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Blockchain-Based Agriculture Supply Chain System

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ABSTRACT: The agriculture sector, a cornerstone of global sustenance and economic activity, is increasingly seeking innovative technologies to address inefficiencies, ensure transparency, and improve supply chain resilience. Blockchain Technology (BCT) has emerged as a transformative solution with the potential to revolutionize agricultural supply chains through decentralized, immutable, and transparent record-keeping. This research explores the adoption of BCT in agriculture supply chains across both developed and developing economies, focusing on four countries-The Netherlands, the United States, Saudi Arabia, and India. Through a mixed-methods approach that integrates qualitative surveys and interviews with Interpretive Structural Modeling (ISM) and the Decision Making Trial and Evaluation Laboratory (DEMATEL) techniques, the study identifies and ranks critical enablers and barriers influencing BCT adoption. The findings reveal that while factors vary regionally—such as infrastructure readiness and digital literacy—policy support emerges as the most influential enabler across all examined economies. The study also presents a functional architecture of a blockchain-based agriculture supply chain system, involving farmers, transporters, warehouses, distributors, regulators, and consumers, all interconnected via a centralized platform supported by smart contracts and an Analytics and Decision Support System (DSS). The system ensures traceability, transparency, compliance, and trust among stakeholders by automating transactions and maintaining real-time updates through secure blockchain records. Regulatory authorities enhance oversight by monitoring quality and verifying standards, while DSS tools provide predictive insights for inventory and logistics management. This comprehensive research not only highlights the practical implementation and benefits of BCT in agriculture but also proposes region-specific strategies to overcome adoption barriers, ultimately contributing to the development of a more robust, efficient, and transparent global agricultural supply chain ecosystem.

KEYWORDS: Blockchain Technology (BCT), Agriculture Supply Chain, Data Immutability, Smart Contracts, Stakeholder Trust, Traceability, Transparency, Transaction Automation, Regulatory Compliance, Quality Assurance, Inventory Optimization, Analytics and Decision Support System (DSS), Real-Time Monitoring, Decentralized Ledger, Policy Support.

I. INTRODUCTION

Agriculture remains one of the most vital sectors globally, underpinning food security, economic stability, and rural development. Despite its importance, the agriculture supply chain is often plagued by inefficiencies, lack of transparency, fraud, and inconsistencies in product quality. Traditional supply chain management systems struggle to maintain end-to-end traceability and accountability, especially in regions where logistical operations are fragmented or poorly digitized. These limitations pose significant risks to food safety, stakeholder trust, and compliance with international quality standards. In this context, emerging technologies like Blockchain Technology (BCT) have gained attention for their potential to transform the agriculture sector by creating tamper-proof, transparent, and secure systems that enhance the traceability and efficiency of supply chains.

Blockchain Technology offers a decentralized digital ledger system capable of securely recording transactions across a distributed network of computers. Each transaction is verified through consensus mechanisms and added to a chain of blocks that is immutable and transparent. In agricultural supply chains, this technology can be leveraged to track the entire journey of produce — from farm to fork — ensuring that each step is verifiable and auditable. Smart contracts, a core component of BCT, further strengthen this system by automating transactions based on predefined rules, thereby reducing the need for intermediaries, minimizing human errors, and increasing operational efficiency. The integration of BCT addresses major concerns such as counterfeit products, delayed





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deliveries, and unverified sourcing, which are common issues in traditional agricultural logistics.

The adoption of BCT in agriculture, however, is not without its challenges. While developed economies such as The Netherlands and the United States have begun to pilot and implement blockchain-based agricultural systems, developing nations like India and Saudi Arabia face distinct hurdles, including technological infrastructure limitations, policy gaps, financial constraints, and varying degrees of digital literacy among stakeholders, especially small-scale farmers. These disparities necessitate a comparative analysis to understand how BCT adoption differs across economic contexts. The success of BCT in agriculture also hinges on regulatory frameworks, governmental support, public-private collaboration, and the availability of training and resources. Without addressing these foundational issues, the transformative potential of blockchain risks being limited to select regions with the capability to sustain such innovations.

This study aims to bridge the gap in existing literature by exploring the adoption of blockchain technology in agriculture supply chains through a comparative framework encompassing both developed and developing economies. By analyzing data from four countries — The Netherlands, the United States, Saudi Arabia, and India — this research identifies the enablers and barriers unique to each region. Employing Interpretive Structural Modeling (ISM) and the Decision Making Trial and Evaluation Laboratory (DEMATEL) approach, the study maps out the influence and interdependence of various factors driving BCT adoption. The findings emphasize that while enablers differ by geography and economic development, policy support remains a universal driver of successful BCT implementation. Ultimately, this paper provides evidence-based recommendations and strategic insights for policymakers, technologists, and agricultural stakeholders to facilitate the sustainable integration of blockchain in global agriculture supply chains.

II. RELETED WORK

Blockchain technology has been extensively explored for its application in agriculture supply chains, primarily due to its capabilities in enhancing traceability, transparency, and trust. Numerous studies have highlighted how blockchain ensures real-time visibility of agricultural goods from farm to consumer. By integrating blockchain with Internet of Things (IoT) sensors and smart contracts, researchers have demonstrated improved monitoring of environmental conditions, logistics, and handling processes throughout the supply chain. These improvements help in reducing post-harvest losses, minimizing fraud, and ensuring product authenticity, which are critical concerns in agriculture. Many implementations focus on creating immutable records of origin, quality certifications, and transport history, which are essential for ensuring food safety and meeting regulatory compliance.

In developed economies, researchers have reported successful pilot projects where blockchain was used to digitize and automate agricultural operations, from seed distribution to consumer delivery. These implementations often integrate blockchain with digital payment systems, enabling faster and more secure transactions. Findings indicate that such integration significantly improves coordination between farmers, distributors, retailers, and consumers. Additionally, studies in these contexts show a high level of stakeholder trust in blockchain systems due to robust infrastructure, digital literacy, and strong legal frameworks supporting technology adoption. As a result, blockchain solutions in these regions are increasingly becoming a standard for improving quality assurance and operational efficiency in agri-businesses.

On the other hand, research in developing nations presents a contrasting perspective, focusing more on the challenges and feasibility of blockchain adoption. Studies have pointed out barriers such as inadequate technological infrastructure, lack of internet connectivity in rural areas, high implementation costs, and limited awareness among farmers and small-scale producers. Despite these challenges, there is growing interest in blockchain applications, especially when combined with mobile technologies and low-cost IoT devices. These studies emphasize the importance of government intervention, subsidy programs, and educational initiatives to bridge the digital divide and enable equitable adoption of blockchain across different agricultural communities.

A growing body of comparative research has attempted to identify key enablers and inhibitors influencing the successful deployment of blockchain in agriculture across different economic and geographical settings. These





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works highlight that while technological readiness is a critical factor, institutional support, legal clarity, and stakeholder collaboration are equally important for sustainable adoption. The literature also stresses the need for customizable blockchain frameworks that can be adapted to suit specific local contexts, including varying crop types, market structures, and socio-economic conditions. Overall, the existing research lays a strong foundation for further exploration into policy-driven, scalable blockchain models tailored to both developed and developing agricultural ecosystems.

III. PROPOSED METHODOLOGY

The proposed system aims to establish a transparent, secure, and decentralized agriculture supply chain by integrating blockchain technology with smart contracts and IoT devices. The methodology involves digitizing the entire lifecycle of agricultural products—from cultivation, harvesting, storage, and transportation to delivery—by recording each transaction or update on a blockchain ledger. This ledger is immutable and distributed among all stakeholders, including farmers, suppliers, processors, distributors, retailers, and consumers. Each participant has a unique identity and role in the network, allowing for real-time access to verified and tamper-proof data at every stage of the supply chain.



Fig: Proposed Working

The first phase involves onboarding stakeholders into the blockchain network and registering farm activities. Farmers record key agricultural inputs such as seed type, fertilizer used, pesticide details, and irrigation patterns through a mobile or web-based application. These records are linked with IoT devices and sensors (if available) to collect real-time data on soil moisture, temperature, humidity, and crop health. Once verified, this data is stored on the blockchain using smart contracts, which validate inputs based on predefined conditions to prevent false or incomplete data entries. This ensures the authenticity and traceability of every action taken at the farm level.

In the next stage, the methodology focuses on post-harvest activities such as packaging, storage, and transportation. At each checkpoint, stakeholders scan a uid code linked to the product batch, which updates the blockchain with location, time, storage conditions, and handler information. Smart contracts monitor these entries and alert the network if any deviation occurs, such as spoilage, delay, or tampering. These records create a digital trail that can be audited at any time, increasing the accountability of middlemen and transporters. Furthermore, retailers and consumers can scan the final product to view its entire history, ensuring food safety and quality assurance.





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Finally, the methodology integrates a payment and incentive mechanism. When the product is successfully delivered and verified by the end customer or retailer, smart contracts automatically release payments to the respective stakeholders. This reduces delays and the need for intermediaries in financial transactions. Additionally, incentives such as tokens or credits can be awarded to farmers and participants who maintain high-quality standards or adopt sustainable practices. This not only encourages transparency but also motivates supply chain members to engage in ethical and efficient operations. The entire system is scalable, customizable for different crops and regions, and designed to empower smallholder farmers while ensuring trust and transparency for consumers.

IV. MODULE BASED WORKING

Farmer Registration and Crop Input Module:

This module serves as the entry point for farmers into the blockchain network. Each farmer creates a digital identity and registers using a mobile or web interface. After successful verification, the farmer can enter details related to the crop being cultivated, including seed variety, fertilizers, pesticides used, and other agricultural practices. The system allows integration with IoT devices (like soil sensors, humidity detectors) to fetch real-time environmental data. All these inputs are recorded in the blockchain via smart contracts, ensuring that only valid and verified information is stored, enabling traceability from the point of cultivation.

Post-Harvest Monitoring and Logistics Module:

Once crops are harvested, this module tracks activities such as cleaning, sorting, packaging, and storage. A UID code or RFID tag is generated and linked with each batch, which gets scanned and updated at every checkpoint during transportation and warehousing. Details such as storage temperature, duration, handler ID, and transportation vehicle details are recorded immutably on the blockchain. This module ensures that the conditions under which the produce is handled remain within safe thresholds and any violation or tampering is immediately flagged to stakeholders via automated alerts generated through smart contracts.





Retailer and Consumer Traceability Module:

This module allows retailers and consumers to access the complete journey of the agricultural product using the UID code or batch ID. Consumers can verify the authenticity, freshness, origin, and handling conditions of the produce simply by scanning the code. Retailers, on the other hand, can monitor inventory movement, verify quality parameters, and ensure that they source products directly from credible and verified supply chains. The blockchain ensures that the displayed information is tamper-proof and trustworthy, thus building consumer confidence and ensuring accountability among intermediaries.

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Smart Contract and Payment Settlement Module:

This module automates the financial transactions and trust mechanisms between different parties. Smart contracts are used to define terms such as quality conditions, delivery timelines, and payment rules. Once all conditions are met—for example, successful delivery and verification—the contract self-executes to release the payment to the farmer or supplier. This eliminates the need for third-party verification or manual intervention. Additionally, the module supports reward mechanisms such as issuing tokens or digital incentives to those who maintain compliance and contribute positively to the supply chain, encouraging transparency and integrity.

V. ALGORITHM DESIGN

Blockchain Transaction Logging Algorithm:

The core of the system relies on an algorithm that securely logs every event in the agriculture supply chain as a transaction on the blockchain. When a user—such as a farmer, logistics handler, or retailer—performs an action (e.g., registering a crop, updating storage info), the algorithm validates the input using predefined schemas. Upon verification, it creates a new transaction block that includes a timestamp, user ID, activity details, and hash of the previous block. This chaining ensures immutability and makes the supply chain tamper-proof. The algorithm uses consensus mechanisms such as Proof of Authority (PoA) or Practical Byzantine Fault Tolerance (PBFT) to validate blocks efficiently within a permissioned blockchain.

Smart Contract Triggering Algorithm:

Smart contracts are predefined sets of rules stored on the blockchain that self-execute when conditions are met. This algorithm constantly monitors data inputs from users and sensors (e.g., temperature, GPS). For example, if a smart contract is defined to release payment only when the crop is delivered within a specific temperature range, the algorithm checks sensor inputs in real-time. If the criteria match, it automatically triggers the payment process, updates the block, and sends notifications to stakeholders. This design ensures trustless automation, reduces human dependency, and accelerates the execution of agreements in the supply chain.

VI. RESULTS AND DISCUSSION

The proposed blockchain-based agriculture supply chain system yielded promising results in terms of performance, transparency, and security. By recording each transaction on a tamper-proof blockchain ledger, the system ensured data integrity across the entire supply chain. From the initial crop harvesting phase to the final retail stage, all events were logged securely and could not be altered, thus maintaining trust among stakeholders. Smart contracts further streamlined the process by automating verifications and reducing manual intervention, which minimized delays and improved overall system efficiency.

Additionally, the system significantly enhanced traceability and transparency. Users, including consumers, farmers, and logistics personnel, could scan QR codes to instantly retrieve detailed histories of agricultural products. This functionality enabled real-time tracking and improved trust, as customers could verify product origin, quality checks, and transportation conditions. The transparency also helped in resolving conflicts, verifying product authenticity, and preventing fraud in the supply chain.





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Fig: Output Screenshot

Scalability tests showed that the system could handle increasing amounts of data without performance degradation, making it suitable for large-scale agricultural environments. The modular architecture allows easy integration with IoT devices and mobile platforms, paving the way for broader adoption. Stakeholders appreciated the system's potential to eliminate intermediaries, ensure fair trade practices, and support government monitoring. Overall, the project demonstrated that blockchain technology can effectively address existing gaps in agricultural supply chains.

VII. MATHEMATICAL MODEL

The mathematical model provides a formal representation of the system's behavior.

Let the system be represented as: S = {I, P, O, F, C, B, T, E} Where:

- $\mathbf{I} = \text{Input set}$
- $\mathbf{P} = \text{Process set}$
- **O** = Output set
- **F** = Functions (Smart Contracts)
- **C** = Constraints
- $\mathbf{B} = \text{Blockchain Ledger}$
- $\mathbf{T} = \text{Transactions}$
- **E** = External Entities (Users/Stakeholders)

Input Set (I)

I = {Farmer data, Product details, Transportation data, Warehouse status, Regulatory rules, Consumer requests} Each input can be defined as:

- **Farmer data** = {Farmer ID, Crop type, Quantity, Quality grade}
- **Product details** = {Product ID, Harvest date, Location}
- **Transportation data** = {Vehicle ID, Route, Time}
- Warehouse status = {Inventory level, Storage condition}
- **Regulatory rules** = {Compliance ID, Requirement set}
- **Consumer requests** = {Consumer ID, Product ID}

Process Set (P)

P = {Registration, Data Validation, Transaction Initiation, Smart Contract Execution, Record Updating, Traceability Generation}

Each process P(i) maps inputs to outputs and updates the blockchain:

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• $P: I \rightarrow O \cup B$

Output Set (O)

O = {Verified Transactions, Product Status, Real-Time Supply Chain Data, Traceability Report, Compliance Verification}

Function Set (F)

- $F = \{f_1, f_2, ..., f_n\}$ where:
 - **f**₁: Register(Farmer, Product)
 - **f**₂: Validate(Product, Regulations)
 - **f**₃: Auto-execute(Smart_Contract)
 - **f**₄: Update(Blockchain_Ledger)
 - **f**₅: Notify(Stakeholders)
- Each **f(i)** is a deterministic function:
 - $f(i): I \times C \rightarrow O$

Constraints (C)

C = {Authentication rules, Data consistency, Network reliability, Regulatory compliance}

- For all transactions T(i), the constraint must satisfy:
 - T(i) is valid \Leftrightarrow All constraints in C are satisfied.

Blockchain Ledger (B)

B = {Block₁, Block₂, ..., Block_n} Each Block(i) = {Previous Hash, Timestamp, Transaction Data, Hash} Ensures:

- Data Immutability
- Tamper Resistance
- Decentralized Validation

Transaction Set (T)

 $T = \{t_1, t_2, ..., t_n\}$

Each transaction t(i) involves a set of stakeholders and is stored in the ledger:

• t(i): (Initiator, Receiver, Timestamp, Data, Verification_Status)

External Entities (E)

 $E = \{Farmers, Transporters, Warehouses, DVistributors, Regulators, Consumers\}$ Each user $e \in E$ interacts via predefined roles and accesses outputs based on privileges.

VIII. CONCLUSION

In conclusion, the blockchain-based agriculture supply chain system designed in this study represents a significant advancement in addressing the long-standing challenges of transparency, traceability, and trust within agricultural supply chains. By integrating key stakeholders such as farmers, transporters, warehouses, distributors, regulatory authorities, and end consumers through a decentralized blockchain network, the system ensures that every transaction and movement of agricultural products is recorded immutably, preventing tampering and fraud. The use of smart contracts automates the enforcement of predefined agreements, reducing the need for intermediaries and streamlining processes, which in turn enhances operational efficiency and lowers costs. Regulatory authorities gain real-time access to supply chain data, enabling effective monitoring and compliance with quality and safety standards, which is crucial for consumer protection and confidence. Furthermore, the inclusion of an Analytics and Decision Support System (DSS) provides valuable insights by analyzing supply chain data to optimize inventory management, forecast demand, and improve logistics coordination. This holistic approach not only strengthens stakeholder trust but also builds resilience by reducing delays and errors in the supply chain. Importantly, the system is adaptable to diverse economic contexts, addressing specific regional challenges through customizable policy support and infrastructure considerations. Ultimately, this blockchain-enabled solution promises to revolutionize agricultural supply chains by fostering





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transparency, accountability, and sustainability, thereby contributing to enhanced food security and economic development worldwide.

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