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A Blockchain-Integrated and AI-Enhanced Traceability Framework for Ensuring Authenticity in Organic Food Supply Chains

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Abstract: The rapid global shift toward organic food consumption has increased the need for reliable methods to verify product authenticity and track supply-chain activities. Conventional record-keeping systems are highly susceptible to manipulation, missing data, and certification fraud, making consumers uncertain about product quality. This research presents an advanced Organic Food Traceability Framework called TrustTrace, designed using blockchain technology, artificial intelligence, and cloud-based data management. Blockchain ensures immutable and transparent event logging, while an AI-based Trust Score evaluates each product batch using parameters such as certification validity, freshness, logistic performance, and stakeholder behavior. MongoDB Atlas functions as the cloud backbone for storing dynamic multi-stakeholder data. Consumers verify authenticity through QR-based access to tamper-proof farm-to-fork histories. This integrated approach significantly improves data reliability, minimizes fraud, and increases consumer confidence in organic food ecosystems.
Keywords: Blockchain Traceability, Organic Supply Chain, AI Trust Score, Food Authenticity, Farm-to-Fork Tracking.

I. INTRODUCTION

Organic food consumption is rising worldwide due to increased public awareness about health, sustainability, and the environmental impact of farming practices. However, as demand grows, so does the risk of counterfeit organic products, manipulated certification records, and mislabelled supplies. Traditional supply-chain documentation methods often rely on centralized databases or paper-based systems, both of which are vulnerable to alteration, unauthorized modification, and data gaps. These weaknesses undermine the credibility of organic labels and reduce consumer trust.

To address these issues, this research proposes a blockchain-enabled Organic Food Traceability System, reinforced with AI-based analytics to quantify the reliability of each organic product. Blockchain ensures permanent, tamper-proof storage, while artificial intelligence evaluates supply-chain behavior and assigns a Trust Score to each batch. MongoDB Atlas integrates all modules through secure cloud storage, allowing seamless mapping of all stakeholder activities.

The system empowers consumers to verify authenticity instantly while guiding producers toward ethical and compliant practices. This work provides a comprehensive model that demonstrates how modern technologies can strengthen transparency and auditability in organic supply chains.

II. MAIN CONCEPT

A. Concept Overview

The core concept of TrustTrace is to create a transparent, decentralized, and intelligent traceability system capable of tracking organic food products across all supply-chain stages. Organic goods typically pass through multiple transitions—from cultivation to packaging, transportation, retail distribution, and final consumption. Each transition generates critical metadata required to prove authenticity.

TrustTrace captures, secures, and analyzes this information using three primary technologies:

1) Blockchain for immutable record-keeping.
2) Artificial Intelligence for credibility assessment.
3) Cloud Infrastructure for scalable data synchronization.
4) This triangular technological integration forms a digital chain of trust that enhances quality assurance across all participants.

B. Working Mechanism

Each stakeholder contributes authenticated data to the system:

1) Farmers: Start the traceability chain by entering crop information, organic certifications, location, harvest date, and quality details.
2) Manufacturers: Add processing-related events such as cleaning, grading, packaging, and batch generation.
3) Distributors: Record transportation logs, cold-chain status, route information, and warehouse storage parameters.
4) Retailers: Update stock details, expiry dates, sales metrics, and product availability.
5) Consumers: Verify authenticity by scanning a QR code that retrieves blockchain-backed data.

AI then interprets this multi-stage input to generate a Trust Score that predicts product authenticity and reliability.

C. Core Principles

The proposed system is governed by six foundational principles:

1) Transparency: All supply-chain events are open to subsequent actors, eliminating information asymmetry.
2) Immutability: Blockchain prevents unauthorized edits once records are written.
3) Distributed Trust: No single authority controls the data; cryptographic linkage secures each block.
4) Traceability: Backward and forward tracking ensures a complete view of the product lifecycle.
5) Accountability: Every update is permanently linked to the actor who submitted it.
6) Data-Driven Validation: The AI model assigns credibility scores through evaluation of multi-factor inputs.

D. Innovation in the Concept

Key contributions of TrustTrace include:

1) A multi-layer blockchain ledger for tamper-proof tracking.
2) A consumer-centric AI Trust Score transforming raw data into actionable insight.
3) Instant verification using QR-based data retrieval.
4) Real-time updates and synchronization using MongoDB Atlas cloud storage.
5) Cold-chain data integration for temperature-sensitive organic products.
6) Cross-phase data fusion (farm → retail → consumer) for enhanced understanding.

E. Significance of the Concept

The system provides a powerful framework for combating fraudulent organic certifications, improving supply-chain transparency, supporting ethical production, and empowering consumers through verified data. It enhances product confidence while establishing a unified digital ecosystem for all stakeholders.

III. WORKING OF THE SYSTEM

A. User Registration and Roles

TrustTrace adopts a Role-Based Access Control (RBAC) system where users register as either Farmers, Manufacturers, Distributors, Retailers, or Consumers. Each user is granted permissions tailored to their role. This ensures strict data segregation while maintaining accountability. Every activity carried out by a user is linked to a unique system-generated ID.

B. Farmer Module

Farmers upload harvesting details, certification proofs, crop specifics, quantity, location, and pricing. The system automatically generates a batch ID that becomes the genesis block for the product. This stage ensures that every subsequent event in the supply chain is rooted in verified primary production data.

C. Manufacturer Module

Manufacturers log processing activities such as:

1) Cleaning and sorting
2) Quality inspection
3) Packaging

4) Shelf-life calculation
5) Batch creation

Each processed batch is appended as a new block in the blockchain ledger.

D. Distributor Module

Distributors maintain logistics details including:

1) Routing and transportation logs
2) Cold-chain temperature values
3) Delivery timelines
4) Storage facility details

Every delivery update generates an immutable block to prevent misinformation.

E. Retailer Module

Retailers verify arrival conditions, update inventory, maintain expiry details, and list products for sale with transparency. Retail-level events help complete the end-to-end traceability chain.

F. Consumer Module

Consumers access the entire product journey via a QR scan. They view origin details, certifications, process logs, logistics data, and the AI-generated Trust Score.

G. AI-Based Trust Score

The Trust Score is calculated using weighted inputs such as:

1) Certification validity
2) Freshness index
3) Delivery accuracy
4) Stakeholder reliability
5) Pattern-based fraud detection

A hybrid ML-and-rule-based model normalizes the results to a 0–100 scale.

H. Simulated Blockchain Implementation

TrustTrace uses a lightweight blockchain simulation for academic demonstration. Each event forms a block containing:

1) Previous hash
2) Current hash
3) Timestamp
4) User role
5) Event details

Tampering with any block disrupts all future blocks, replicating real-world blockchain immutability.

I. Database Integration

MongoDB Atlas stores operational data such as:

1) User details
2) Orders
3) Inventory
4) Product metadata
5) Shipment logs

The system integrates blockchain records with database entries, ensuring synchronized verification and analytics.

IV. LITERATURE SURVEY

Sr. No.	Paper Title and its Author	Details of Publication	Findings
1.	Blockchain for Organic Food Traceability (M. van Hilten, G. Ongena, P. Ravesteijn)	In 2020, in Volume 3, Wageningen Research, Utrecht Univ. of Applied Sciences.	This paper says blockchain helps track organic food and makes the process transparent. But it also warns that protecting privacy and connecting systems is still a challenge
2.	Blockchain in Agriculture Traceability Systems (Konstantinos Demestichas , Nikolaos Peppes, Theodoros Alexakis and Evgenia Adamopoulou)	June 2020 Institute of Communication and Computer Systems, Zografou, 15773 Athens, Greece	It says blockchain makes food tracking better than old systems, but real use still has problems like cost, data accuracy, and scaling.
3.	Consumers' Intention to Adopt Blockchain Food Traceability Technology towards Organic Food Products (Xin Lin, Shu-Chen Chang, Tung-Hsiang Chou)	In 2021, International Journal of Environmental Research and Public Health	Consumer trust and perceived food quality are the most important factors driving the intention to adopt blockchain food traceability for organic products.
4.	Organic Food Supply Chain Traceability using Blockchain Technology (Milon Biswas)	2021 International Conference on Science & Contemporary Technologies (ICSCT), Dhaka	This research shows how smart contracts in blockchain can stop fake products, keep data safe, and help check if organic food is real or not.
5.	Potentials and Limitations of the Traceability Process of Organic Food Production (J. P. R. Carneiro)	In 2024, Revista de Administração e Contabilidade (FOCO Publicações), Article No. 4424 in FOCO's system	The organic food traceability system emerges as a strategic tool to ensure food safety and support environmental dynamics—helping to guarantee the integrity of organic production and reveal the links across spatially distributed supply chain stages.

V. COMPREHENSIVE STUDY

A. Benefits

1) Transparency and tamper-proof certification
2) Protection against fake organic claims
3) Consumer empowerment
4) Supply-chain efficiency
5) Strong data security
6) Enhanced farmer credibility
7) Reduced adulteration risk
8) Sustainability support
9) Scalable architecture
10) Improved brand reliability

B. Objectives
1) To develop a blockchain-anchored traceability model
2) To ensure authenticity using AI-driven verification
3) To enable real-time stakeholder communication
4) To improve consumer confidence through transparency
5) To automate trust evaluation via AI algorithms

C. Limitations
1) Dependency on internet availability
2) Initial training requirements
3) Higher cost for full-scale deployment
4) Limited AI accuracy in early datasets
5) No data corrections possible after blockchain entry
6) Integration issues with external authorities
7) Potential privacy concerns depending on data visibility

VI. RESULT
The implemented prototype demonstrated that blockchain and AI can drastically enhance supply-chain verification. Each stakeholder could register updates seamlessly, and AI-based Trust Scores successfully differentiated high-credibility batches from suspicious ones. The system proved capable of efficient real-time synchronization, tamper detection, and transparent consumer interaction.

VII. DISCUSSION
Results show that blockchain provides robust protection against data manipulation, while AI simplifies complex trace histories into intuitive trust metrics. The system aligns with global sustainable food objectives and shows strong potential for real-world adoption. The research also highlights the need for improved data literacy and regulatory cooperation to scale such solutions.

VIII. CONCLUSION
This research establishes an effective framework for ensuring authenticity and transparency in organic food supply chains through blockchain and AI. TrustTrace provides secure, trustworthy, and data-driven insights into the farm-to-fork process. Future improvements include IoT integration for real-time monitoring, smart-contract automation, and mobile application development to broaden accessibility.

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