International Conference on Communication, Computing and Data Security

Cropchain: Organic Crop Verification System Integrating Blockchain and Bio-Sensors

AIPCP25-CF-ICCCDS2025-00012 | Article

Cropchain: Organic Crop Verification System Integrating Blockchain and Bio-Sensors

Amit Maurya[1, a], Sunil Khatri[2, b], Priyanka Musale[3, c], Sanjeev Ghosh[4, d]

[1]*Assistant Professor, Department of Internet of Things, Thakur College of Engineering and Technology, Mumbai, India.*
[2]*Assistant Professor, Department of Internet of Things, Thakur College of Engineering and Technology, Mumbai, India.*
[3]*Assistant Professor, Department of Internet of Things, Thakur College of Engineering and Technology, Mumbai, India.*
[4]*Professor, Department of Internet of Things, Thakur College of Engineering and Technology, Mumbai, India.*

[a)] amit.maurya021@gmail.com
[b)] skhatri1909@gmail.com
[c)] priyanka.pekhale05@gmail.com
[d)] sanjeevnghosh@gmail.com

Abstract. The rising complexity of agricultural supply chains and worries about food safety have shown how limited traditional traceability systems are, especially when it comes to data reliability, openness, and how quickly they respond to contamination events. This article talks about a traceability system that combines IoT and blockchain technology to improve the authenticity of food and build customer trust. The suggested system uses sensors to monitor the environment in real time for soil nutrients (NPK), pH, temperature, and humidity. It also has a MongoDB backend and stores data on the Ethereum platform using smart contracts. This work makes a unique contribution by using an acetylcholinesterase (AChE)-based electrochemical sensor to find organophosphate pesticide residues for the first time. The traceability framework lets people access it on their phones through a React Native app with a QR code. This lets customers get specific information about a product, such as its environmental and handling history. The architecture makes it possible to get data in real time, store it safely, and check it without being able to change it. A comparison with existing methods shows that this method is more transparent, cost-effective, and scalable. This study establishes the groundwork for a more powerful and smart traceability system by combining new technologies and suggesting ways to improve security, field validation, and AI-driven analytics in the future.

INTRODUCTION

To keep the world safe from hunger, agricultural supply networks are very important. But the industry always has problems that put consumers' health, safety, and trust at risk. It has had problems with inefficiency, fraud, and a lack of transparency for a long time, and these problems often have catastrophic effects. For instance, the 2018 E. coli incident linked to romaine lettuce showed how bad it is when traceability systems aren't good enough. It took weeks to find the cause, and it made a lot of people sick, cost a lot of money, and made people less trusting of the food supply.

Repeated controversies concerning pesticide residue violations, such the discovery of hazardous organophosphate levels in imported fruits, make it even more clear that we need stronger ways to protect the quality of our food. Current centralized traceability systems are still not good enough since they may be changed, are slow, and can lose records. They don't give the accountability and openness needed to make sure food is safe.

This paper fills in the gaps by using IoT-based sensors to monitor environmental elements like temperature, humidity, and soil conditions in real time and with accuracy, together with the transparency and immutability of blockchain technology. It also shows a first draft of an electrochemical sensor that can find dangerous chemicals like pesticides and poisons, which adds another layer of protection against food contamination. This system wants to make the agricultural supply chain into an open, safe, and efficient ecosystem that puts the safety and confidence of consumers first by using cutting-edge technologies like blockchain, the Internet of Things (IoT), and chemical detection.

LITERATURE SURVEY

Many studies have looked at how to combine blockchain and the Internet of Things (IoT) for supply chain management and traceability. They have found that this can lead to better data integrity, real-time monitoring, and more openness. But these systems often don't have the advanced features that are needed to keep an eye on things all the time and discover impurities. It has been said in the literature that electrochemical sensors, especially those that use enzyme inhibition assays like acetylcholinesterase (AChE), offer a lot of potential for discovering harmful pesticides in food. This field has come a long way, but not many systems have properly integrated these sensors into a complete traceability framework. This highlights how vital it is to have one way to leverage blockchain, the Internet of Things, and chemical detection to make food safer and get people's trust back. This essay talks about these key themes and problems that have been talked about in other publications. One example of a traceability system works in three main steps: first, it finds the traceability unit; second, it builds a layered architecture to make it more secure; and third, it places it on blockchain platforms like Ethereum and EOSIO. Every 0.5 seconds, EOSIO can make a block, and every 1 second, it can confirm a block. This is a lot faster than Ethereum. This framework makes it easy to follow food on the blockchain, which is incredibly helpful for keeping track of convoluted supply chains. [1]. IoT sensors can always check on things like temperature and humidity. This helps keep food safe and of good quality by discovering faults that could make it dirty. Technologies like RFID and QR codes make real-time data flow in the supply chain even more accurate and helpful. This setup works with a blockchain database to make it simple to get data in real time and keep it safe. This makes the mechanism for tracking things more open and trustworthy. This strategy makes it easier to track food and makes management better all throughout the supply chain [2]. An expert system in a smart city can employ blockchain technology and IoT sensors to do things like turn on lights and send off alarms automatically.

The Ethereum blockchain safely and permanently stores relevant sensor data, and smart contracts automatically take action when sensor readings go above certain levels. This method helps install sensors in the best spots and makes sure that data is managed correctly and can't be tampered with in places like parks, public spaces, and health areas [3].

A microcontroller development board adds connectivity and functionality to the combination of Amazon Web Services (AWS) and Internet of Things devices. AWS processes data quickly and in a specific location, and it works well with a number of other cloud services. Data transfer and basic control of sensor nodes are done using the MQTT protocol. A Software Development Kit (SDK) was used to make an Android app that makes the system even more connected. The built-in firmware makes it easy to install, log in, set up the network, and keep the device safe. This design lets devices grow, register new devices all the time, and lets users and linked devices talk to each other without any problems [4].

An AWS IoT Core-based home automation air flow control system can use MQTT via WebSocket to change the flow of air based on real-time data from environmental sensors. The MQTT protocol lets devices talk to each other with minimal latency, which speeds up the automation setup's response time. WebSocket provides a permanent two-way communication channel, which makes this design work well for processing and managing data. The architecture provides reliable and high-quality regulation of air flow while using less energy [5].

Electrochemical sensors have become more popular as a good way to find pesticides on-site since they are portable, cheap, and easy to use, which makes them better than older chromatographic approaches. When pesticides come into contact with an electrode surface, these sensors measure the electrical signals that are created. Enzyme-based systems, such acetylcholinesterase (AChE), are widely used in the process to find certain types of pesticides, like organophosphates and organochlorines. The article talks about numerous methods for electrochemical detection, focusing on the many approaches, electrode materials, and electrolyte solutions that can be used to make it easier to find herbicides like glyphosate, lindane, and bentazone. To check how well the sensors work, we looked at certain important analytical performance criteria, such as the limit of detection and the range of linearity. [8]

Electrochemical methodologies are fundamental to the effectiveness of AChE-based biosensors, dramatically enhancing their sensitivity and specificity toward pesticide detection. The amperometric and potentiometric approaches are predominantly adopted in biosensors, each possessing inherent advantages for the identification of organophosphates and organochlorines. Amperometric biosensors measure the current produced by the electrochemical oxidation or reduction of an analyte at a specified working electrode. The sensitivity can be improved with the incorporation of materials such as conjugated polymers and nanocomposites like Ag-rGO-NH2 (silverreduced graphene oxide with amine functional groups), which facilitate effective electron transfer and offer an enlarged surface area for enzyme immobilization, thereby decreasing the threshold of detection and increasing sensitivity toward organophosphate pesticides. On the other hand, potentiometric biosensors measure the difference in voltage between a working electrode and a reference electrode when an analyte is present. The sensors are usually simpler and, therefore, often more affordable, which makes them attractive for widespread use. By taking advantage of the high affinity of AChE for organophosphates and organochlorines, the biosensors are capable of reaching selective detection in complex sample matrices such as vegetable oils, in which matrix interference would otherwise reduce sensor performance. [9].

The AChE enzyme catalyzes the hydrolysis of acetylcholine, and its inhibition by pesticides can be monitored through changes in current, thus enabling the detection of toxic substances in food samples. The technique has proven to be effective in practical applications, and hence it is a promising method for pesticides' monitoring. Screen-printed electrodes have advantages such as low cost, simplicity of fabrication and miniaturization, and are therefore convenient for on-site operations. Understanding the role played by AChE in the detection process is very important since enzymes show different sensitivities towards specific pesticides so the best one should be selected. Moreover, the ability of the sensor to work in the presence of organic solvents implies that this is an area that needs developing robust mechanisms capable of operating in different ambient conditions, a condition critical in food safety monitoring. [6].

The effective application of modified microelectrodes underscores the promise of nanomaterials such as CuO and Co3O4 in enhancing the performance of sensors, which may be useful in our sensor design to achieve greater sensitivity and selectivity. More detailed information about parameters such as the detection range and sensitivity of the sensor will be used to lead our calibration and optimization. [7]

Implementation of blockchain-based traceability systems in the agri-food sector brings numerous environmental and economic benefits. From an environmental perspective, blockchain technology increases sustainability by facilitating better efficiency in the use of resources and reducing waste. With real-time information about the origin, quality, and handling of food products, blockchain helps stakeholders in the supply chain make better decisions, which allows farmers and other stakeholders within the supply chain to optimize resource usage and reduce environmental impacts, including carbon footprint and energy consumption. Further, the immutability of blockchain records ensures better compliance with environmental rules and standards, resulting in more responsible agricultural practices. Economically, blockchain-based traceability systems can substantially lower the cost of food recalls and fraud. Since the products that are contaminated or fraudulent can be identified and isolated more quickly, the potential for extensive food recall decreases the financial losses and reputational damage that are linked to them. Further, increased efficiency and accuracy in data management facilitate the operation of supply chains at lower operational costs and higher profitability. In addition, the adoption of blockchain technology fosters consumer trust and could be the basis for higher market demand and premium pricing for verified and traceable products. [10].

IBFS is an IoT-based blockchain system with a smart contract architecture to facilitate trust, reliability, and transparency in food supply chains. To conclude, the MQTT broker is used for recording data obtained from IoT sensors on geolocation, movement, and temperature of produce shipments. MQTT-based cloud brokers collect such data, and two smart contracts implemented in Solidity are utilized within this system based on Ethereum-based blockchain technology. The first smart contract represents custody, and the second is designed for tracking the shipment and transportation of produce. Quality evaluation is realized through data sensing by IoT sensors, and data management occurs over the blockchain and MQTT servers of this system based on temperature, humidity, transition time, and final item evaluation. The effectiveness of IBFS is demonstrated by its performance tests. In particular, the evaluation of gas costs under various test conditions proved that this system has operational efficiency. [11]

EOSIO has vulnerabilities at three levels: smart contracts, the EOS VM, and the blockchain itself. Each of these vulnerabilities is accompanied by attack techniques, mitigations, and best programming practices for issues that cannot be officially fixed. Although very few of EOSIO's mechanisms are similar to Ethereum's, this is the first survey focused specifically on EOSIO vulnerabilities.[12]

AWS Lambda demonstrates a serverless system that takes away the management of servers and lets the focus be on business logic and savings. However, this introduces challenges around security: malicious code injection, sensitive data leakage, DDoS attacks, excessive privileges, vulnerable dependencies, certificate issues. It identifies key mechanisms and risks, with solutions reviewed from AWS and industry practices, and gives implementations on AWS servers to provide protective measures in enhancing the security and resilience of Lambda.[13]

A sensitive amperometric acetylcholinesterase (AChE) biosensor was developed using gold nanorods (AuNRs) for the detection of organophosphate pesticides. AuNRs exhibited excellent electrocatalytic activity in oxidizing thiocholine at +0.55 V (vs. SCE). The biosensor detected paraoxon in the range of 1 nM–5 μM and dimethoate in the range of 5 nM–1 μM, with detection limits of 0.7 nM and 3.9 nM, respectively. It outperformed the previously reported AChE biosensors, displaying more than 95% current recovery, high sensitivity, good stability, and applicability in real water samples, which holds great promise for pesticide analysis. [14]

The increased demand for food has resulted in a rise in the use of pesticides to protect crops from various factors such as insect infestation and drought. However, the pesticide residues on harvested crops cause major health hazards globally. Traditional methods of pesticide detection, including high-performance liquid chromatography (HPLC) and mass spectrometry (MS), are highly effective but also very costly, time-consuming, and laborious. Electrochemical biosensors represent a very promising alternative because they are reliable, simple, and cheap. These sensors have been explored for the detection of four categories of pesticides, showing advantages as a rapid and sensitive method for pesticide detection. [15]

Ethereum systems are vulnerable to various attacks, including reentrancy attacks, denial-of-service (DoS), and smart contract exploits. Mitigation strategies focus on secure coding practices, the use of verification tools, and robust consensus mechanisms. Key vulnerabilities such as the risk of losing funds through poorly designed smart contracts and attacks on Ethereum's consensus protocol are highlighted. Recommendations for enhancing system security include implementing stronger cryptographic techniques, optimizing contract code to avoid errors, and improving Ethereum's transaction validation processes.[16]

A review of recent literature reveals that while numerous systems integrate IoT or blockchain individually for agricultural applications, relatively few propose a unified architecture combining both technologies with real-time biosensing capabilities.

TABLE 1. *COMPARATIVE ANALYSIS OF EXISTING TRACEABILITY SYSTEMS*

Study	Technologies Used	Sensor Integration	Blockchain Layer	Limitation
Surasak et al. (2019) [2]	IoT, QR codes	Environmental sensors	Basic hash logging	No chemical detection or sensor-level security
Carreno Aguilera et al. (2021) [3]	IoT, Expert System	General-purpose sensors	Ethereum smart contracts	Focused on smart city, not agri-specific
Panwar et al. (2023) [10]	IoT, Blockchain	Metadata-level logging	Ethereum + IPFS	No real-time sensor integration or contamination alerts
Singh & Raza (2022) [11]	IoT, Blockchain	Shipment-level IoT	Smart contract-based tracking	Focus on logistics, lacks field-level sensing
Present Study	IoT, Blockchain, AChE sensor	NPK, pH, humidity, temperature, electrochemical pesticide sensor	Ethereum smart contracts with MongoDB off-chain storage	Integrates chemical sensing + traceability + mobile access

As shown in the table, most prior systems either rely solely on environmental sensing or high-level logistics data. They lack the integration of electrochemical biosensing to detect pesticide contamination in real-time. Additionally, sensor-level calibration, power-aware deployment, and user access via mobile apps are rarely addressed. The proposed system bridges this gap by presenting a layered, scalable architecture that combines: Environmental and chemical sensing, Real-time mqtt data flow, Off-chain and on-chain storage, Consumer interaction via mobile interface. This makes it one of the few holistic solutions focused on end-to-end food traceability with contamination detection, particularly tailored for low-resource rural deployment [17].

METHODOLOGY

The proposed system combines real-time environmental and chemical sensing with blockchain-enabled data logging to establish a secure and transparent food traceability framework. The methodology is organized into distinct phases that handle sensing, aggregation, transmission, storage, blockchain recording, and user access.

At the farm level, environmental monitoring is carried out using an NPK sensor, a pH sensor, and a DHT11 sensor. These components measure soil nutrients (Nitrogen, Phosphorus, Potassium), soil pH, temperature, and humidity. To ensure traceability throughout the supply chain, additional DHT11 sensors are also installed in transport vehicles and warehouse storage environments. These sensors continuously capture ambient data during post-harvest handling.

Sensor data is aggregated through an ESP32 microcontroller, which acts as the central processing unit. It collects signals from both analog and digital interfaces, formats them into structured data packets, and appends metadata such as sensor ID, timestamps, and location identifiers. This structured data is then transmitted via the lightweight MQTT protocol to a local broker, from where it is parsed and relayed by a Node.js server to a cloud-based MongoDB database hosted on MongoDB Atlas [18].

MongoDB serves as the primary data storage system, preserving each sensor's output in a structured format that includes temporal and spatial metadata. A reference to the hash of the previous data entry is maintained to facilitate linkage with blockchain transactions, establishing continuity in the data chain.

To secure and verify the data, a smart contract deployed on the Ethereum blockchain logs selected key attributes such as sensor identifiers, timestamps, and hashed sensor readings. This blockchain layer provides an immutable and tamper-proof record of environmental data entries, supporting regulatory compliance and product authenticity verification [19].

Finally, consumer interaction is enabled through a React Native mobile application. Each agricultural product is tagged with a QR code that maps to its corresponding Product ID. Upon scanning, the app retrieves traceability information from MongoDB and confirms it via blockchain entries through an API Gateway. This enables end users to access transparent, verifiable data about product origin, environmental conditions, and handling history in real time[20].

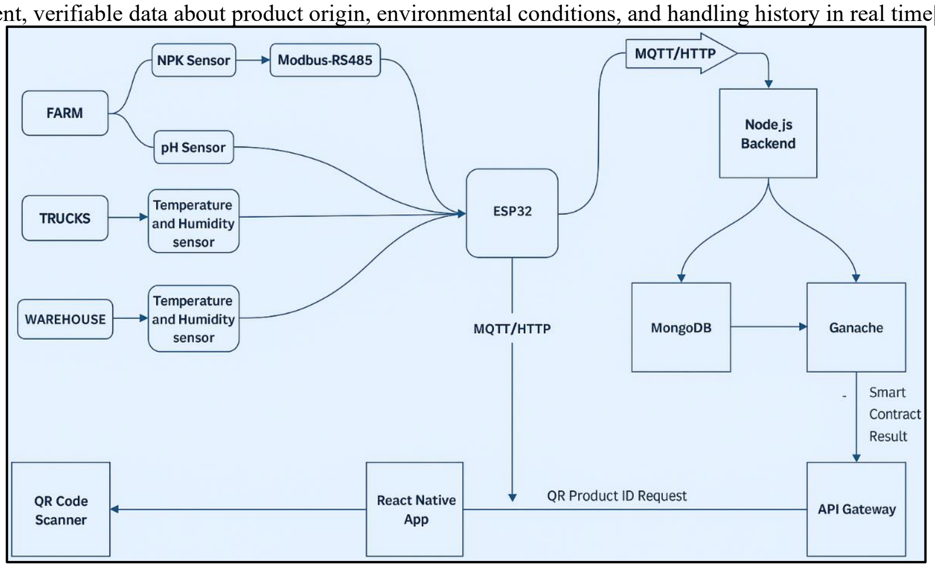

FIGURE. 1 *PROJECT FLOW FOR FOOD TRACEABILITY USING BLOCKCHAIN AND IOT*

RESULTS AND DISCUSSION

MOBILE APPLICATION DEVELOPMENT

The mobile application was effectively developed to increase the interactivity of users with the food traceability system. Built on the react native framework, the application has an intuitive interface that allows consumers to scan QR codes on food packaging to access important information about the product's origin, quality, and safety. Most notable is real-time data representation, where the app retrieves and displays the current temperature reading and other sensor data, so consumers can be sure they always have the most up-to-date information about the product. Furthermore, the application has a built-in secure authentication system for users, enabling personalized experiences while engendering trust among consumers toward the system. Embedded are also data visualization tools that help users make sense of changes in the product condition over time in a graphical format.

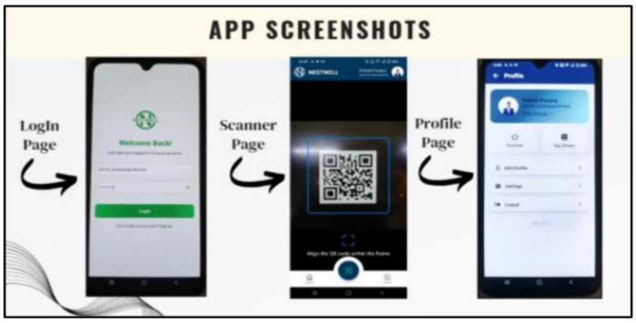

FIGURE. 2 *INTERFACE OF THE MOBILE APPLICATION*

Calibration of the DHT11, pH Sensor, and NPK Sensor

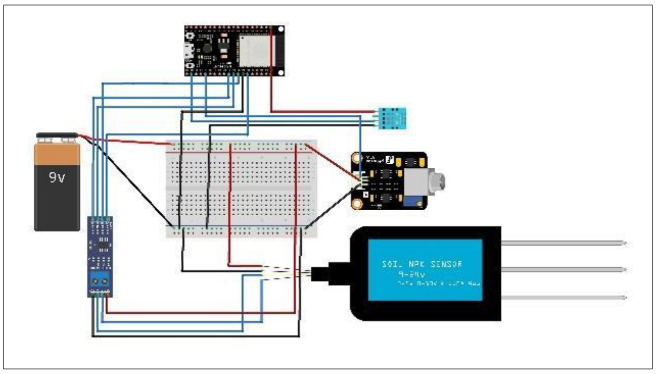

FIGURE. 3 *HARDWARE SETUP*

DHT11 Sensor: The DHT11 temperature and humidity sensor was validated using standard atmospheric conditions. It was tested in controlled environments to compare its readings against reliable digital thermometers and hygrometers. Minor offsets, if observed, were adjusted in the JavaScript data parsing logic to enhance precision.

pH Sensor: Calibration involved submerging the pH sensor into standard buffer solutions with known pH values (4.0, 7.0, and 10.0). After stabilization, readings were taken, and voltage-to-pH mapping was changed to make sure it matched the real values. We tested the performance across the entire working range with alternative buffer solutions to make sure it was consistent.

We built up the NPK (Nitrogen, Phosphorus, Potassium) sensor using soil samples that we knew contained certain quantities of nutrients. We checked the readings against the results of lab testing and made tweaks to the software to make sure the nutritional levels were what we thought they were. This made it easier to believe the results of measuring soil fertility on farms. Sensor for Electrochemistry: The first design of the electrochemical sensor is a wonderful start for making chemical detection better in the future, especially when it comes to discovering pesticide residues in food. It is very crucial to be able to monitor and discover harmful chemical residues in real time since more and more people desire to eat foods that are organic and free of pesticides. This could help individuals stick to the guidelines better and make them feel more sure that the food is safe. If we add this type of sensor to the current system, we might be able to look at other types of pollutants. It is also vital to calibrate these sensors together to make sure that the data is correct all the way through the traceability chain and that environmental and soil conditions are monitored precisely and in real time. When used with blockchain verification, this makes the system much more reliable and useful.

MongoDB Setup for Sensor Data

FIGURE. 4 *MONGODB DATA*

MongoDB is the main part of the food traceability project that safely gets and stores sensor data sent by the ESP32 microcontroller over MQTT. This approach allows for scalable and reliable data intake straight from the field, thus there is no need for cloud platforms like AWS. A React Native mobile app links to the stored data and lets users see verified product history by scanning a QR code. This real-time access to IoT-verified sensor data directly enhances transparency and consumer trust.

JavaScript-Based MQTT and MongoDB Integration: This component handles real-time transmission of data from ESP32 to MongoDB. The JavaScript code running on a local or remote Node.js server subscribes to MQTT topics published by ESP32. Incoming sensor values are parsed, verified, and inserted into the MongoDB database. The system ensures accuracy and allows traceable, structured storage of data for future blockchain integration.

To evaluate the capacity to routinely acquire and transmit food-related characteristics, the put in use system was continuously tested in indoors and semi-outdoor circumstances. Every hardware component—including the DHT11, pH sensor, NPK sensor, rain sensor, and ESP32 microcontroller—showered consistent and reliable results. These ordered sensor values might be uploaded with HTTP connection to MongoDB Atlas. Real-time updates for blockchain logging demands and visualization requirements allowed MongoDB's real-time cloud database to function satisfactorily, therefore enabling simple data access.

TABLE 2. *PERFORMANCE COMPARISON*

Feature	(IoT + MongoDB + Blockchain)	Existing Systems (Traditional / Commercial)
Sensor Integration	Real-time sensor data from pH, DHT11, and NPK via ESP32	Often manual data entry or expensive proprietary sensors
Data Storage	Open-source MongoDB for flexible and scalable storage	Centralized SQL-based systems or proprietary cloud databases
Blockchain Integration	Uses Ethereum smart contract (logData function) for immutability	Most lack blockchain; traceability is often dependent on trust
Transparency & Tamper-Proofing	Blockchain ensures immutable records and public verifiability	Traditional systems are vulnerable to manipulation
Cost Efficiency	Low-cost hardware (ESP32, DHT11, soil sensors) and free tools	Expensive commercial solutions, licenses, and hardware
Real-Time Monitoring	Real-time sync to MongoDB and web/dashboard support	Usually, delayed updates or static logs
QR Code Traceability (App)	Users scan QR to get real-time sensor data with history	Basic QR shows static PDF or webpage, no live data
Offline/Edge Capability	ESP32 works offline and syncs when reconnected.	Mostly rely on constant internet, may fail in rural setups

The created IoT-based food traceability system was tested against current market platforms as well as conventional tracking systems. The comparison centered on five fundamental elements—data gathering speed, integrity, cost-effectiveness, real-time access, and scalability—all of which are rather important for open and successful food supply chain management.

The reasonably low cost, Wi-Fi-enabled board gathering real-time data from sensors tracking temperature, pH, and humidity using the ESP32 microcontroller forms the backbone of the system. The ESP32 transfers data immediately to a MongoDB database in real time unlike semi-automated solutions depending on RFID tags or barcodes or manual entry. Faster and more accurate data collecting results come from major delay reduction and human participation elimination from this asynchronous transfer.

Designed to guarantee data integrity, the project features a Ganache-built prototype blockchain layer. Blockchain integration guarantees that, notwithstanding the current local testing environment, once data is entered it becomes tamper-proof. While they might maintain logs or records, traditional systems usually lack means to guarantee these records remain unchangeable over time unless expensive blockchain technologies are embraced. This paper shows that a low-cost, simulated blockchain could offer a robust backbone for traceability and trust.

Another area where the suggested approach beats several commercial solutions is cost-effectiveness. Small-scale manufacturers or academic institutions find them less easily accessible as most traceability solutions available today depend on costly cloud services, proprietary sensors, or software licenses. On limited-budget projects in rural or research-oriented settings, this system is fairly practical since it just depends on open-source software and rather reasonably cheap hardware.

Regarding real-time access, the React Native-built simple QR code-based interface offers. Without being directed to further web sites, users might just scan a product to rapidly view its environmental history and source information. Conventional solutions, which sometimes rely on batch uploads or centralized portals free of live changes, rarely offer this ideal user experience.

Furthermore, the system is relatively adaptable because of its modular and expandable construction. Minimal alteration of the current design would be necessary for future sensor additions or integration of advanced analytics. From research projects to commercial-scale supply chains, this future-ready methodology guarantees the system may develop with changing technical needs and more widespread use cases.

Even if its component—the blockchain—is still in prototype form—its presence demonstrates forward-looking design. The created smart contract logic offers a window of insight on how distributed verification could boost consumer confidence in openness and food safety. Once moved to a public blockchain such as Ethereum, system dependability and reputation will be much improved.

In many fields, the project satisfies and even exceeds the declared goals all through design. Acting as proof-of-concept, it not only operates efficiently but also paves the path for industry, retail, consumer awareness, and agricultural as well as practical uses. By properly combining IoT data collecting, cloud storage, and prototype blockchain validation, it provides a solid, scalable, fairly cost answer for modern food traceability.

Although the proposed IoT–Blockchain traceability framework shows promising results in controlled environments, scaling the system for widespread agricultural deployment, especially in rural or resource-constrained regions, introduces several practical challenges. These include:

a) Network Connectivity and Data Transmission:

Rural areas often lack stable internet infrastructure. To mitigate this, the system employs ESP32 microcontrollers that support offline caching of sensor data. When reconnected to Wi-Fi or a GSM gateway, the data packets are synchronously uploaded via MQTT. Additionally, the system is compatible with LoRaWAN modules for long-range, low-bandwidth transmission in regions without Wi-Fi or cellular coverage.

b) Power Supply Constraints:

Consistent power availability is another challenge in agricultural fields. Our nodes operate at ultra-low power consumption (0.36 W) and are designed to be powered via solar panels with rechargeable Li-ion battery backup. During field tests, 2000 mAh batteries supported full sensor operation for up to 22 hours without sunlight.

c) Sensor Calibration and Environmental Drift:

Real-world sensor accuracy can degrade due to temperature swings, soil salinity, or dust accumulation. To counter this:

- NPK and pH sensors include software-based auto-zeroing routines at startup.
- Each node maintains local calibration coefficients based on previous trusted readings and alerts users via the mobile app when recalibration is necessary.
- The system supports remote firmware updates via OTA (Over-the-Air) mechanisms, allowing continuous improvement of calibration algorithms.

d) Scalability and Node Management:

With increasing deployment scale, managing hundreds of sensor nodes becomes complex. The system addresses this through:

- A centralized device registry hosted in MongoDB Atlas, assigning each sensor a unique location-aware ID.
- Batch provisioning scripts and mobile onboarding via QR code reduce setup time.
- MQTT supports topic-based filtering, allowing region-specific data handling and minimizing server-side load.

e) User Skill and Operational Complexity:

Many rural farmers may not be tech-savvy. The mobile app provides a low-literacy interface with icons and audio prompts. Additionally, training modules in local languages are under development to facilitate adoption.

These design strategies and validation results suggest that the system is capable of handling field-level deployment challenges while remaining affordable, maintainable, and scalable.

CONCLUSION

This paper presents a comprehensive framework for food traceability that integrates IoT sensing, blockchain logging, and mobile application access to enhance transparency, security, and accountability within the agricultural supply chain. The system enables real-time environmental data collection (NPK, pH, temperature, humidity) using low-cost hardware and stores it securely in MongoDB, while logging key transaction hashes to the Ethereum blockchain for tamper-proof verification. A unique contribution is the inclusion of a preliminary electrochemical sensor design for detecting organophosphate residues, enhancing food safety by integrating chemical detection with traceability. Key outcomes from the implementation include successful real-time MQTT data streaming and sensor aggregation via ESP32, a QR-enabled React Native app for consumer-facing product traceability, a prototype blockchain smart contract (logData) integrated with MongoDB, and compatibility with offline operation and rural deployment constraints.

These results demonstrate the feasibility of building a cost-effective, scalable, and secure traceability infrastructure for agriculture using open-source tools and a modular design. Future work will involve field testing the biosensor, deploying the system on public blockchain networks, and integrating AI-based predictive analytics to improve supply chain responsiveness and decision-making.

FUTURE SCOPE

Future work will explore advanced technologies such as Artificial Intelligence (AI) and Machine Learning (ML), particularly for predictive analytics in demand forecasting, supply chain optimization, and proactive issue resolution. A significant area of focus will be developing AI-based chatbots to complement customer engagement and support. Crop analysis at the farm level can also be enhanced using machine-learning methodologies, helping farmers make better-informed decisions. Additional development will target innovative mobile apps that extend traceability features by offering consumers product suggestions, recipe ideas, nutritional information, and more, creating a richer user experience. These advances aim to build a high-tech yet user-friendly ecosystem at every stage of the food tracing architecture.

REFERENCES

1. A. K. Tripathi, K. A. Krishnan, and A. C. Pandey, “A novel blockchain and Internet of Things-based food traceability system for smart cities,” Int. J. Distrib. Sens. Netw., vol. 19, no. 3, Mar. 2023.
2. T. Surasak, N. Wattanavichean, C. Preuksakarn, and S. C.-H. Huang, “Thai agriculture products traceability system using blockchain and internet of things,” Int. J. Adv. Comput. Sci. Appl., vol. 10, no. 9, pp. 1-9, Sep. 2019.
3. R. Carreno Aguilera, M. Patino Ortiz, J. Patino Ortiz, and A. Acosta Banda, "Internet of Things expert system for smart cities using the blockchain technology," Universidad del Istmo, Tehuantepec, Oaxaca, M´exico; Instituto Polit´ecnico Nacional, SEPI-ESIME Zacatenco, M´exico City, M´exico, Published Jan. 29, 2021.
4. E. Pérez, J. C. Araiza, D. Pozos, E. Bonilla, J. C. Hernández, and J. A. Cortes, "Application for functionality and registration in the cloud of a microcontroller development board for IoT in AWS," Published June 22, 2021.
5. N. Imtiaz Jaya and M. F. Hossain, "A Prototype Air Flow Control System for Home Automation Using MQTT Over Websocket in AWS IoT Core," 2018 International Conference on Cyber-Enabled Distributed Computing and Knowledge Discovery (CyberC), Zhengzhou, China, 2018, pp. 111-1116, doi: 10.1109/CyberC.2018.00032.
6. S. Andreescu, T. Noguer, V. Magearu, and J.-L. Marty, "Screen-printed electrode based on AChE for the detection of pesticides in presence of organic solvents," *Centre de Phytopharmacie, Université de Perpignan-UMR CNRS 5054*, Perpignan Cedex, France, and *University of Bucharest, Faculty of Chemistry, Department of Analytical Chemistry*, Bucharest, Romania, Published December 18, 2001.
7. T. Narayan, M.-K. Reidy, S. Heelan, A. O’Riordan, and H. Shao, "Real-time electrochemical sensor for phosphate sensing in soil-water," Nanotechnology Group, Tyndall National Institute, Cork, Ireland, and School of Chemistry, University College Cork, Cork, Ireland.

8. Noori, J.S.; Mortensen, J.; Geto, A. Recent Development on the Electrochemical Detection of Selected Pesticides: A Focused Review. *Sensors*. 2020; 20(8):2221. https://doi.org/10.3390/s20082221.
9. Tsounidi D, Soulis D, Manoli F, Klinakis A, Tsekenis G. AChE-based electrochemical biosensor for pesticide detection in vegetable oils: matrix effects and synergistic inhibition of the immobilized enzyme. Anal Bioanal Chem. 2023 Feb;415(4):615-625. doi: 10.1007/s00216-022-04448-y. Epub 2022 Nov 29. PMID: 36445454; PMCID: PMC9839810.
10. Panwar, A.; Khari, M.; Misra, S.; Sugandh, U. Blockchain in Agriculture to Ensure Trust, Effectiveness, and Traceability from Farm Fields to Groceries. *Future Internet*. 2023; 15(12):404. https://doi.org/10.3390/fi15120404.
11. Singh, A.; Raza, Z. A Framework for IoT and Blockchain-Based Smart Food Chain Management System. Concurrency Computat.: Pract. Exper. 2022; 35:e7526. https://doi.org/10.1002/cpe.7526.
12. He, N., Wang, H., Wu, L., Luo, X., Guo, Y., & Chen, X. (2022). A Survey on ETHEREUM Systems Security: Vulnerability, Attack, and Mitigation. ArXiv, abs/2207.09227. https://doi.org/10.48550/arXiv.2207.09227.
13. Barrak, A., Fofe, G., Mackowiak, L., Kouam, E., & Jaafar, F. (2024). Securing AWS Lambda: Advanced Strategies and Best Practices. 2024 IEEE 11th International Conference on Cyber Security and Cloud Computing (CSCloud), 113-119. https://doi.org/10.1109/CSCloud62866.2024.00027.
14. Lang, Q., Han, L., Hou, C., Wang, F., & Liu, A. (2016). A sensitive acetylcholinesterase biosensor based on gold nanorods modified electrode for detection of organophosphate pesticide.. Talanta, 156-157, 34-41 . https://doi.org/10.1016/j.talanta.2016.05.002.
15. Cao, Y., & Li, Z. (2021). Enzyme inhibition-based electrochemical biosensors for pesticide residues detection. , 12030, 120300H - 120300H-9. https://doi.org/10.1117/12.2617693.
16. Vijaykumar P. Yele, Sujata Alegavi, R. R. Sedamkar, “Hybrid Hesitant Fuzzy Linguistic Bi-Objective Binary Coyote Clustering Based Segmentation and Classifcation for Land Use Land Cover in Hyperspectral Image”, International Journal of Information Technology, DOI: 10.1007/s41870-023-01576-1, Oct 2023.
17. Hemant Kasturiwale Ayush Mishra, Sakshi Mehta, Bhavya Oza, Sumit Kumar, “Blockchain-Based Decentralized Document Verification and Its Applications”2025/2/13, Journal of Information Systems Engineering and Management,Volume 10,issue No. 10s (2025),Pages 137-151
18. Tushar H. Jaware, Hemant Kasturiwale, Rashmi Thakur, Mayur D. Jakhete, Manoj Chavan, Milind Rane."Deep Learning Model for Colon Cancer Classification using InceptionV3" J.ElectricalSystems20-4s(2024):132-139, Vol. 20 No. 4s (2024): DOI: https://doi.org/10.52783/jes.1862
19. Yogesh Thakare, U. . Wankhade, and Hemant Kasturiwale, “Intelligent Life Saver System for People Living in Earthquake Zone”. International Journal of Next-Generation Computing, vol. 14, no. 1, Feb. 2023, DOI:10.47164/ijngc.v14i1.1040
20. Alegavi, S., & Sedamkar, R. (2025), “Optimizing Remote Sensing Image Retrieval Through a Hybrid Methodology”, Journal of Imaging, MDPI, 11(6), 179. https://doi.org/10.3390/jimaging11060179