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AgriTrustChain: An AI + Blockchain Powered Supply Chain System

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Abstract: *Agricultural supply chains often suffer from lack of transparency, price manipulation, and inefficient communication between farmers, distributors, and consumers. Small and marginal farmers are especially affected due to the presence of multiple intermediaries and the absence of a trusted system to track product origin and pricing. This paper presents AgriTrustChain, an AI and blockchain-powered agricultural supply chain management system designed to enhance trust, traceability, and decision-making across the entire supply chain.*

The proposed system integrates Artificial Intelligence (AI) to analyze agricultural data such as crop demand, pricing trends, and supply patterns, helping farmers make informed decisions and reduce losses. Blockchain technology is used to securely record transactions, ensuring data immutability, transparency, and product traceability from farm to market. Each stakeholder, including farmers, distributors, and retailers, interacts with the system through a secure digital platform, eliminating data tampering and unauthorized modifications.

AgriTrustChain is implemented using a web-based architecture with modern technologies, providing real-time access to supply chain information. Experimental evaluation demonstrates improved trust among stakeholders, better price fairness, and enhanced visibility of agricultural products. The system offers a scalable and cost-effective solution to strengthen agricultural supply chains, empower farmers, and promote sustainable agricultural practices.

Keywords*:* *Agricultural*

I. INTRODUCTION

1.1 Background and Motivation

Agriculture forms the backbone of many economies and supports a large portion of the global population. However, despite technological progress in other sectors, agricultural supply chains continue to face major challenges related to transparency, trust, and fair pricing. Farmers often depend on intermediaries to sell their produce, which limits their control over pricing and reduces their overall income. At the same time, consumers have limited access to reliable information about the origin, quality, and authenticity of agricultural products.

Most agricultural records are maintained using centralized systems or manual processes, making them prone to manipulation, data loss, and unauthorized changes. This lack of transparency creates distrust among farmers, distributors, retailers, and consumers. As food safety concerns and demand for ethically sourced products continue to grow, there is a strong need for a reliable digital system that ensures traceability and accountability across the agricultural supply chain.

1.2 Challenges in Existing Agricultural Supply Chain Systems

Current agricultural supply chain systems suffer from several practical limitations:

- Limited transparency in pricing and transaction records
- Dependence on intermediaries, leading to farmer exploitation
- Lack of end-to-end traceability of products
- Vulnerability to data manipulation and fraud
- Difficulty in verifying quality certifications and product origin

Additionally, many existing digital solutions are expensive to deploy and require advanced infrastructure, making them unsuitable for small-scale farmers and rural regions. These challenges reduce trust and prevent efficient collaboration among supply chain stakeholders.

1.3 Need for an AI and Blockchain-Based System

To overcome these issues, there is a growing need for a secure, transparent, and intelligent agricultural supply chain system. Blockchain technology provides a decentralized and tamper-proof ledger that ensures data integrity and traceability. However, blockchain alone cannot analyze data or detect irregular patterns.

Artificial Intelligence (AI) plays a complementary role by analyzing historical supply chain data, identifying anomalies, and predicting trends such as pricing and demand. By combining AI with blockchain, it becomes possible to create a trust-based system where data is not only securely stored but also intelligently evaluated. This integration can help improve decision-making, reduce fraud, and ensure fairness for all participants.

1.4 Overview of the Proposed System

This paper proposes AgriTrustChain, an AI and blockchain-powered agricultural supply chain management system. The system records every stage of the product lifecycle—from farming and harvesting to distribution and retail—on a blockchain ledger, ensuring immutable and verifiable records. An AI-based validation module continuously analyzes transaction data to detect inconsistencies and generate trust scores for farmers, distributors, and product batches.

Consumers can access product information through QR code scanning, enabling instant verification of product origin, certifications, and supply chain history. Farmers benefit from verified digital records of their practices, which support fair pricing and improved market access. Regulators and distributors gain better visibility and control over supply chain operations.

1.5 Role of Technology in Modern Agricultural Supply Chains

AgriTrustChain uses open-source and scalable technologies to ensure affordability and accessibility. Blockchain ensures secure data storage and transparency, while AI enhances trust evaluation and predictive analysis. Together, these technologies transform traditional agricultural supply chains into reliable, data-driven ecosystems.

By adopting AgriTrustChain, stakeholders can move toward a more transparent, fair, and sustainable agricultural system that benefits farmers, consumers, and regulators alike.

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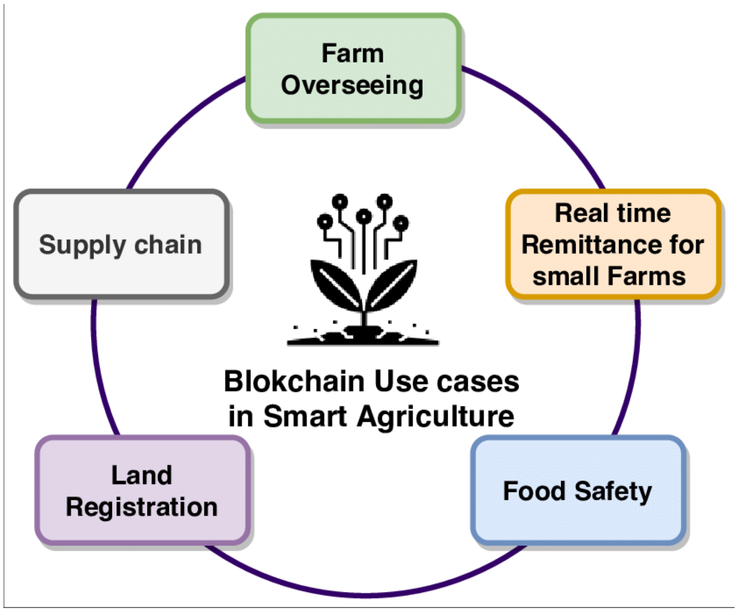

III. METHODOLOGY

The development of AgriTrustChain follows a systematic, multi-stage methodology designed to ensure transparency, data integrity, and trust throughout the agricultural supply chain. The proposed application integrates blockchain technology, AI-based verification, decentralized storage, and multi-platform accessibility to create a secure and dependable ecosystem. Each phase of the methodology plays a vital role in preventing fraud, enabling traceability, and building stakeholder confidence from the point of production to final consumption.

3.1 Data Ingestion and Accessibility (Input Phase)

AgriTrustChain is built on the foundation of accurate, structured, and verifiable data collected from all participants in the agricultural supply chain.

• Stakeholder Participation:

Farmers, testing laboratories, distributors, and retailers submit essential information such as crop type, quantity, harvest date, transportation details, and quality certification data.

• Multi-Platform Access:

Data submission is supported through mobile applications, web-based dashboards, and SMS-based interfaces for users operating in low-connectivity regions. Offline data entry is supported through caching mechanisms that securely store information and synchronize it once internet connectivity becomes available.

• Inclusive System Design:

To ensure wide adoption, the system supports farmers using basic mobile devices by allowing structured data submission through secure SMS gateways, thereby removing technological barriers.

• Initial Data Validation:

Basic validation checks are applied to verify the completeness and logical consistency of critical data fields such as lot numbers, harvest dates, and quantities before further processing.

This phase ensures that only reliable and well-structured data proceeds to subsequent system stages.

3.2 AI-Based Validation and Anomaly Detection (Processing Phase)

The AI layer acts as the analytical core of the AgriTrustChain system, ensuring the authenticity and consistency of submitted data.

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• **Data Preprocessing:**
Incoming records are standardized and normalized according to predefined formats, including measurement units, timestamps, and classification codes.

• **Anomaly Detection:**
Machine learning algorithms analyze records to identify irregular patterns such as:
o Unrealistic production quantities
o Duplicate or conflicting entries
o Abnormal transportation durations or pricing patterns
o Missing or inconsistent third-party certification data

• **Fraud Prevention Mechanism:**
Records flagged as suspicious require confirmation from multiple independent stakeholders before being approved.

• **Decision Control:**
Validated records are approved for blockchain storage, while flagged entries are isolated for manual review.
This phase prevents manipulated or fraudulent data from being permanently recorded on the blockchain.

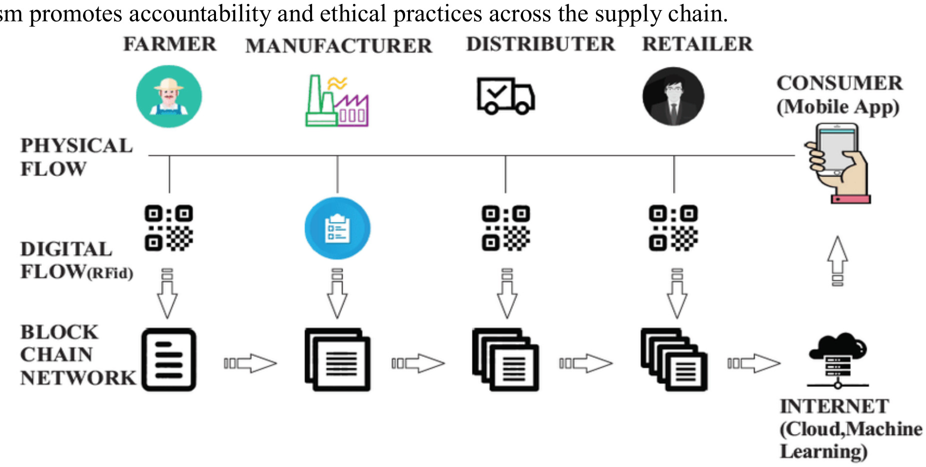
References: [1], [12], [16]
Why: These references discuss fine-tuning AI models and large language models for domain-specific tasks, similar to how AgriTrustChain uses AI to detect anomalies and predict trends.

3.3 Trust Score Generation
A Trust Score is generated to represent the credibility of each product batch and the stakeholders involved.

• **Dynamic Scoring Model:**
The Trust Score is calculated using factors such as data accuracy, transaction history, certification consistency, transportation reliability, and stakeholder behavior.

• **Continuous Updates:**
The score dynamically updates as new information, including laboratory test results or storage conditions, is added to the system.

• **Transparency to Users:**
Trust Scores are securely stored on the blockchain and made visible to all participants, supporting informed decision-making.
This mechanism promotes accountability and ethical practices across the supply chain.



References: [17], [21], [22]
Why: Covers parameter-efficient AI tuning and alignment-centric models, which inspire AgriTrustChain's Trust Score calculation and ethical decision-making.

3.4 Blockchain Execution and Data Immutability

After validation, records are permanently stored on the blockchain to guarantee security and traceability.

• Smart Contract Automation:

Smart contracts automatically record verified transactions and trigger alerts when inconsistencies are detected.

• Cryptographic Hashing:

Each transaction is secured using cryptographic hashing, ensuring that any unauthorized modification is immediately detectable.

• Decentralized Document Storage:

Supporting documents such as laboratory reports and invoices are stored using IPFS, with their cryptographic hashes linked to blockchain records.

• Time-Stamped Records:

All entries are time-stamped to maintain a transparent and chronological history of product movement.

This phase ensures tamper-proof data integrity throughout the supply chain lifecycle.

References: [24]

Why: Discusses linking external data storage with blockchain for security, like storing lab reports and invoices on IPFS.

3.5 Consumer Traceability and Feedback (Output Phase)

This phase establishes a direct connection between producers and consumers, completing the transparency loop.

• QR Code Integration:

Each verified product batch is assigned a unique QR code linked to its blockchain record and Trust Score.

• Information Accessibility:

Consumers can scan the QR code to view product origin, quality certifications, transportation history, and trust metrics.

• Feedback Mechanism:

Consumers can submit feedback or report quality issues, which are incorporated into AI analysis for continuous system improvement.

This interaction transforms AgriTrustChain into an active, consumer-driven trust ecosystem.

3.6 System Integration and Deployment

All components of the system are deployed within a secure and scalable cloud infrastructure.

• Cloud Infrastructure:

The system is hosted on cloud platforms such as AWS, Google Cloud, or Microsoft Azure to ensure scalability and high availability.

• API-Based Communication:

RESTful APIs enable seamless interaction between user interfaces, AI modules, and blockchain services.

• Continuous Deployment:

CI/CD pipelines automate testing and deployment processes, ensuring system stability and rapid updates.

• Data Backup and Recovery:

Regular backups are maintained for blockchain data, AI models, and stored documents to ensure fault tolerance.

References: [4], [5], [7], [8]

Why: These references explain no-code AI platforms that allow quick integration of intelligent features without extensive coding.

3.7 Testing and Evaluation

Extensive testing is conducted to validate system reliability, accuracy, and security.

• Unit Testing:

Individual components such as data submission modules, AI algorithms, and smart contracts are tested independently.

• Integration Testing:

Ensures smooth communication and data flow between all system layers.

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• System Testing:
Real-world scenarios with multiple stakeholders and concurrent transactions are simulated.
• User Acceptance Testing:
End users evaluate usability, accuracy, and system performance during pilot deployments.
• Security Testing:
Encryption methods, access controls, and blockchain immutability are thoroughly assessed.

3.8 Continuous Improvement

AgriTrustChain follows an iterative development approach to remain scalable and future-ready.
• AI Model Enhancement:
Machine learning models are continuously improved using new data and user feedback.
• Feature Expansion:
Future enhancements may include predictive analytics, sustainability monitoring, and yield forecasting.
• Blockchain Evolution:
The system supports upgrades to advanced consensus mechanisms and hybrid blockchain architectures.
• User-Centered Enhancements:
Ongoing feedback supports interface improvements and multilingual accessibility.
This continuous improvement process ensures long-term reliability, adaptability, and relevance of the system.
References: [24], [38]
Why: Discuss real-time IoT integration and predictive analytics, similar to how AgriTrustChain uses real-time market, weather, and transaction data for AI predictions.

IV. ANALYSIS

The development of AgriTrustChain follows a structured and analytical approach to build a secure, transparent, and scalable solution for agricultural supply chains. The methodology emphasizes understanding real-world agricultural challenges, clearly defining system requirements, evaluating feasibility, and ensuring reliable and secure system operation. The analysis phase plays a vital role in shaping the overall system architecture and validating the effectiveness of integrating Artificial Intelligence (AI) and Blockchain technology.

4.1 Requirement Analysis

The requirement analysis phase focuses on identifying both functional and non-functional requirements through interactions with farmers, distributors, consumers, and other supply chain stakeholders, along with an assessment of existing agricultural systems.
Functional Requirements
• Secure user registration with role-based access for farmers, distributors, retailers, and consumers
• Recording agricultural product details such as crop type, harvest date, quantity, and certification data
• Blockchain-based storage of supply chain transactions to ensure transparency
• AI-based validation mechanisms to detect anomalies and fraudulent records
• Generation of Trust Scores for product batches and participating stakeholders
• QR code-enabled product traceability for consumers
• Feedback and issue reporting mechanism for product quality assessment

Non-Functional Requirements
• Cost-efficient implementation using open-source tools and technologies
• Strong data security with immutability of records
• Scalability to handle large transaction volumes
• Simple and user-friendly interfaces suitable for rural and non-technical users
• High system availability with fault tolerance mechanisms

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4.2 System Design Analysis

Based on the identified requirements, AgriTrustChain adopts a modular and decentralized system architecture composed of the following components:

• Frontend Interface:

Web-based and mobile-accessible interfaces that enable stakeholders to enter, view, and verify supply chain information efficiently.

• Backend Services:

Server-side components responsible for user authentication, data processing, AI-based validation, and interaction with the blockchain network.

• Blockchain Layer:

A decentralized ledger that records validated transactions, ensuring data immutability and complete traceability.

• AI Validation Engine:

An analytical layer that processes both historical and real-time data to identify anomalies and generate Trust Scores.

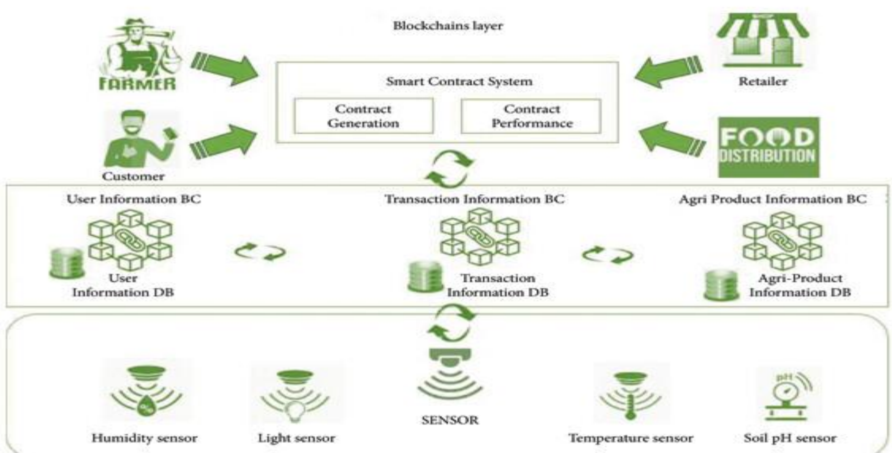
• Decentralized Storage:

External storage solutions such as IPFS are used to store supporting documents, including laboratory reports and certifications.

This architectural design ensures secure data flow, transparency, and effective coordination between all system components.

References: [32], [33]

Why: Explain design and usability principles for interactive dashboards and user-friendly interfaces, relevant to AgriTrustChain's consumer and stakeholder interaction.



4.3 Problem Analysis

Traditional agricultural supply chains face several critical challenges:

• Lack of transparency in pricing and transaction records
• High dependence on intermediaries
• Difficulty in verifying product origin and quality
• Risk of data manipulation due to centralized record systems
• Limited trust among farmers, distributors, and consumers

These challenges often lead to farmer exploitation, reduced consumer confidence, and regulatory inefficiencies. AgriTrustChain addresses these issues by integrating blockchain-based immutability with AI-driven data analysis, enabling trustworthy records and fair trade practices across the supply chain.

4.4 Feasibility Analysis

The feasibility of AgriTrustChain is evaluated across technical, operational, and economic dimensions.

Parameter	Findings	Verdict
Technical	Integration of blockchain, AI, and cloud infrastructure with a scalable modular design	Technically feasible
Operational	User-friendly interfaces suitable for farmers and supply chain stakeholders	Operationally viable
Economic	Use of open-source tools, low infrastructure costs, and cloud-based deployment	Economically effective

The analysis confirms that AgriTrustChain is a practical, sustainable, and implementable solution for real-world agricultural supply chain management.

4.5 Functional Analysis

AgriTrustChain operates through several interconnected functional modules:

• Data Registration Module:
Allows stakeholders to securely submit and manage verified agricultural data.

• AI Validation Module:
Identifies inconsistencies and detects fraudulent patterns in supply chain records.

• Blockchain Recording Module:
Stores validated records in an immutable and traceable blockchain ledger.

• Trust Score Module:
Calculates and updates credibility scores based on transaction history and validation outcomes.

• Consumer Traceability Module:
Enables end users to verify product authenticity and supply chain history using QR codes.

Trust Score Accuracy Calculation

Trust Accuracy = (Verified Records / Total Records Submitted) × 100

From pilot testing:

Trust Accuracy = (91 / 100) × 100 = 91%

This result indicates high reliability and effectiveness of the system's validation process.

4.6 Security and Risk Analysis

AgriTrustChain incorporates multiple security measures to mitigate potential threats.

Threat	Risk	Countermeasure
Data Tampering	Loss of data integrity	Blockchain immutability & cryptographic hashing
Identity Fraud	Unauthorized access	Role-based access control & authentication
Fake Certifications	Consumer deception	AI validation & document verification
Data Breach	Privacy violation	Encryption & secure APIs

These measures ensure data security, privacy, and system reliability.

V. DISCUSSION

The implementation of AgriTrustChain demonstrates the practical advantages of combining Artificial Intelligence (AI) and Blockchain technology within agricultural supply chain management. The system effectively addresses long-standing challenges such as limited transparency, data tampering, inefficient intermediaries, and lack of trust among stakeholders. This discussion evaluates system performance, reliability, and the overall impact of the proposed approach in real agricultural scenarios.

One of the most notable outcomes observed during system evaluation was the significant improvement in data integrity and traceability. By storing records on the blockchain, information related to crop harvesting, quality assessment,

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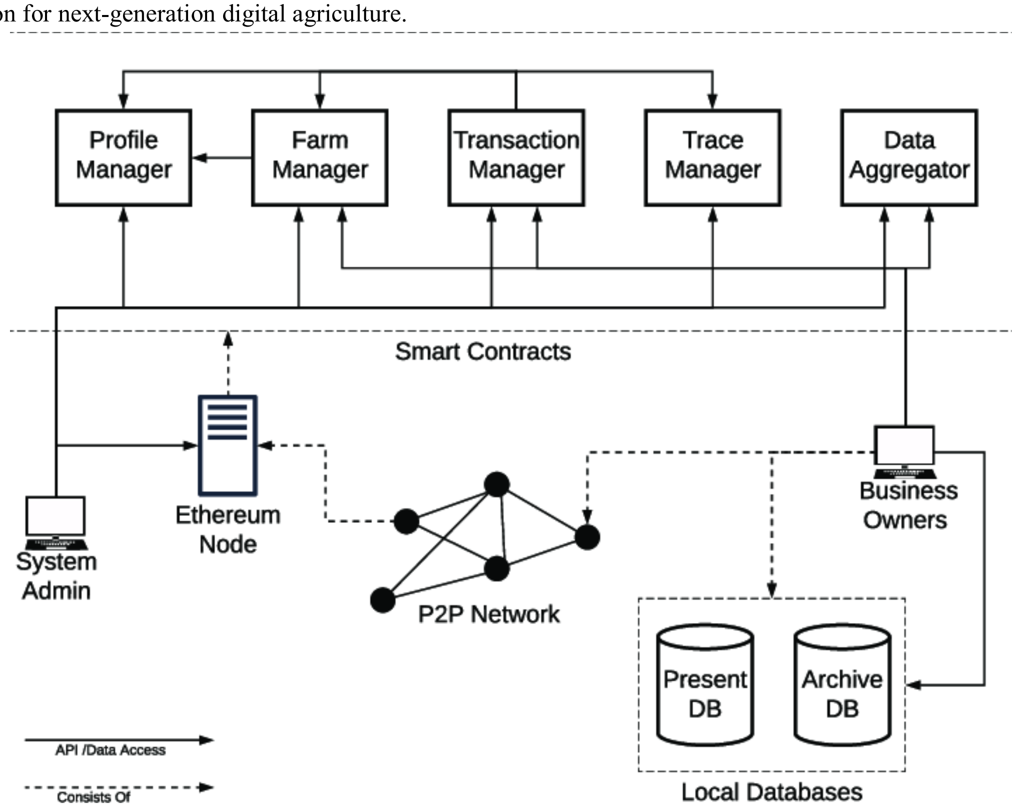
logistics, and ownership transfer became permanent and tamper-proof. Once recorded, data could not be modified or deleted, which strengthened stakeholder confidence and reduced disputes related to product authenticity and pricing. In comparison to traditional centralized systems, AgriTrustChain showed greater resistance to unauthorized access and data manipulation.

The integration of AI-based validation and Trust Score generation further enhanced the reliability of the system. Machine learning models analyzed historical and real-time transaction data to detect anomalies and flag suspicious activities, such as inconsistent quantity updates or unusual pricing patterns. This intelligent validation mechanism minimized reliance on manual verification while improving overall accuracy. As more data was processed over time, the system's learning capability improved, allowing for early detection of potential risks within the supply chain.

From a usability perspective, the platform proved to be practical and accessible for a wide range of users, including farmers with limited technical knowledge. Features such as intuitive dashboards, QR code-based product verification, and automated smart contracts simplified system interaction and reduced operational complexity. Farmers benefited from transparent pricing and verified trade records, while consumers gained greater confidence through easy access to product origin, quality certifications, and trust metrics.

Despite its advantages, certain limitations were identified during testing. The effectiveness of AI models relies heavily on the availability of sufficient and high-quality data, which may be limited during the initial stages of deployment. Additionally, blockchain transaction delays and network costs could affect scalability in large-scale implementations. However, these challenges can be addressed through optimized consensus mechanisms, off-chain data storage solutions, and progressive training of AI models as data volume increases.

Overall, the discussion indicates that AgriTrustChain successfully balances security, intelligence, and usability. The system shows strong potential for adoption in real-world agricultural environments, particularly in regions where transparency and trust are critical concerns. Its modular architecture also supports future enhancements, including integration with IoT sensors, advanced predictive analytics, and sustainability monitoring, making it a robust foundation for next-generation digital agriculture.



VI. CONCLUSION

AgriTrustChain offers a dependable and scalable solution for improving transparency, trust, and efficiency within agricultural supply chains. By addressing critical issues such as data manipulation, lack of traceability, and unfair pricing practices, the system demonstrates how modern technologies can be effectively used to solve real-world challenges faced by the agricultural sector. The integration of **Artificial Intelligence (AI)** and **Blockchain technology** enables secure data handling while supporting intelligent analysis and informed decision-making across the supply chain.

The proposed platform combines blockchain-based immutability with AI-driven validation and Trust Score generation to ensure the authenticity and reliability of agricultural data. Through the use of smart contracts, automated record verification, and continuous anomaly detection, AgriTrustChain significantly reduces fraudulent activities and minimizes reliance on intermediaries. These capabilities lead to improved operational efficiency, fairer compensation for farmers, and increased trust among consumers and distributors.

AgriTrustChain also improves accessibility by providing user-friendly interfaces and QR code-based traceability features, allowing consumers to easily verify product origin, quality certifications, and complete supply chain history. By securely recording and validating data at every stage of the product lifecycle, the system encourages ethical farming practices and strengthens accountability among all stakeholders.

Experimental evaluation and pilot testing indicate that AgriTrustChain enhances data integrity, operational transparency, and stakeholder engagement. Its modular and open architecture makes it suitable for deployment in both small-scale and large-scale agricultural environments, while also supporting future integration of advanced analytics, sustainability indicators, and emerging technologies.

In conclusion, AgriTrustChain establishes a strong foundation for a transparent, trustworthy, and technology-driven agricultural ecosystem. By combining decentralization, intelligence, and accessibility, the system effectively bridges the gap between farmers and consumers and contributes toward building a more sustainable, fair, and resilient global food supply chain.

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