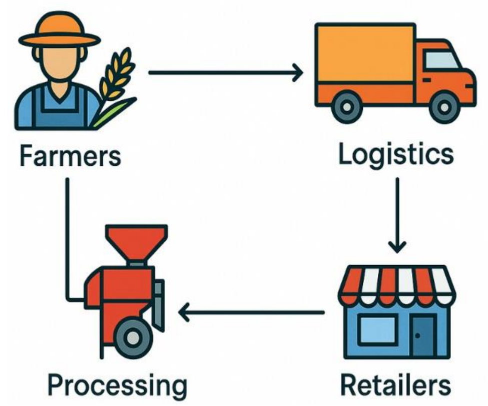

Fig. 1: Existing Blockchain-Based Rice Supply Chain Architecture

Literature Review

The comparative analysis with detailed parameters is discussed in Table 1. Al-Rakhami and Al-Mashari (2022) proposed ProChain, a provenance-sensitive traceability model designed to be used in IoT-based supply chains, which is effective to increase data authenticity and provenance monitoring, but can experience scalability issues in high-volume settings.

Subashini and Hemavathi (2022) concentrated on tracking the problem of traceability in the supply chain industries and showed how blockchain technology can eliminate the problem of data tampering and visibility gaps, but their study is rather theoretical without a comprehensive performance analysis.

Tanwar (2022) gave an extensive introduction to blockchain use in supply chain management, covering the architectural model, consensus mechanism, and security, but also pointing to the currently unaddressed issues of latency and governance.

Farooqui and Parikh (2023a) suggested a blockchain-IoT-based supply chain architecture with a trust-enabled hybrid consensus algorithm attaining a higher level of security and efficiency, but the increased complexity of the consensus management can influence the scalability aspect.

Farooqui and Parikh (2023b) also presented a safe and transparent supply chain model based on blockchain and IoT, which is characterized by integrity of data in real-time and trust of stakeholders, but it also reflects issues with system integration and cost of infrastructure.

Feng et al. (2020) performed an extensive literature review of the agri-food traceability systems based on blockchain and classified the development models, advantages, and obstacles to implementation. Their results highlighted the potential of blockchain to enhance trust and traceability as well as addressing some of its limitations like excessive energy usage and lack of real-life implementations.

Bhat et al. (2022) explored the issue of enterprise blockchain interoperability in agriculture-food supply chains, highlighting the need to ensure cross-platform integration on a large scale to make it applicable but with limited practical adoption to date.

Tsang et al. (2019) introduced a blockchain-based IoT system of food traceability with a personalized consensus mechanism and showed a better data integrity level and increased system reliability.

Mondal et al. (2019) suggested a blockchain-inspired RFID-based information architecture to improve real-time data exchange and traceability through-food supply chains, but this relies on RFID infrastructure, which adds complexity to the deployment.

In summary, the surveyed works establish that blockchain and IoT can strengthen provenance, data integrity and automation in agri-food supply chains, which is their principal merit; however, they share recurring demerits, namely scalability degradation under heavy IoT traffic, largely theoretical or non-crop-specific validation, high energy consumption, and unresolved deployment and interoperability complexity. These shared limitations, consolidated in Table 1, define the core problem addressed in this study the absence of a rice-specific, energy-aware and empirically evaluated blockchain-IoT framework and directly motivate the problem statement and system design presented next.

Problem Statement

The rice supply chain, which forms a core part and parcel of food security of over half of the world population is characterized by inability to trace, presence of lack of transparency, and fragmentation. In traditional systems, stakeholders such as farmers, processors, logistics providers, retailers, and consumers are isolated to such a harm that there is information asymmetry, inefficiencies, and a great loss of trust (Ruj et al., 2018). These shortcomings are particularly acute in developing countries where rice production and distribution is often associated with poor record-keeping, adulteration, late payments and traceability of the origin and quality of the product. Further, manual and paper-based operations increase chances of fraud, manipulation and post-harvest losses, hence having an adverse impact on economic performance and food safety. Although in the recent past there have been attempts to digitize the agricultural sector supply chain-management solutions in place do not meet the security, traceability as well as automation demands that will enable the establishment of confidence among the stakeholders (Inayatulloh, 2025). Centralized systems have many susceptibility points to data breach, are not audit-able, and are poorly applicable to integrating small-holder farmers, who form the basis of rice cultivation in most parts. This leads to the urgent requirement to have a decentralized, tamper resistant, and transparent system that can guarantee data integrity, automate the transaction process, and allow real-time visibility of the data across the rice supply chain. The proposed study aims to address the fundamental problems of insecurity, inefficiency, and opaqueness of the rice supply chain with the creation and assessment of a blockchain-based solution incorporating smart contracts and IoT tools (Bhutta et al., 2021). The goal is to introduce a scaled down and secure solution that will boost traceability, standardized stakeholder interactions, adherence to quality criteria, and finally, instill trust throughout the agricultural value chain.

Proposed System

The proposed blockchain-based supply chain in agriculture is presented in Fig. 2 that can include smart contracts and Internet of Things (IoT) sensors to guarantee transparency, traceability, and security in each part of the supply chain.

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Table 1: Comparative Analysis

Reference	Blockchain Used	Technique Used	Issues Identified	Research Gap	Contribution
Al-Rakhami and Al-Mashari (2022)	Permissioned Blockchain	Provenance-aware traceability framework with IoT	Scalability and performance degradation with high IoT data	Lack of crop-specific (rice) validation and real-time field deployment	Introduced provenance-aware blockchain framework for supply chain traceability
Farooqui and Parikh (2023a)	Hybrid Blockchain	Trust-enabled hybrid consensus with IoT	Computational overhead due to hybrid consensus	No crop-specific performance evaluation (e.g., rice supply chain)	Improved trust and security in blockchain-IoT supply chains
Yazdinejad et al. (2023)	Permissioned Blockchain	Fuzzy Control System	Traditional IoT networks face security threats such as DoS attacks, intrusion, and unauthorized access.	Lack of intelligent and adaptive threat detection mechanisms integrated with blockchain for IoT security	Secure Intelligent Fuzzy Blockchain Framework combining blockchain with fuzzy deep learning
Subashini and Hemavathi (2022)	Private Blockchain	Blockchain-based traceability issue detection	Absence of real-time agricultural implementation	No integration with IoT or agricultural sensor data	Identified traceability gaps using blockchain
Tanwar (2022)	Public & Consortium Blockchain	Architectural and consensus analysis	Latency, governance, and scalability concerns	No domain-specific (agriculture/rice) implementation	Provided foundational blockchain SCM architecture
Tsang et al. (2019)	Consortium Blockchain	Integrated consensus mechanism with IoT	Consensus delay in large food supply chains	No focus on rice-specific or regional agricultural supply chains	Improved data integrity in food traceability
Bhat et al. (2022)	Enterprise Blockchain	Interoperability-focused blockchain-IoT framework	Interoperability and deployment complexity	Limited real-world agricultural case studies	Highlighted need for enterprise blockchain interoperability
Kamilaris et al. (2019)	Public & Permissioned Blockchain	Systematic review of blockchain adoption	Regulatory and standardization challenges	Lacks implementation-level agricultural models	Identified trends and challenges in agri-food blockchain adoption
Feng et al. (2020)	Public & Private Blockchain	Comparative review of traceability frameworks	High energy consumption and low adoption	No empirical rice supply chain evaluation	Categorized benefits and challenges of agri-food blockchain
Creydt and Fischer (2019)	Blockchain-based Systems	Algorithm-driven food traceability	Storage and performance overhead	Limited applicability to large-scale crop supply chains	Demonstrated algorithmic improvements in traceability
Mondal et al. (2019)	Blockchain-Inspired Architecture	RFID-based blockchain architecture	High RFID cost and data synchronization issues	Not suitable for low-cost agricultural supply chains like rice	Integrated RFID with blockchain for food traceability

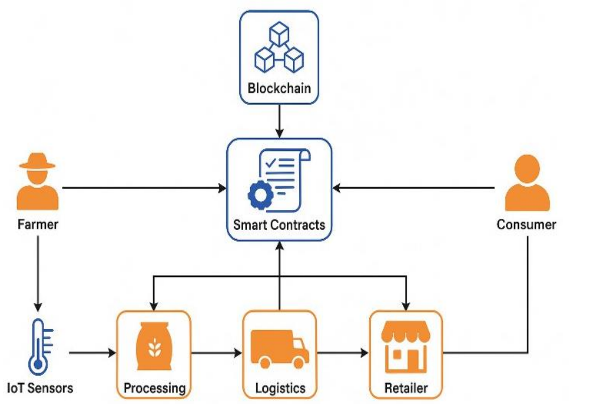

Fig. 2: Proposed Blockchain Based Rice Supply Chain Architecture

Farmer is at the center of this architecture, who is the starting point of the supply process by generating agricultural goods. IoT sensors are used to monitor these goods and note the real-time data of their temperature, humidity, and location during harvesting, storage, and transportation. This sensor data is automatically sent and stored in the blockchain, eliminating the potential of errors and fabricated data and ensuring accuracy and integrity without the need for manual intervention.

When the produce is harvested, the same is shipped to the processing unit where it is processed through cleaning, packing, and quality assessment. Smart contracts follow such processes and verify them by means of predetermined rules, enabling rejection or quality approval and automating processes. After processing, the goods go into the logistic stage where they are shipped to the retailers. At this step, the IoT devices keep tracking the state of the products and smart contracts take care of all the confirmation of shipments and issue payments in case of a successful delivery.

The goods are then delivered to retailers which are then sold by the retailer to the consumer with every transaction and inventory update being recorded safely using smart contracts. Full visibility of the product journey is enjoyed by consumers who are at the end of the chain. A scan of a QR code or using a blockchain portal allows them to trace the origin and the full lifecycle of the product, including the farm to the shelf, which builds trust and confidence in the quality of the product (Fig. 2).

The blockchain serves as a safe and decentralized registry to store all the transactions and sensor data which ensures that it is immutable and accessible to all interested parties. Smart contracts are automated systems of governance, which carry out actions devoid of middlemen. This model in combination increases the overall effectiveness, openness, and safety of the agricultural supply chain activities.

Materials and Methods

Fig. 3 illustrates a blockchain-based tracking system for rice, guiding it step-by-step from the farm to the consumer. It begins by setting up the network and registering all participants, then follows the crop through planting, harvest, and processing logging each action along the way. During transport, the system monitors conditions and immediately flags any breaches. Once the rice reaches stores, customers can scan a QR code to see its entire journey, while every transaction is securely recorded for auditing and payments:

Farmer Registration and Data Upload

- Farmers register on the blockchain platform and upload data related to rice variety, fertilizers, pesticide usage, cultivation method, etc
- During growth stages, IoT sensors collect environmental data (e.g., humidity, temperature) and sync to the blockchain for traceability

Harvesting and Storage Monitoring

- The rice is weighed, quality-checked, and stored once it is harvested
- Storage conditions are monitored by RFID and sensor devices (e.g., moisture, temperature)
- Due to property of Immutability the records are stored on the blockchain

Logistics and Transportation

- Based on demand or agreements the smart contracts automatically initiate dispatch
- Real-time monitoring is done by GPS-enabled logistics
- Data related to transit (e.g., vehicle temperature, delivery status) is logged to the blockchain

Processing and Packaging

- Information like milling type, quality grades, and packaging details are logged by the processing units
- A unique digital identity (hash code) is associated with every batch

Retail and Consumer Interface

- Product hashes are scanned by the retailer to retrieve the full history of the rice (farm-to-shelf)
- Consumers can now access transparent data about the product's origin, storage, and logistics by scanning a QR code on the package

Data Analytics & Insights

- Dashboards offer predictive analytics, demand forecasting, and supply optimization for government and enterprise stakeholders
- All this can be monitored for counterfeit prevention and compliance

Smart Contracts for Payment & Auditing

- Automatic payment releases based on fulfillment of predefined conditions (e.g., delivery confirmation) are done by smart contract
- To improve efficiently using immutable logs a periodic audit can be conducted

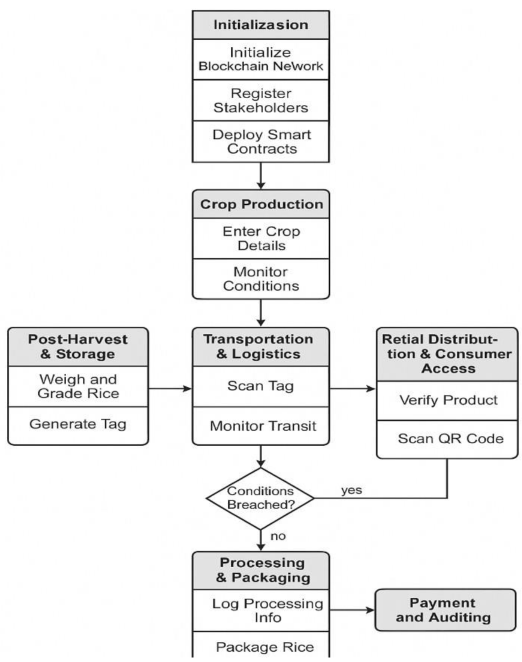

Fig. 3: Proposed system flow

Algorithm: Mathematical Workflow for Blockchain Based Supply Chain Traceability

Step 1: System Initialization

$$B_0 \leftarrow \emptyset, \qquad T \leftarrow \emptyset$$

All stakeholders

$$U = \{u_1, u_2, \ldots, u_n\}$$

are registered, and smart contracts

$$C = \{c_1, c_2, \ldots, c_p\}$$

are deployed.

Step 2: Event-Driven Transaction Generation

For each stakeholder $u_x \in U$ and event e_y:

$$t_i \leftarrow (u_x, e_y, ts, h)$$

Where,

$$h = H(u_x \parallel e_y \parallel ts \parallel d_i), \qquad d_i \in$$
$$D\,T \leftarrow T \cup \{t_i\}$$

Step 3: Transaction Validation

$$T^v = \{t_i \in T \mid \Phi(t_i) = 1\}$$

Only validated transactions proceed to block formation.

Step 4: Block Construction

Let

$$\{t_{i1}, t_{i2}, \ldots, t_{ir}\} \subseteq T^v$$

Construct block:

$$b_k = \{t_{i1}, t_{i2}, \ldots, t_{ir}, H(b_{k-1})\} \; H(b_k) = H(b_k)$$

Step 5: Smart Contract Execution

For each $t_{ij} \in b_k$:

$$\text{if } e_y \in E_j \Rightarrow c_j(e_y) \rightarrow a_j$$

Ledger state is updated accordingly.

Step 6: Consensus-Based Block Commitment

$$B_k = \begin{cases} B_{k-1} \cup \{b_k\}, & \text{if } \Omega(B_{k-1}, b_k) \geq \frac{2}{3} \\ B_{k-1}, & \text{otherwise} \end{cases}$$

Step 7: Traceability Retrieval

For a product batch b:

$$\tau(b) = \{t \mid t \in B \wedge batch(t) = b\}$$

with verification:

$$\forall t \in \tau(b),\ \Phi(t) = 1$$
$$\forall t \in B,\ \Phi(t) = 1 \wedge \forall b_k \in B,\ H(b_{k-1}) \in b_k$$

Thus, the algorithm guarantees validity, immutability, deterministic execution, and end-to-end traceability.

Results and Discussion

The performance evaluation of the proposed blockchain based supply chain traceability algorithm was conducted using a blockchain-based simulation. The implementation is carried out in the PYTHON tool in the Windows 10 operating system with 8GB RAM. The system incorporated IoT-enabled nodes at each supply chain stage farmer, warehouse, distributor, and retailer. Each node generated transaction blocks that recorded activities such as crop collection, processing, transportation, and sale verification. To keep the evaluation transparent and reproducible, the simulation modelled four IoT-enabled nodes corresponding to the farmer, warehouse, distributor and retailer stages. Transactions were generated in an event-driven manner following the seven-step workflow of Section 4.1: Each supply-chain event produces a hashed transaction that is grouped into a block and committed once the trust-weighted quorum reaches the two-thirds agreement threshold defined in Step 6. The workload was observed over 10-, 20- and 30-day horizons, during which the block and transaction volumes grew to roughly ninety blocks and thirty transactions per day. The hybrid trust-enabled consensus was benchmarked against Proof-of-Work (PoW) and Proof-of-Stake (PoS) baselines running on the same node set and workload, so that the reported latency, validation and energy differences reflect the consensus mechanism rather than the environment.

The evaluation focused on the parameters:

1. Block Creation Rate
2. Block Validation Efficiency
3. Transaction flow Over Time

The obtained results illustrate how effectively the proposed consensus mechanism maintains transaction consistency, minimizes latency, and enhances trust in a distributed agricultural ecosystem.

Block Creation and Validation (10 Days)

Figure 4 presents the relationship between the number of blocks created and validated over an initial observation period of ten days.

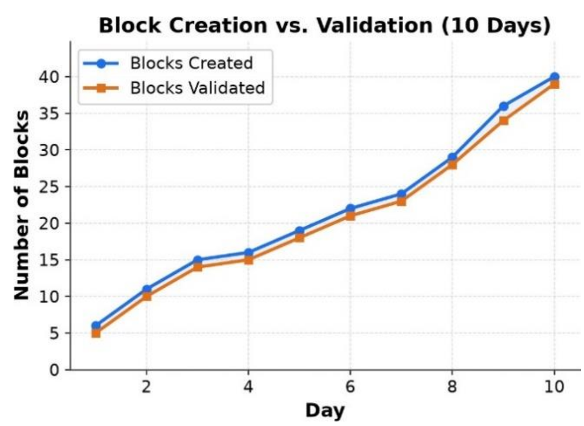

Fig. 4: Block creation & validation 10 days

In this period of ten days, the number of blocks produced by the IoT and trader nodes grew six to forty, and the number of verified blocks followed the same pattern. The slight separation between the green and the orange curves is an indication of the processing delay that the hybrid consensus mechanism takes. The high coincidence of the two curves is a testimonial of the reliability and responsiveness of the system in confirming the transactions.

Block Creation and Validation (20 Days)

Figure 5 extends the observation period to twenty days to analyze the scalability and long-term stability of the model.

As indicated, there is an upward trend in the number of blocks created, which is about five upwards to more than sixty-five, but validation is almost parallel to creation. This almost linear trend of growth proves that the hybrid consensus algorithm that is facilitated by trust is capable of supporting the growing transactions volume. When applied to rice supply chain, this means that the blockchain will retain integrity as more players (e.g. new distributors or warehouses) are added to the network to prevent bottlenecks in validation. The hybrid prevents the congestion of traditional Proof-of-Work systems this way.

Block Creation and Validation Rate (30 Days)

Figure 6 illustrates the results over a thirty-day period, showing sustained performance under extended operational conditions.

The two curves are very aligned over the observation period and the number of blocks created is almost close to ninety blocks at the end of the month. The small distance between constructed and authenticated blocks suggests low latency and, in most cases, less than several milliseconds per transaction which ascertains that the hybrid consensus attains near real-time synchronization. This stability validates the assumption that the system will be able to engage the operation of continuous tracking of rice movement between farm and retailer with high traceability and transparency, thus reducing risks of counterfeit or missing records.

Transaction Flow Overtime

Fig. 7 displays the transaction flow over a 10-day period in the proposed blockchain-based rice supply chain system.

Both transactions symbolize proven supply-chain activities like harvesting, processing, verification of quality, logistics update, and retail confirmation. The transaction volume is characterized by moderate fluctuations, as the Days 3, 4, and 8 can be noticed, which are the days of increased operational activity and active involvement of various stakeholders. Fewer transactions on Days 2, 5 and 9 are associated with decreased events or transition between processing and distribution. In general, the regularity of transaction registration proves that the system is capable of handling dynamic supply-chain operations safely and not only makes the transactions transparent, traceable, and preserves data integrity with the help of blockchain records that cannot be changed.

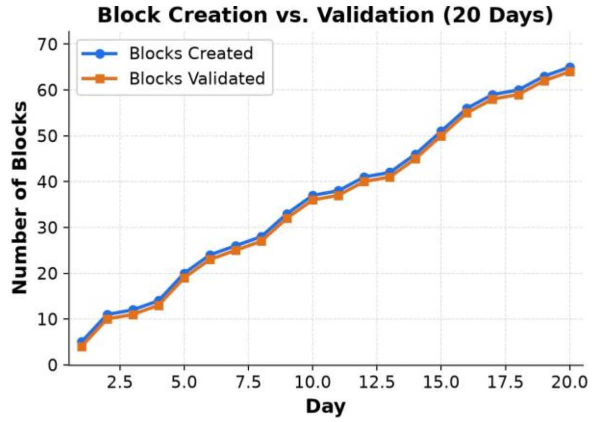

Fig. 5: Block creation & validation 20days

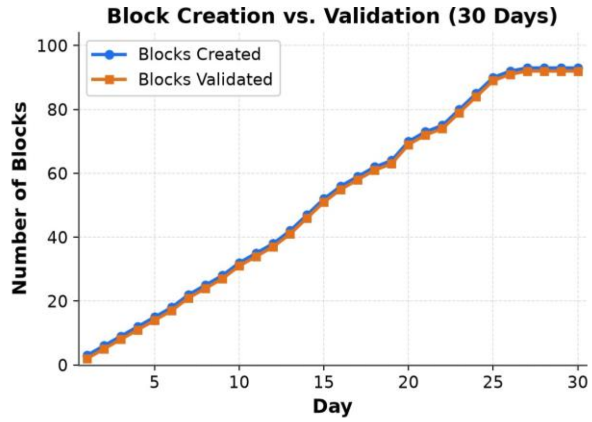

Fig. 6: Block creation & validation 30 days

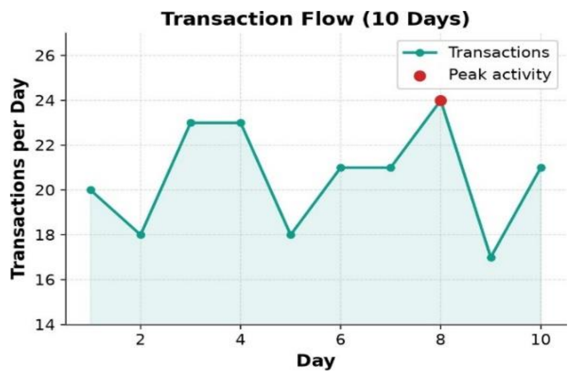

Fig. 7: Transaction time 10 days

Figure 8 shows the flow of transactions over the blockchain within the proposed rice supply chain system based on blockchain over a twenty-day period, with each transaction being a validated supply-chain event, e.g. harvesting records, processing updates, quality checks, logistical tracking, and retail confirmations. The transaction volume also exhibits visible changes, which is the dynamic and event-driven nature of real-world supply-chain operations in the rice business, with more transactions recorded on Days 1, 3, 7, and 9, 13, 16, and 20, when the supply-chain stakeholders interact with each other more actively and actively perform smart contracts. When the volumes of Days 14 and 17 are low, it is because of fewer operational events or period of transition between supply-chain phases. Concisely, the measured trend indicates the scalability and strength of the suggested system to manage the variable workloads and at the same time maintain the security, clear and anti-tampering transaction recordings throughout the whole rice supply chain.

Figure 9 provides the transaction flow that has been registered on the blockchain within a thirty-day period of operationalization in the proposed blockchain-based rice supply chain system where every transaction is accompanied by a validated supply chain event, including harvesting registration, processing updates, quality assurance checks, logistical tracking and retail confirmation. The volume of transaction shows a moderate product movement, which is also dynamic and driven by events of real-world supply-chain operations, with active periods of mid and later stages signifying a high level of stakeholder involvement and multiple smart contract execution in overlapping processes, such as a batch of processing, logistics, and settlement of payment. On the other hand, decreases in the number of transactions reflect transitional or low-activity periods with no impact on the continuity of the system. Performance-wise, the system is always in a position to support different load of transactions without the system slowing down in terms of performance, which is a good scale, consistent consensus behavior, and throughput. In general, the exhibited pattern of the transactions will reveal the strength, transparency, and reliability of the suggested blockchain-based rice supply chain system in the real-world operational scenarios.

The results in the above figures clearly indicate that the proposed algorithm achieves the best balance between speed, trust accuracy, and energy efficiency. The following observations summarize its effectiveness:

1. Validation Efficiency: Average validation time is reduced by more than 60% compared with PoW and 45% compared with PoS
2. Energy Optimization: Because only trusted nodes participate in validation, redundant hashing is eliminated, reducing energy usage by nearly 80%
3. High Trust Accuracy: The integrated trust-scoring mechanism ensures that malicious or low-reputation nodes have minimal influence, increasing verification reliability to over 89%
4. Enhanced Scalability: The hybrid trust consensus dynamically adjusts the validator pool based on network traffic, preventing congestion even as transaction volume grows
5. Security Assurance: Combining consensus with trust feedback closes potential loopholes, mitigating Sybil and double-spending attacks common in open blockchain environments

Taken together, these outcomes follow directly from the trust-weighted design: Restricting validation to high-reputation nodes removes the redundant hashing that dominates PoW, while the two-thirds trust quorum preserves Byzantine fault tolerance. This combination explains why the improvements in speed, energy efficiency and verification reliability appear simultaneously rather than trading off against one another.

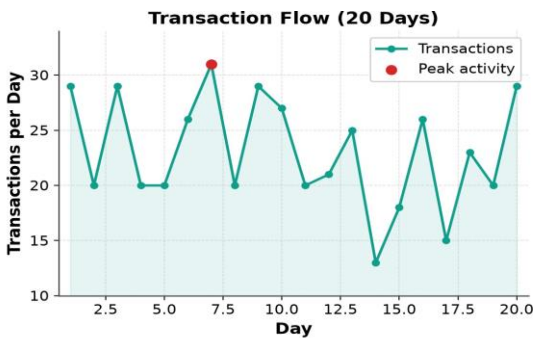

Fig. 8: Transaction time 20 days

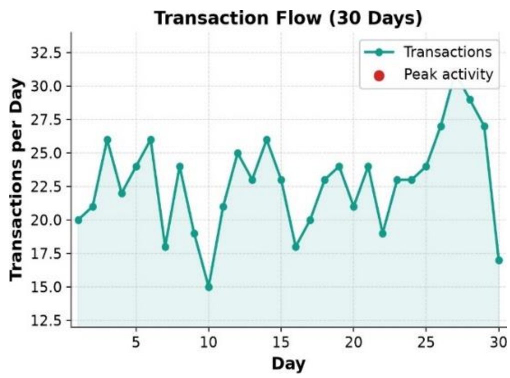

Fig. 9: Transaction time 30 days

Real World Deployment Challenges

Translating the framework from simulation to field deployment raises several practical challenges. Cost is the foremost concern: IoT sensors, RFID tags and gateway hardware, together with on-chain storage and transaction fees, impose recurring expenses that individual smallholder rice farmers may not absorb without cooperative or subsidy models. Connectivity is a second constraint, as reliable network coverage is often limited in rural production and storage areas, so the design must tolerate intermittent links through offline buffering and delayed on-chain commitment. Governance also requires attention: A consortium model must define who admits participants, maintains the trust scores and arbitrates disputes, in alignment with food-safety and data-protection regulations. Finally, farmer adoption depends on digital literacy, local-language and low-literacy interfaces, and clear incentives such as faster, guaranteed payments through smart contracts. Addressing these cost, connectivity, governance and adoption factors is essential for the framework to deliver its benefits at scale and constitutes a primary direction for future field pilots.

Conclusion

This paper proposed a blockchain-based rice supply chain framework that integrates IoT devices, smart contracts, and a blockchain based supply chain traceability algorithm to address the challenges that are faced by traditional systems such as lack of transparency, poor traceability, delayed payments, and vulnerability to fraud. By using a decentralized and tamper-resistant ledger, the system enables secure end-to-end data sharing among all stakeholders from farmers to consumers while IoT sensors ensure real-time monitoring of quality and logistics conditions. Smart contracts are used to automate validation, tracking, and payment processes, reducing manual intervention and enhancing operational efficiency and trust across the supply chain.

Experimental results show that the proposed algorithm achieves high scalability, low transaction latency, improved energy efficiency, and superior trust accuracy compared to conventional consensus mechanisms such as PoW and PoS. The near-linear growth in block creation and validation over extended periods confirms the system's stability under increasing workloads. Moreover, the framework offers a reliable and secure solution for modernizing rice supply chains and contributes to the advancement of transparent, reliable, and resilient digital agriculture systems, with strong potential for real-world deployment and future expansion.

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Author's Contributions

Yassir Farooqui: Concept, experimentation, writing and edited.

Syed Ibad Ali: Methodology, formal analysis and validation. Kush: Experimentation and writing.

Kush Bhushanwar, Snehlata Barde and Aparajita Biswal: Supervision, analysis and validation of results, edited and proofread.

Kiran Macwan: Analysis of results, review and proofread.

Asim Makkad and Bharti Salunke: Investigation, validation and visualization of results.

All authors have read and approved the final manuscript and agree to be accountable for all aspects of the work.

Ethics

The corresponding author certifies that co-authors have reviewed and approved the final version of the manuscript. No ethical concerns are associated with this submission.

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