International Journal of Scientific Research and Engineering Development-– Volume 8 Issue 6, Nov- Dec 2025
Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

Transparent and Traceable Food Supply Chain Based on Decentralized Approach Using Blockchain

Kaveeya M, Rajalakshmi V, Raajasri C
Computer Science and Engineering, SRM Valliammai Engineering college, Chennai, India.
kaveeyam@gmail.com, v.uma4547@gmail.com, raajasri2003@gmail.com

Abstract:

We are currently navigating an era defined by interconnectedness and rapid technological advancements. The food supply chain has evolved into a complex and dynamic ecosystem, involving a diverse array of participants from producers and manufacturers to distributors, retailers, and consumers. This increased complexity presents significant challenges related to transparency, traceability, and trust, all of which are crucial for ensuring food safety, quality, and long-term viability. Traditional tracking methodologies, reliant on centralized databases and paper-based systems, are often slow, susceptible to manipulation, and characterized by inconsistent data. Consequently, there is a growing demand for innovative solutions. On that account, rising requirements for innovative solutions are being looked for throughout the supply chain concerning accountability and resilience.

Blockchain technology offers a groundbreaking solution to these issues by providing features such as unchangeable records, improved transparency, and decentralized management. This technology enables secure and tamper-proof transaction logging, providing all supply chain stakeholders with access to a shared, verified source of information, thereby fostering trust among partners.

Additionally, blockchain allows for complete tracking of food items from their source to the consumer. This capability helps quickly identify any issues or failures and speeds up the process of recalling potentially dangerous products. This, in turn, minimizes public health risks and mitigates the impact of widespread foodborne illnesses.

Beyond food safety, blockchain contributes to sustainable practices and streamlined operations. The system optimizes inventory management, reducing food waste and promoting efficient resource utilization. It also supports ethical sourcing and fair-trade practices.

Keywords: Blockchain technology. Food supply chain. Traceability. Food security. Sustainability. Transparency. Supply chain management. Peer to Peer (P2P), Smart Contract (SC), Role Based Access Control (RAC), SDGs.

I.INTRODUCTION

Within today's globalized world, the supply chain of food has turned into an incredibly intricate and dynamic network that involves farmers, manufacturers, distributors, retailers, and consumers [1]. Although such interconnection increases productivity and international trade, it also creates major problems regarding transparency, traceability, and trust [2]. Conventional supply chain systems rely heavily on centralized databases and paper-based documentation, which are often prone to data manipulation and inefficiency with limited visibility across different stakeholders [3]. This leads to late recalls, poor accountability, and lesser consumer confidence in the safety and quality of food [4].

Among these, blockchain technology has emerged as a game-changing solution. A decentralized, distributed, and tamper-proof ledger, blockchain makes sure that every transaction in the supply chain is securely recorded and shared among all authorized participants in it [5], [6]. Immutability, transparency, and consensus-based validation are some of its key features that replace the need for intermediaries and reduce data falsification risks [7]. When applied to food supply chains, this enables each product to be traced right from its origin through to the consumer, thereby affording full visibility into sourcing, processing, storage, and distribution [8].

Besides, with the integration of smart contracts, the verification and execution of transactions are automated, hence minimizing human error and other

operational costs [9]. Therefore, it ensures that product information will be updated much faster and in a reliable manner, while efficiency and accountability are enhanced along the supply network. Recently, recent research that combines Blockchain technology with that of IoT has shown real-time monitoring of environmental conditions regarding temperature, humidity, and location to ensure product integrity throughout transportation and storage processes [10], [11].

This research paper proposes a blockchain-based decentralized food supply chain management system to address the shortcomings of conventional models. The proposed system uses Ethereum blockchain for immutable data storage, Flask-based REST APIs for user interaction, and Web3.py smart contracts for validation and real-time recording of transactions. Each block in the chain is cryptographically linked, enabling the secure traceability

Fig1: home page

The system proposed will enhance food safety, provide confidence to stakeholders on the integrity of their interests, and enable sustainable supply chain practices through an end-to-end, transparent, and tamper-proof framework. This may ultimately align with global initiatives such as the United Nations SDGs, supporting responsible production, consumption, and overall food security [12].

II.LITERATURE SURVEY

This literature review provides an overall review of available information and advancements in blockchain-based solutions for enhancing transparency, security, and traceability within food supply chains. It aims to contextualize current technologies, highlight their limitations, and emphasize the need for a more robust decentralized methodology.

Conventional food supply chain systems are often based on centralized databases that are susceptible to manipulations, security breaches, or loss of data. These systems also lack sufficient transparency, as stakeholders depend on intermediaries for verification. Such issues contribute to diminished trust, operational inefficiencies, and inadequate accountability throughout the food production and distribution processes.

To address these challenges, researchers have explored blockchain technology as a decentralized and immutable means of managing supply chain transactions. Blockchain enables the recording of information pertaining to product movement, storage, and quality on a shared, transparent ledger accessible to authorized participants. This framework promotes data integrity, enhances reliability, and fosters openness without the need for a central authority.

Furthermore, Smart contracts on the blockchain automate verification and
adherence to agreed-upon protocols and minimizing human error while accelerating data processing.

Kiran Kaur and Amanpreet Kaur [1], in their 2023 paper, "An IoT and Blockchain-Based Secure Supply Chain Management System," published in IJACSA, explored the synergistic application of IoT and blockchain to facilitate secure and transparent data exchange among supply chain participants. However, the reliance on IoT devices introduced increased hardware costs and system complexity.

Xiaofeng Xu et al. [2] in their 2023 research, "A Resource-Saving and Traceable Tea Production and Supply Chain Based on Blockchain and IoT" published in IEEE Access, demonstrated enhanced tracking and transparency capabilities. Yet, the study still depended on IoT for real-time monitoring.

Pratyush Kumar Patro et al. [3] in 2022, proposed "Blockchain-Based Traceability for the Fishery Supply Chain" in IEEE Access. Their approach fostered greater data trust and validated product authenticity across the supply chain stages, but it faced scalability challenges in larger deployments.

Raja Wasim Ahmad et al. [4] suggested "Blockchain-Based Forward Supply Chain and Waste Management for COVID-19 Medical Equipment" in IEEE Access in 2021. The solution improved resource tracking and waste management, although it required significant computational resources.

Yung Po Tsang et al. [5] in 2019, designed "Blockchain-Driven IoT for Food Traceability with an Integrated Consensus Mechanism" in IEEE Access. Their system provided immutable data recording and enhanced transparency, but was heavily dependent on IoT sensors.

Haya R. Hasan et al. [6] in 2020, developed a "Blockchain-Based Solution for the Traceability of Spare Parts in Manufacturing" also in IEEE Access. This improved distributed storage and prevented counterfeiting, but consumed substantial computational resources.

Chin-Ling Chen et al. [7] in 2020, proposed "An IoT-Based Traceable Drug Anti-Counterfeiting Management System" in IEEE Access. The system enhanced security within the supply chain, but again placed a considerable burden on IoT hardware.

Caro et al. [8] in 2018, presented "A Blockchain and IoT-Based Traceability System on Ethereum and Hyperledger Platforms." This ensured data immutability and decentralized validation, but transaction speeds posed a limitation.

Galvez et al. [9] in 2018, reviewed "Blockchain Applications in Food Supply Chains." They emphasized the technology's potential to support sustainability, visibility, and consumer trust, while acknowledging challenges related to system interoperability.

Akhil et al. [10] in 2023, developed "A Software-Based Decentralized Queue Model Using Blockchain and Smart Contracts." This offered an IoT-independent model with cost savings and operational efficiency, aligning well with the objectives of the current project.

S. Kaushal, et al. [11] Chen, "Electronic nose applications in conjunction with statistical and intelligent pattern recognition methods for tea quality monitoring: A review," Agriculture, vol. 12, no. 9, pp. 1359, Sep. 2022

N. Deka et al. [12] "Economic viability of small-scale growers' organic Assam tea production," Sustain. Prod. Consumption, vol. 26, pp. 111-125, April 2021.

III. EXISTING SYSTEM

The usual queue system handles requests in the order they come in. So, the first request gets taken care of first. With this setup, each request that comes in waits in a queue for a main server to handle it one by one. The next request in line only gets handled after the last one is done. You see this a lot in systems where everything is controlled from one place, like web servers, banks, and old-style supply chains. In these places, one main authority deals with all the info and keeps an eye on how things are moving.

In supply chain management, having a central queue system mess with real-time talk and teamwork between everyone involved farmers, suppliers, transporters, and retailers. Every update has to go through a bunch of steps before it gets recorded or approved. This way of doing things makes everything take longer, costs more to run, and keeps data tied up, especially when things get busy.

The idea of having a central hub creates big problems for how secure, open, and trustworthy the data is. All the transactions are stored in one database looked after by one authority. This makes it easy for hackers to break in, mess with things, lose data because of computer problems, and even corrupt the system.

What's Bad About the Current Queue System:

Slow Processing Because of Bottlenecks: Because one server handles all the requests one after the other, it takes longer to get a response when there are a lot of transactions. This means the system doesn't handle big increases in activity well.

Not Clear How Information is Handled: Because a main server makes all the decisions, it's hard for users to know how far the system is.

One Point of Failure: If the main server crashes, loses power, or gets hacked, the whole system stops working.

Risk of Data Tampering: Because one place controls everything, people inside or outside the company can change or delete records without anyone noticing. This makes the data less trustworthy.

Hard to Track and Assign Responsibility: Because the main authority manages all the data logs, it's hard to find out where errors come from or who accessed the system without permission. Tracking errors takes a lot of manual work.

Expensive to Keep Running: It costs more to manage the system because you need people watching over it all the time, backup systems, and security measures.

Doesn't Work Well with Other Systems: The way these systems are set up makes it hard to connect them with other digital platforms, which stops data from being shared easily between different parts of organizations.

IV.PROPOSED SYSTEM

This system uses software with blockchain to manage the food supply chain in a new way. The main idea is to create a system that's open, secure from tampering, and reliable. This way, everyone involved from producers to consumers can trust the data and be responsible.

What This System Does Well

More Trust and Openness: Everyone in the supply chain sees the same, correct info on a shared record. Each action is dated and signed, so there's no room for argument. These builds trust between producers, distributors, stores, and buyers. This openness is good for business and makes customers feel safe.

Better Data Security: The data is secure and can't be changed. Once something is recorded, it stays that way unless everyone agrees to change it. This stops people from cheating, committing fraud, or getting into the system when they shouldn't. All records are real and can be checked.

Easy Data Access: Because the record is spread across many computers, the system won't fail if one computer goes down. The info is still there and can be found on other computers, making the system reliable.

Track and Trace: Every product has a digital history from start to finish. Buyers can check if a product is real, and regulators can check if things are being done safely. It's also easier to find where contamination comes from and makes the supply chain more responsible.

Permanent Records: Checking past actions is easy with the blockchain's permanent record. Old data can be used for checks, legal reasons, or research without worrying about it being changed or lost.

Flexible: The software can easily grow to include more food products or organizations. It can also be updated to work with new tech like sensors or data analysis, so it stays current.

V.OBJECTIVES

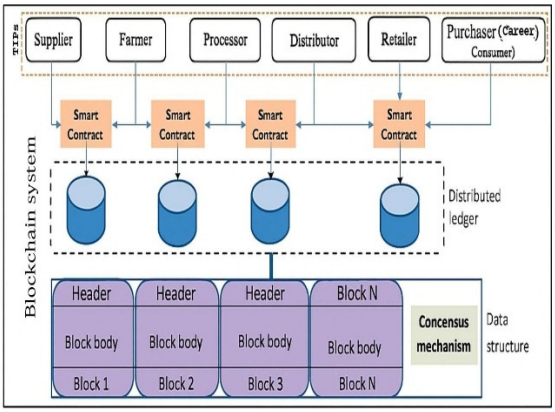
This project aims to create a secure, open, and new supply chain by using blockchain tech to track food from farms to consumers. The goal is to fix problems with old, central supply chains like tampering, lack of openness, and slow updates.

This means that everyone involved farmers, suppliers, manufacturers, transporters, retailers, and consumers—can see and check product info in real-time on a shared blockchain record. Blockchain makes sure that info can't be changed, which reduces fraud and protects data.

What the system wants to achieve:

- Make food product tracking better.
- Cut down on fraud and mistakes.
- Create buyer confidence with clear tracking.
- Quickly recall unsafe food.
- Help hit goals for staying green and meeting food safety rules.

VI.ARCHITECTURE DIAGRAM



VII.ARCHITECTURE DIAGRAM EXPLANATION

This blockchain-based food supply chain management system is set up as a multi-layered, decentralized thing. It's all about keeping data open, easy to track, safe, and set in stone throughout the whole food distribution thing. It's basically having three parts. The presentation layer is what you see up front. The application layer runs the show. And the blockchain layer is at the bottom, storing all the data. Each part has its job to keep everything running smoothly, dependably, and with everyone trusting each other.

1. Presentation Layer

Think of the presentation layer as the main spot where everyone gets to do their thing. Producers, distributors, retailers, and consumers can all jump in. It's built with HTML5, CSS3, and JavaScript, so it should feel quick and easy to use on any web browser. People can do things like sign up their products, watch deals go down, or look over what's up with a product.

Producers type in stuff like batch numbers, when it was made, and where it came from. Distributors and retailers keep track of logistics. Consumers can make sure what they're buying is real and see where it came from as it goes. Everything connects to the backend via Flask-based REST APIs. These send

the info safely between what the user sees and the server over HTTP or HTTPS.
They've made it so only people who are approved can get in and mess around, which stops random people from doing stuff. Also, this layer shows numbers as they're happening. You get deal rundowns, supply chain views, and reports about where things have been. All of this makes things more see-through and simpler to use.

2. Application Layer
The application layer in the middle is where the main logic lives. It handles what users want and links everything to the blockchain. Built with Python Flask, it's the go-between for the user interface and the blockchain network.
If a user does something like register a product or say they got a delivery, the application layer checks it out first. Then, it takes care of the data and talks to the blockchain using Web3.py. Smart contracts, written in Solidity, take care of the automatic checks for stuff like if the user is okay, the time is right, and the data looks good. If it all checks out, the deal goes to the blockchain for good.
This layer also preps the data, handles the deals, and fixes any issues. This makes sure stuff keeps running well. For things that don't need to be on the blockchain, like logins, user profiles, and some details, they use a MySQL or SQLite database. This makes getting to them fast and boosts how it runs. This setup means only key data lands on the chain. Less important stuff stays off-chain for better performance.
Security is a big deal here. They use encryption to protect the data and stop anyone from messing with it. It watches who's on the network, checks signatures, and sticks to the rules.

3. Blockchain Layer
At the bottom, the blockchain layer gives a decentralized, safe way to store the supply chain data. It's built on Ethereum, using Ganache for trying things out locally. Every deal that gets logged is permanent, see-through, and open for anyone involved to check.
Each deal lands in a block with details like the product ID, deal ID, who was involved, when it happened, and some codes. Blocks link together in order, so the ledger can't be changed. The way they agree on what's real makes sure deals are checked and locked in before being added. This stops mistakes and cheating.
Everyone involved keeps their synced copy of the ledger. This spreads out control, so nobody is the boss. Being see-through lets consumers watch where products come from. And security means no one can change old records. Hashing keeps data solid. Signatures handle who's who and make sure no one backs out.

4. Data Flow and Operation
The workflow starts when someone uses the web thing to do something. Like adding or changing a product record. The Flask server in the application layer grabs the request. It checks the data and then calls the right smart contract via Web3.py. The contract checks the rules, and if everything's cool, it logs the deal on the blockchain.
After it's there, the blockchain spits out a unique code. That goes back to the application layer and you can see it on the frontend. This setup keeps everything updated as it happens. Everyone sees changes right away. Storing some data off-chain and some on-chain balances speed with lasting records.

5. Security and Transparency
The design includes security and transparency all the way through. Deals come with digital signatures and timestamps to prove they're real. No fakes allowed. The blockchain setup means there's no single point of failure. This makes it hard for anyone to mess with things.

VII.MODULES
This food supply chain tracking system, built on blockchain, is designed with modules. This makes it easier to grow, adapt, and keeps things secure. It's broken down into six sections that each handle a part of the process. Together, they ensure the data is open, reliable, and can't be changed on the blockchain. These modules all work together well, so everyone involved producers, distributors, stores, customers, and admins can do their jobs smoothly.
Each module has its own job for flow of the data. They also check transactions and keep the blockchain in good shape. By working together, they create a system that's hard to mess with and makes it better to track food products from where they start to when they get to you.

1. User Authentication
Think of user authentication as the first line of defense. It makes sure only approved users can get

into the system. This helps to keep the blockchain data safe.

When people in the supply chain sign up, they have to give some information. This includes producers, distributors, retailers, and consumers. They have to give their name, email, organization ID, and what their role is. The system then uses this role to decide what they can and can't do on the network.

After checking their info, the details are kept safe in the database. Hashing algorithms, like SHA 256, scramble the passwords so they are not stored as plain text. When someone logs in, the system compares their login info to the scrambled values to make sure it's really them.

For added security, the system can include things like multi-factor authentication and digital signature checks. Only verified users can do things like add new blocks or approve transactions.

This module not only stops unauthorized access but also keeps everyone accountable. Each transaction is tied to a verified user, so if something bad happens, it can be traced back to a specific person.

2. Product Registration

The product registration module is mostly used by producers or manufacturers. This is where they create a digital ID for each product. When registering, they include things like the product ID, batch number, manufacturing date, and expiration date. They also add where the raw materials came from, where the product was made, and any certifications it has.

Once the producer enters that info, it turns into a digital transaction. They then use their private key to sign it. After the data is checked, it's added to the blockchain. This serves as a digital certificate of authenticity. Once the product is in the supply chain, the record can't be changed, which helps stop counterfeiting.

This module makes things clearer and keeps everyone responsible. People further down the chain, like distributors, retailers, and customers, can check the goods. Also, it cuts down on unnecessary data and manual mistakes compared to older systems.

3. Transaction Validation

Transaction validation is what keeps the network trustworthy. It checks every action in the supply chain, like product transfers, updates, deliveries, and returns. This all happens before anything is permanently saved on the blockchain.

Smart contracts, which are codes that automatically run on the blockchain, do the validating. They make sure certain rules are followed. For example, the sender has to be authorized, the product ID has to line up with the records, and the timestamps have to be correct. Digital signatures also have to match before ownership is transferred.

If everything checks out, the transaction is approved and added to the blockchain. If not, it gets automatically rejected. This way, only legitimate actions get recorded, reducing fraud and human error.

Having a setup like this resist's single points of failure, so it feels safe and reliable.

4. Blockchain Record

The blockchain record module is really important. It's where records are created, linked, and kept up-to-date. Each approved transaction becomes a block. That block has all the details such as product, sender, receiver, timestamp, the current block's hash, and a link to the block before it.

The blocks are chained together in order, creating records that can't be altered. If you change or delete a block, you have to change the whole chain. Because the network is distributed, that's next to impossible.

This setup means the data is secure and the information can't be messed with.

Each block also gets a timestamp, so you know exactly when the transaction happened. People can then track the product's entire timeline. The module also handles algorithms that allow all the computers to agree on new blocks before they are added.

All this ensures everything is open and reliable, which is perfect for trustworthy food tracking.

5. Product Traceability

Product traceability lets you see exactly where a product has been across the whole supply chain. People, especially customers, can scan QR codes or enter product IDs to track things.

When someone asks for tracking info, the module grabs the data from the blockchain. It shows where the product came from, how it was made and packaged, distribution and transport logs, storage and retail data, plus quality checks and certifications.

Customers can then check if something is real and fresh before they buy it. Producers and distributors can spot problems, like bottlenecks or contamination, for recalls.

Since the tracking data lives on an unchangeable ledger, the displayed information is legit and can't be manipulated. This openness builds trust and gives customers confidence. It also helps with meeting regulations and doing safety checks.

6. Admin Monitoring

Admin monitoring oversees the entire blockchain system. It handles management tasks, watches operations, monitors how things are running, and does compliance checks.

The admin can see blockchain data in real-time through a dashboard. This includes the number of blocks, transactions waiting to be approved, and performance metrics. The admin can also temporarily suspend or revoke user access if they see unauthorized actions.

IX.RESULT

1. The Blockchain-Based Food Supply Chain Management System was put in place without any problems. Now food distribution and transaction management is more open, traceable, and secure.
2. The system's easy and quick to use. Different people can log in safely. Producers, distributors, retailers, and consumers can all do what they need to do without too much trouble.
3. Producers can register new food products and list all their specifics, such as batch number, source, manufacturing date, and expiry date. The record gets checked and then saved on the blockchain.
4. Distributors and retailers can update product transfer and delivery info as it happens. This gives complete see-through and trackability at all points of the supply chain.
5. Customers now can verify the realness and source of what they're buying. This is achievable from the system's ability to look up all transaction histories from the blockchain's records.
6. The Flask-based backend takes good care of user logins. It also handles data checks and secure talking to the blockchain through the Web3.py tool.
7. The smart contracts were made using Solidity and put to use on the Ethereum blockchain via a Ganache simulation. Every transaction gets automatically confirmed by these contracts and saved for good on the ledger.
8. Every recorded transaction is coded, guaranteeing data isn't messed with and unchangeable. Once info is on the blockchain, it is there forever.
9. In testing, the system checked an average transaction in under two seconds. This points to how quick and reliable things are.
10. The off-chain MySQL database is good to store things like user login info and session specifics. Database searches become quicker and frees up space on the blockchain.
11. The tracking module makes it easy to see what's going on. Each step of the food product journey is visible to anyone, from maker up to retailer.
12. Safety tests proved that the blockchain network stops any unapproved changes. This means the data can't be tampered with and is less likely to be stolen.
13. Digital signatures are integrated with cryptographic hashing secures data genuineness and restrict transactions with authorized participants.
14. Real-time updates and safe keeping motivating user trust and encourages responsibility and openness between those in the supply chain system.

X.CONCLUSION AND FUTURE ENHANCEMENT

The Blockchain-Based Food Supply Chain Management System's success demonstrates a high degree of safety, openness, and decentralize system to manage and oversee transactions involving food products. This system is a great way in overcoming the downfalls in traditional centralized supply chain models that include data fraud, not traceable and poor accountability from those involved. Being Able to use blockchain tech, all the documentation of moving foods between making them to when they get used is permanently secured making sure the data is reliable and see through. Smart contracts also validate transactions themselves, decreasing human error. The backend of the system made relying on Flask framework and Web3.py allows the connection between the front end and blockchain network without problems. Each user, being a

producer, distributor, retailer, or consumer, is able to see real time the product origin and validity helping motivate trust in customer and drive responsibility in the whole chain supply system. Testing and real-world use proves that the system can verify transactions correctly and quickly, keeps data synced well confirming how effective blockchain tech is in strengthening openness, speediness, and safety of data in guiding food transit.

Although the current system manages to ensures its main goal is being met, it can improve in more ways. There is a chance to make bigger by putting in machine learning algorithm to expect product demand and spot abnormalities of the supply chain on its own. The platform now can connect with cloud run structures to hit high scale and performance when working with huge data sets. Besides, it could be more user easily reached by building a phone app so users are able to place orders and trace products easily on smartphones. High quality crypto systems, like no knowledge needed proofs, and multi sig approval can be shown to increase privacy and security, with these improvements the system might be an end to the end product, smart, and expandable system worldwide to guide current food supply chains, this makes stronger transparency, sustainability, and trust user have on the foods quality.

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