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FOOD SUPPLY CHAIN HEALTH TRACKER

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Abstract: In order to guarantee that agricultural produce reaches customers in a safe, fresh, and nourishing state, the food supply chain is essential. However, issues like contamination, spoiling, nutritional deterioration, lack of transparency, and ineffective traceability plague conventional food monitoring systems. Due to the dependence on human inspections and centralized record-keeping systems, these restrictions raise health risks, cause monetary harm, and erode customer confidence.

In order to guarantee food safety and quality along the whole supply chain, the Food Supply Chain Health Tracker is a clever, technologically advanced solution that combines Blockchain, AI, and ML. While ML models forecast nutritional degradation based on storage and climatic conditions, AI-based computer vision techniques are utilized to identify contamination and spoiling in crops. Blockchain technology ensures transparency and end-to-end traceability from farm to consumer by providing a decentralized, unchangeable ledger for all supply chain transactions.

Through a web-based platform, the system provides farmers, distributors, retailers, and customers with role-based access. While stakeholders receive real-time information on food quality and handling circumstances, consumers can use QR code scanning to confirm product quality and origin. The suggested solution improves food safety, lowers post-harvest losses, increases responsibility, and fosters confidence in the food supply ecosystem by fusing secure traceability with predictive analytics.

I. INTRODUCTION

The Food Supply Chain Health Tracker is a smart digital platform aimed at enhancing transparency, efficiency, and safety in the agricultural and food supply chain. Conventional food supply systems frequently experience issues such as limited visibility, postponed quality evaluations, and unreliable traceability. These problems contribute to food spoilage, economic losses, and diminished consumer confidence. This initiative aims to address these challenges by offering a systematic and technology-based method for tracking food products from the moment they are harvested until they reach the end consumer.

Farmers can use the system to create and oversee crop batches by documenting key information like the type of crop, quantity, date of harvest, and location of the farm. The platform employs AI-based analysis to assess food quality and forecast potential spoilage risks, taking into account environmental conditions and handling practices. With real-time tracking of transit and status updates, distributors and retailers can keep a close watch on the movement and condition of food products, guaranteeing prompt action when risks are identified. The integration of QR codes boosts traceability by enabling immediate access to comprehensive batch history and quality records.

The Food Supply Chain Health Tracker enables informed decision-making at every stage of the supply chain by integrating AI, secure data storage, and intuitive dashboards. The system aids in minimizing food waste and operational inefficiencies while also bolstering trust among farmers, distributors, retailers, and consumers. In the end, this project helps to create a food supply chain ecosystem that is safer, smarter, and more sustainable

1.1 Project Description

Due to its complexity and the involvement of numerous stakeholders, ensuring food quality, safety, and transparency in the global food supply chain is a challenge. Problems like inadequate storage, lengthy transport durations, and manual oversight frequently result in food spoilage, contamination, and economic losses. Conventional systems depend on manual documentation or simple digital tools, which do not provide real-time tracking, precision, or comprehensive visibility. This diminishes trust and hinders the early identification of quality problems. Using advanced technologies such as AI and blockchain for real-time observation and predictive analysis, the Food Supply Chain Health Tracker tackles these gaps. The Food Supply Chain Health Tracker is a smart platform that allows for batch tracking, quality monitoring, and QR-based traceability from farm to consumer.

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1.2 Motivation
Food safety and quality assurance are critical concerns in modern agricultural supply chains, where food products pass through multiple stages such as harvesting, storage, transportation, and retail before reaching consumers. Even minor lapses in handling conditions—such as improper temperature control, delayed transportation, or unhygienic storage—can lead to spoilage, contamination, and nutritional degradation. These issues not only result in significant economic losses but also pose serious risks to public health.

Despite the importance of food safety, most existing supply chain monitoring practices rely on manual inspections, periodic quality checks, and centralized record-keeping systems. Such approaches are often reactive, error-prone, and incapable of providing real-time visibility into food quality conditions. Moreover, the lack of transparent and trustworthy traceability makes it difficult for consumers to verify the origin, handling history, and freshness of food products, leading to reduced consumer confidence.

The increasing demand for fresh, safe, and traceable food highlights the need for an intelligent and automated monitoring framework. Advances in Artificial Intelligence (AI) and Machine Learning (ML) enable early detection of spoilage and prediction of quality degradation, while Blockchain technology offers immutable and transparent record-keeping across the supply chain. Motivated by these challenges, this project aims to develop an integrated Food Supply Chain Health Tracker that combines AI-based quality analysis with blockchain-backed traceability to ensure safer food delivery, reduce post-harvest losses, and enhance trust among all stakeholders

II. RELATED WORK

Several studies have explored AI-based approaches for food spoilage detection using computer vision and machine learning techniques. CNN-based models have demonstrated high accuracy in identifying discoloration, mold growth, and texture degradation in fruits and vegetables. Other works utilize ML models such as SVM, Random Forest, and LSTM to predict spoilage risks based on environmental and storage conditions.

Blockchain-based food supply chain solutions focus on improving traceability, transparency, and fraud prevention by maintaining immutable records of supply chain events. IoT-enabled blockchain architectures further enhance data reliability by capturing real-time environmental parameters. However, most existing approaches address quality detection or traceability independently. There remains a research gap in developing a unified system that integrates AI-based quality assessment, predictive analytics, and blockchain-backed traceability. The proposed system addresses this gap by combining these technologies into a single cohesive framework

III. METHODOLOGY

A. System Environment
The proposed Food Supply Chain Health Tracker is implemented as a web-based intelligent monitoring system designed to model real-world food supply chain operations. The system represents the supply chain as a sequence of stages including harvesting, storage, transportation, and retail distribution. Each food batch is treated as a digital entity with associated metadata such as crop type, harvest date, storage conditions, and location. The environment supports interaction among multiple stakeholders including farmers, distributors, retailers, administrators, and consumers. Realistic supply chain scenarios are simulated by capturing batch movement, environmental variations, and handling events throughout the lifecycle of food products

B. Quality Monitoring and Traceability Architecture
AI-Based Quality Analysis
Artificial Intelligence-based computer vision models are employed to analyze images of agricultural produce uploaded by users at different stages of the supply chain. Convolutional Neural Networks (CNNs) are used to detect visual indicators of spoilage, such as discoloration, texture degradation, and mold growth. The output of the model includes a quality grade and a spoilage probability score, enabling early identification of compromised food batches.

ML-Based Quality Risk Prediction
Machine Learning models are used to predict freshness and quality degradation risks based on environmental and logistical parameters such as storage duration, temperature, humidity, and transportation time. These predictive models analyze historical and real-time data to estimate the likelihood of spoilage, allowing stakeholders to take preventive actions before food quality deteriorates
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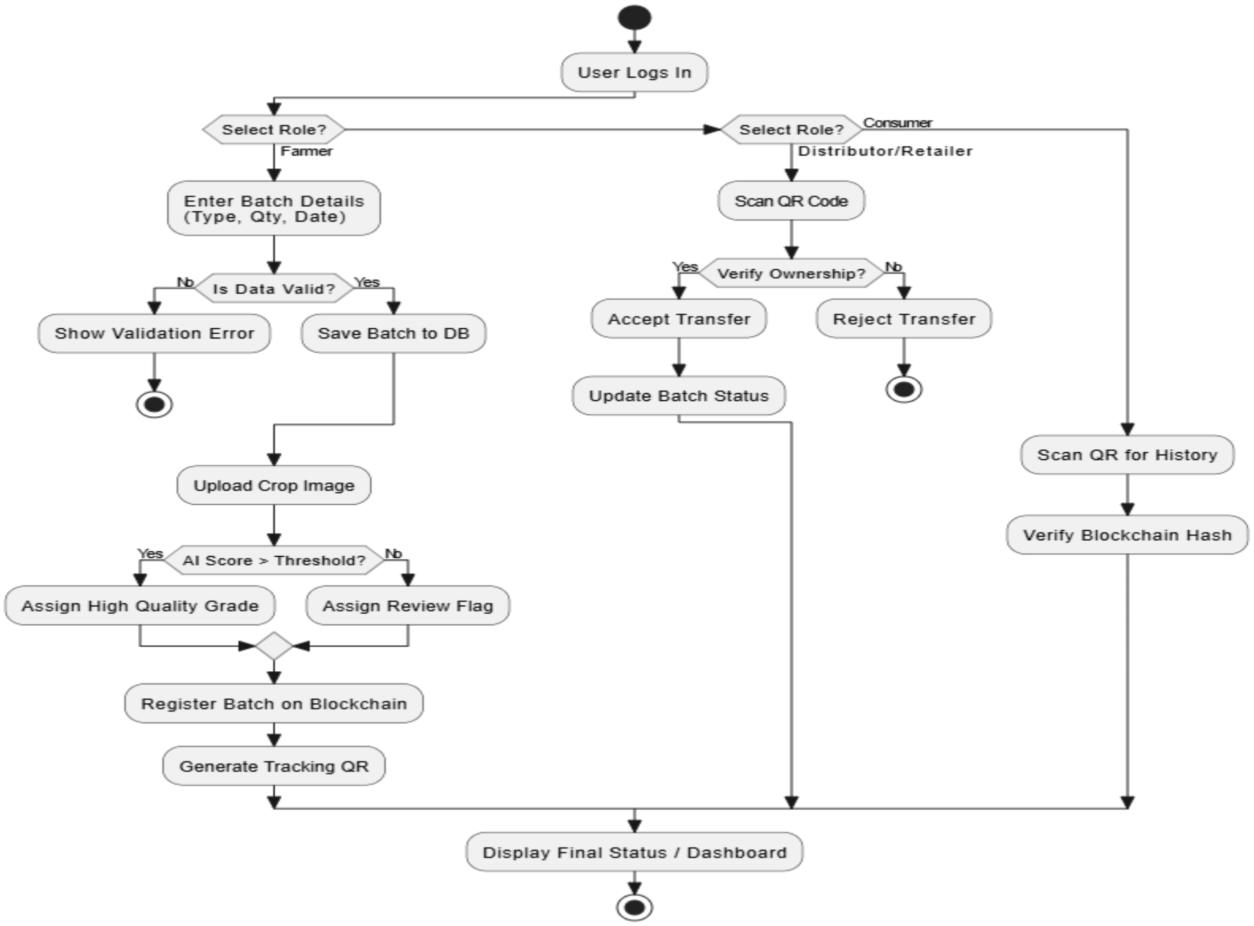

Fig. 1. Flowchart of methodology

C. Blockchain-Based Supply Chain Traceability

Blockchain technology is used to ensure secure and tamper-proof traceability of food supply chain events. Each batch is assigned a unique digital identifier, and critical events such as batch creation, storage updates, transit milestones, and inspections are recorded on a distributed ledger. This guarantees data immutability and transparency across all supply chain participants. Smart contracts are used to validate and log events automatically, reducing reliance on manual record-keeping.

D. QR-Code Enabled Verification

To bridge the physical and digital supply chain, each food batch is associated with a QR code generated at the time of batch creation. Scanning the QR code retrieves complete batch history, including origin, handling conditions, AI-based quality assessment results, and blockchain verification details. This mechanism enables instant verification for distributors, retailers, and consumers, enhancing trust and accountability.

E. Implementation Flow

1. Initialize the system environment and authenticate users based on assigned roles (farmer, distributor, retailer, administrator, consumer)
2. Create a new food batch by capturing crop details, harvest date, quantity, and geographic location.At each simulation timestep:
    - Generate a unique batch identifier and associate it with a corresponding QR code for digital traceability.
3. Acquire crop images and submit them to the AI-based computer vision module for spoilage and contamination analysis
4. Collect storage and transportation parameters such as duration, temperature, and handling conditions for quality assessment
5. Apply machine learning models to predict freshness levels and potential quality degradation risks

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6. Record all critical supply chain events and analysis outcomes on the blockchain ledger to ensure immutability and transparency
7. Update role-based dashboards with real-time batch status, quality indicators, and predictive alerts.
8. Enable QR-code-based access for stakeholders and consumers to verify batch origin, handling history, and quality status.
9. Log system performance metrics and analytical results for evaluation and future optimization

F. Hardware and Software Requirements

- Standard desktop or laptop system with a minimum of 8 GB RAM and a quad-core processor.
- Python 3.7 or later, TensorFlow/Keras for AI models, Scikit-learn for ML prediction, MongoDB for data storage, Ethereum/Hyperledger for blockchain implementation, React.js for frontend development, and supporting visualization libraries

IV. SIMULATION AND EVALUATION FRAMEWORK

This section describes the overall system design, evaluation process, and performance assessment strategy adopted for the proposed AI-driven Food Supply Chain Health Tracker. The framework integrates Artificial Intelligence (AI), Machine Learning (ML), and Blockchain technologies to assess food quality, predict spoilage risks, and ensure end-to-end traceability across the supply chain. The system is implemented as a web-based platform with Python serving as the backend processing layer, enabling real-time data analysis, secure event logging, and stakeholder interaction

A. System Architecture and Workflow

The proposed architecture aims to ensure rapid and uninterrupted movement of emergency vehicles (EVs), including The proposed architecture is designed to ensure continuous monitoring of food quality and transparent traceability from farm to consumer. The major components of the system are summarized as follows:

Web-Based Application Platform:
The application provides role-based access for farmers, distributors, retailers, administrators, and consumers. It enables batch creation, data submission, quality visualization, and traceability verification.

AI and ML Processing Layer:
AI-based computer vision models analyze uploaded crop images to detect spoilage and contamination, while ML models predict freshness levels and quality degradation risks based on storage and transportation parameters.

Blockchain Traceability Module:
Blockchain technology is used to securely record all critical supply chain events, including batch creation, inspections, storage updates, and transit milestones. This ensures data immutability, transparency, and resistance to tampering.

Database and Analytics Layer:
A centralized database stores structured batch metadata and analytical outputs, supporting real-time dashboards, alerts, and evaluation metrics for stakeholders.

B. System Evaluation Setup

The evaluation framework is designed to assess the effectiveness of the proposed system under realistic food supply chain scenarios. Multiple food batches are tracked across different supply chain stages to evaluate quality monitoring accuracy and traceability performance.

Batch Configuration:
Food batches are created with varying crop types, harvest dates, and storage conditions to simulate real-world agricultural diversity.

Data Collection Scenarios:
Image uploads, environmental parameters, and transit data are collected at different stages to evaluate AI-based detection accuracy and ML-based prediction reliability.

C. Traceability and Verification Process

The traceability mechanism links physical food products to their digital records using QR-code-based identification. When a batch progresses through the supply chain, each event is recorded on the blockchain ledger. Scanning the QR code retrieves complete batch information, including origin, handling history, AI-based quality assessment results, and blockchain verification details. This process enables transparent and trustworthy verification for all stakeholders, including end consumers

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D. Results and Observations

Food Quality Monitoring Performance:

- AI-based image analysis successfully identified visible spoilage and contamination indicators.
- ML models provided early predictions of freshness degradation under adverse storage conditions.

Traceability and Transparency:

- All supply chain events were recorded securely on the blockchain ledger without data loss.
- QR-code-based access enabled instant verification of batch origin and quality history.

Stakeholder Impact:

- Farmers and distributors received timely alerts regarding potential quality risks.
- Consumers gained improved confidence through transparent access to verified food information.

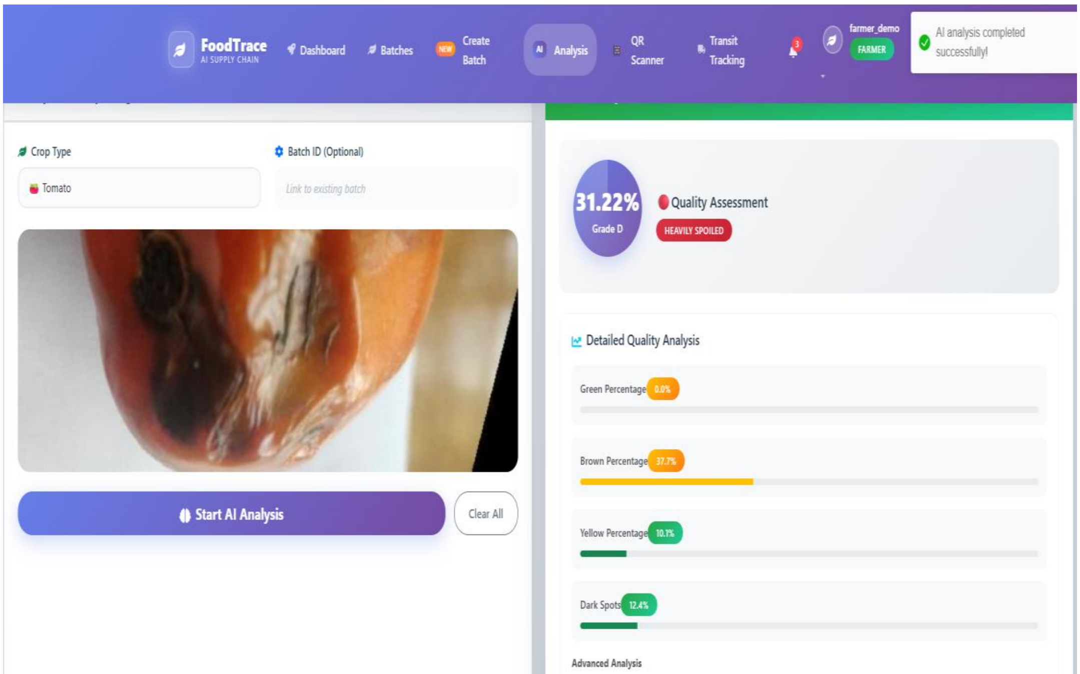

Fig.2. AI-based spoilage detection output for uploaded crop image

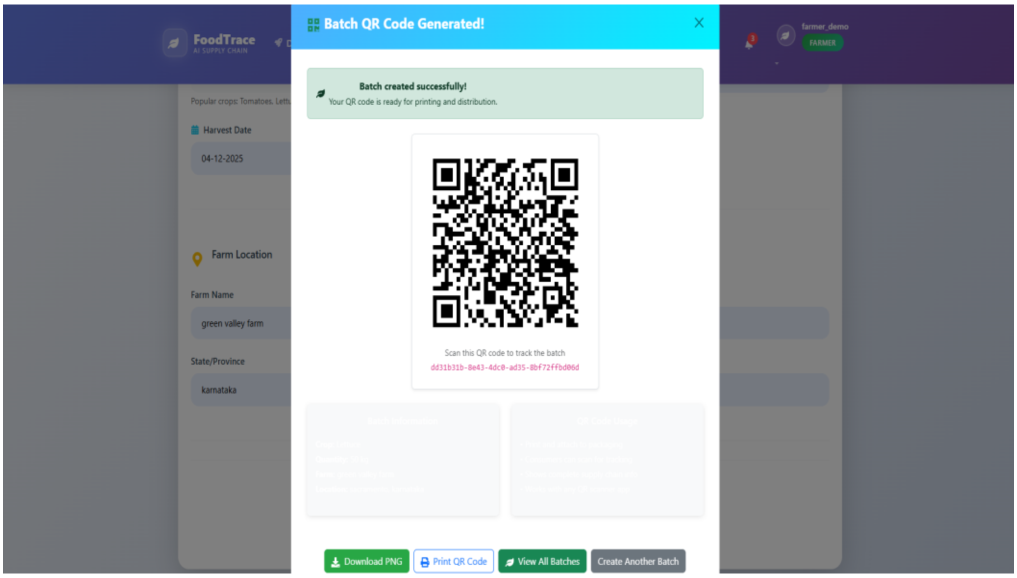

Fig.3.QR-code-based food batch traceability and verification output

- Food batches with early spoilage indicators were identified promptly through AI-based analysis.

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- Predictive alerts enabled timely handling decisions, reducing the risk of quality degradation during storage and transportation.

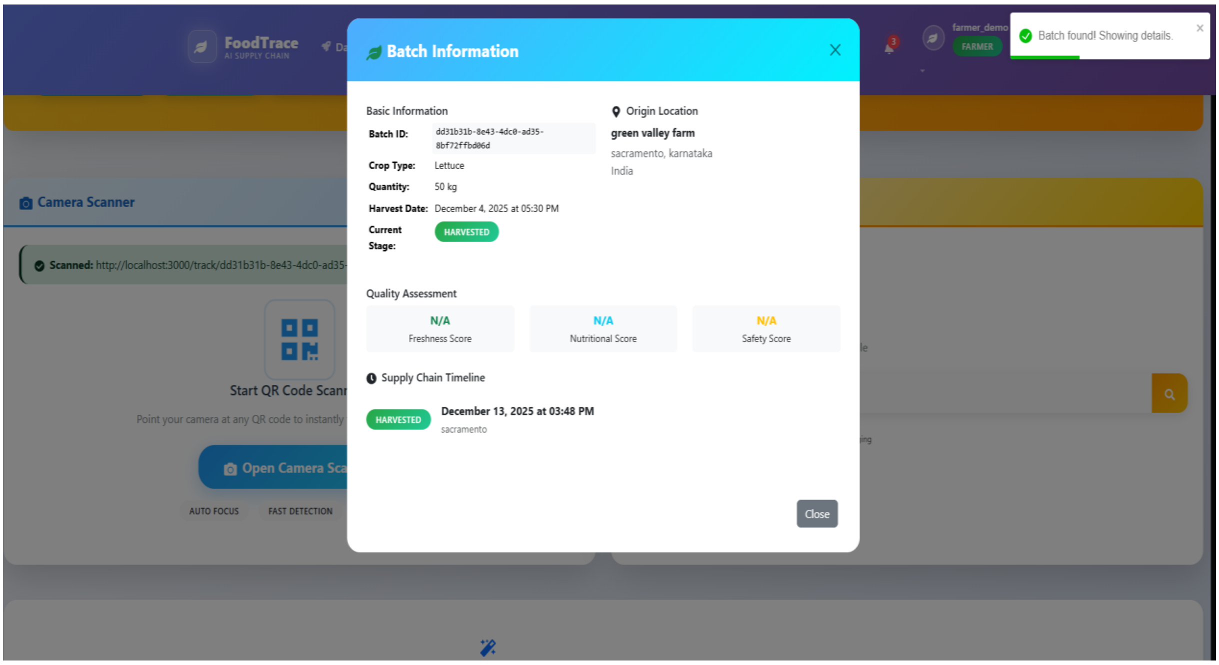

Fig. 4. System-generated food batch information retrieved through QR code scanning

V. RESULTS AND DISCUSSION

The experimental evaluation of the proposed AI-based Food Supply Chain Health Tracker demonstrates its effectiveness in improving food quality monitoring, spoilage prediction, and supply chain transparency. Multiple food batch scenarios were evaluated across different supply chain stages, including harvesting, storage, and transportation, to assess system performance under varying handling and environmental conditions.

The results indicate that the AI-based computer vision model successfully identified visible indicators of spoilage and contamination from uploaded crop images. Early detection of quality degradation enabled timely intervention, reducing the likelihood of spoiled products progressing further along the supply chain. Compared to manual inspection methods, the automated image analysis provided faster and more consistent quality assessment.

The machine learning models effectively predicted freshness levels and quality degradation risks based on storage duration, temperature, and transit conditions. These predictions allowed stakeholders to anticipate spoilage risks before they became critical, supporting proactive decision-making and reducing post-harvest losses.

In addition, the blockchain-based traceability mechanism ensured secure and tamper-proof recording of all supply chain events. Each batch's origin, handling history, and quality assessment results were reliably stored and retrieved through QR-code-based access. This improved transparency and accountability across stakeholders while enhancing consumer trust. Overall, the integrated system demonstrated improved food safety, reduced quality uncertainty, and minimal operational overhead for non-disrupted supply chain activities.

VI. CONCLUSION

This work demonstrates the practicality and effectiveness of integrating Artificial Intelligence (AI), Machine Learning (ML), and Blockchain technologies to enhance food quality monitoring and traceability across agricultural supply chains. The proposed Food Supply Chain Health Tracker successfully models real-world supply chain operations and enables intelligent assessment of food quality from harvest to consumption.

AI-based computer vision techniques provide automated detection of spoilage and contamination, while ML models enable early prediction of freshness degradation based on storage and transportation conditions. These capabilities transform conventional reactive inspection processes into proactive quality management mechanisms. Furthermore,

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blockchain-backed traceability ensures secure, immutable, and transparent recording of all supply chain events, reducing data manipulation and improving accountability.

The inclusion of QR-code-based verification allows stakeholders and consumers to access reliable batch-level information, strengthening trust and transparency within the food ecosystem. Overall, the proposed system improves food safety, reduces post-harvest losses, and demonstrates the potential of intelligent, technology-driven solutions for modern food supply chain management.

VII. FUTURE WORK

Although the proposed system effectively demonstrates the use of AI, ML, and blockchain technologies for food quality monitoring and traceability, several enhancements can be explored to improve its scalability and real-world applicability. Future work may focus on integrating IoT-based sensors to capture real-time environmental parameters such as temperature, humidity, and gas levels during storage and transportation, enabling more accurate and continuous quality assessment.

Another important extension involves expanding the AI models to support a wider variety of crops and food products, as well as incorporating advanced deep learning architectures to improve spoilage detection accuracy. Integration of edge and cloud computing can further optimize processing efficiency by reducing latency and enabling faster decision-making for large-scale deployments. Additionally, future implementations may explore interoperability with government food safety authorities and regulatory systems to support compliance, automated auditing, and large-scale adoption of intelligent food supply chain management solutions.

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