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Agro Based E- Commerce Application with Integrated Cryptocurrency

Ms. ELAKIA K[1] , Mugilan S[2] , Sanjeeve Kumar V[3], Kathiravan I[4]
Rajiv Gandhi College Of Engineering And Technology Department Of Computer Science And Engineering Puducherry-607402

Abstract: This e-commerce platform is specifically designed for agriculture-based trade, leveraging advanced blockchain technology and decentralized file storage to create a transparent, secure, and efficient marketplace for farmers, buyers, and suppliers. The platform utilizes Ganache, a simulation of Ethereum transactions, to ensure that all transactions are secure, immutable, and verifiable on the blockchain. The decentralized architecture is further enhanced with IPFS (Interplanetary File System), enabling farmers to securely store their product information, including images and descriptions, in a way that prevents alteration or loss. This ensures that the product listings are transparent and tamper-proof. The platform also incorporates cryptocurrency payments, enabling fast, secure, and borderless transactions between buyers and sellers. Utilizing smart contracts, the system automates payment flows based on predefined conditions, reducing the reliance on intermediaries and minimizing fraud risks. This fosters a trusted environment for agricultural trade, where both buyers and sellers can engage in transparent, efficient, and secure transactions. In addition to these core features, the platform includes a staking mechanism, allowing users to lock tokens to gain transaction privileges, influence governance decisions, and access premium features. This incentivizes long-term commitment and creates a sense of ownership within the platform. Active participants, such as those verifying transactions or maintaining data integrity, are rewarded with tokens, further promoting continuous engagement. The system also supports multilingual user interfaces, making it accessible to a global audience, and includes real-time updates for seamless interaction. Through transparent governance, decentralized voting, and economic incentives, the platform ensures a resilient and future-ready ecosystem for agro-commerce, empowering stakeholders to participate in decision-making and market dynamics, while addressing the challenges faced by farmers in accessing reliable markets and efficient payment systems.
Keywords: E-commerce, agriculture-based trade, blockchain, Ganache, IPFS, cryptocurrency, smart contracts, decentralized platform, agro-commerce, transparency, decentralized voting.

I. INTRODUCTION

The agri-food sector encompasses the entire spectrum of food production, starting from agriculture and livestock breeding to the final delivery of processed food products. This broad industry includes everything from growing crops and raising animals to processing raw materials into consumable food. It also covers the distribution process, ensuring that food products reach consumers efficiently and meet regulatory standards, such as quality control and food safety. The goal of the agri-food industry is to maintain a sustainable and reliable food supply chain, ensuring that nutritional needs are met globally. Technological advancements, particularly in the areas of blockchain, are becoming increasingly important in the agri-food sector. With growing consumer demand for transparency, sustainability, and food safety, blockchain technology is being integrated into supply chains to enhance traceability. This technology ensures that every step in the production, processing, and distribution cycle is recorded and accessible, providing consumers and regulators with verifiable proof of food origin and quality. It also helps prevent fraud and ensures the authenticity of food products, thereby strengthening the trust between producers and consumers. The agri-food industry continues to evolve in response to challenges such as climate change, population growth, and sustainability concerns. Innovations in farming practices, resource management, and distribution logistics are essential to meeting the increasing demand for food while reducing environmental impacts. Technologies that improve efficiency and sustainability in food production, like precision farming and renewable energy solutions, are becoming more common. As consumer preferences shift towards more transparent and ethically produced food, the agri-food industry is adapting to remain competitive while also contributing to global sustainability efforts.

A. Proof of Stack

Proof of Stake (PoS) is a consensus mechanism used in blockchain networks to validate transactions and secure the network. In PoS, validators are chosen to create new blocks based on the amount of cryptocurrency they "stake" or lock into the network. The more tokens a user stakes, the higher the chance they will be selected to validate a new block and receive rewards.

The primary advantage of PoS is its energy efficiency. Since PoS does not require resource-intensive computational power, it consumes significantly less energy, making it more sustainable. Additionally, PoS incentivizes users to hold and stake their tokens, which can increase network security, as malicious actions like double-spending become economically unfeasible for those with a large stake in the system. In a PoS system, validators are rewarded with transaction fees or newly minted tokens for confirming transactions and maintaining the integrity of the blockchain. The risk of losing their staked tokens is a deterrent to dishonest behavior, ensuring the network remains secure and trustable. Blockchain platforms like Ethereum are transitioning to PoS to improve scalability, reduce energy consumption, and foster a more decentralized and secure ecosystem.

B. IPFS

IPFS (Interplanetary File System) is a decentralized, peer-to-peer file storage protocol designed to make the web more resilient, efficient, and open. Unlike traditional centralized file storage systems, where data is stored on specific servers, IPFS distributes files across a network of nodes, ensuring that no single point of failure exists. Files are identified by a unique hash, and each node stores a portion of the data, making it accessible and immutable once uploaded. This decentralized nature reduces the reliance on central servers, enhancing redundancy and making data less vulnerable to censorship or failure. The key feature of IPFS is its content-addressed storage, which means that files are retrieved based on their unique cryptographic hash rather than their location on a server. When a user requests a file, the network locates it by its hash, pulling data from the nearest available node, making retrieval faster and more efficient. This approach also ensures that the file remains the same over time, providing data integrity and authenticity. IPFS works in conjunction with blockchain technologies to enhance transparency and security, providing a tamper-proof way of storing files and records. IPFS has numerous use cases across different industries. It is widely used in decentralized applications (dApps) and blockchain projects to store large data like images, videos, and documents in a way that is both secure and cost-effective. Additionally, IPFS supports the creation of decentralized websites and enhances the efficiency of peer-to-peer file sharing. By removing intermediaries and promoting a distributed model, IPFS contributes to the creation of a more open, censorship-resistant, and scalable internet.

II. LITERATURE SURVEY

Samantha Islam, Louise Manning, Jonathan M Cullen, 2022[1] This paper discusses the improvements in traceability systems within agri-food supply chains, highlighting their ability to enhance transparency and accountability across the supply chain. The integration of advanced traceability mechanisms allows for better monitoring of food safety and quality. However, the increased implementation costs can be a significant challenge, especially for small-scale producers who may struggle to bear the initial setup and ongoing maintenance expenses. Mladen Krstić, Giulio Paolo Agnusdei, 2022 [2] This research prioritizes the key drivers of electronic traceability systems in agri-food supply chains. It emphasizes the importance of real-time monitoring, which allows stakeholders to track the movement of goods and manage risks effectively. While the benefits are clear, the complexity of establishing such systems and the need for consistent digital infrastructure across regions remain challenges. Ilaria Massa, Roberto Merli, 2022 [3] This study outlines the key drivers behind the adoption of traceability systems, with a focus on food safety improvements. Traceability systems ensure that food products can be tracked from farm to fork, enhancing the reliability and safety of the food supply. However, the widespread accessibility of these benefits to all supply chain participants might not always be guaranteed, particularly in less developed regions.[4]Snežana Tadić, Pier Paolo Miglietta, 2022 [4] This paper focuses on the implementation of food traceability systems in India, emphasizing the importance of uniform compliance and effective implementation. These systems help ensure that food products are accurately tracked throughout the supply chain, providing consumers with more confidence in the safety of the food they consume. The challenge lies in accurately tracking every item in a vast and complex supply chain, particularly when dealing with a diverse range of agricultural products.[5]Silamlak Birhanu Abegaz, 2023 [5] This study explores food safety practices in a student cafeteria, highlighting how the risk of foodborne illnesses can be significantly reduced through proper food safety management. It ensures that food served to students is safe for consumption. However, implementing such safety practices universally across different types of food establishments may face barriers related to awareness, training, and resource allocation.[6]Angelo Marchese & Orazio Tomarchio, 2022 [6] This paper discusses the use of blockchain technology in agri-food supply chain management, focusing on how blockchain ensures transparency and authenticity in transaction records. Blockchain's immutable ledger guarantees that data cannot be altered, creating a secure and transparent system for food traceability. However, the challenge lies in the system's ability to handle a large number of transactions efficiently, especially in global-scale supply chains where transactions can be frequent and voluminous.

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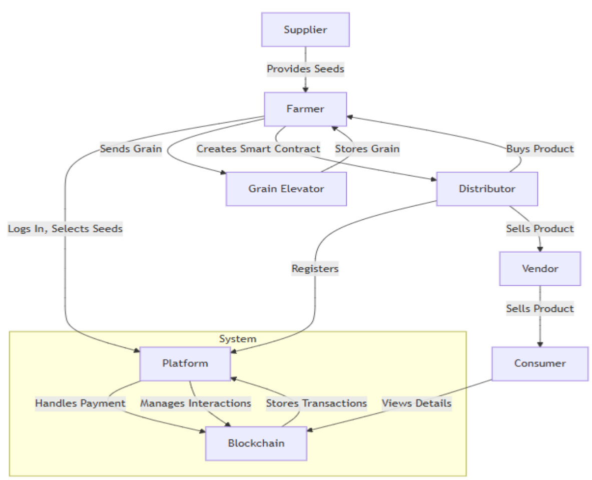
[7] Marchese & Tomarchio, 2023 [7] This research underscores the advantages of traceability systems in ensuring food safety, particularly by tracking agricultural products and ensuring they meet safety standards throughout the supply chain.
The complexity and cost of implementing comprehensive traceability systems, however, can be prohibitive for smaller players in the industry, limiting their ability to fully adopt such technologies without external support or subsidies.[8]Rizwan Matloob Ellahi, Lincoln C. Wood, Alaa El-Din Ahmed Bekhit, 2022 [8] This paper presents a review of blockchain-based frameworks for food traceability, emphasizing the potential of blockchain to track transactions and movements within the food supply chain. The decentralized nature of blockchain enhances security and transparency, but it also introduces the challenge of scalability. As blockchain networks grow, the efficiency of handling large amounts of data without compromising performance becomes a concern. [9] S. Hemming, T. Norton, 2023 [9] This study explores the role of artificial intelligence in the agri-food sector, focusing on its potential to enable farmers to collect and analyze vast amounts of data from various sources. This technological advancement has the potential to enhance productivity and efficiency. However, there is concern about its impact on the livelihoods of those who depend on manual labor in agriculture, as AI could lead to job displacement and require significant re-skilling efforts.[10] Anandika Sharma, Tarunpreet Bhatia, 2023 [10] This paper explores the framework for integrating blockchain into the agri-food supply chain, emphasizing increased transparency, which fosters accountability among stakeholders. The transparency enabled by blockchain ensures that all participants have access to the same reliable data. However, the system faces challenges in terms of scalability, as the growing number of transactions may strain the current blockchain infrastructure, requiring advanced solutions to accommodate large-scale implementations.

ARCHITURE DIAGRAM OF PROPOSED SYSTEM:



The architecture of the proposed blockchain-enabled agricultural supply chain system is designed to ensure secure, transparent, and decentralized interactions between all stakeholders—from the supplier to the end consumer. At the foundation lies the Platform Layer, which serves as the central hub for managing interactions, authenticating users, handling payments via Ethereum, and initiating smart contracts. This platform is tightly integrated with the Blockchain Layer, responsible for storing all transactional data in an immutable, decentralized ledger. Each interaction—from seed purchase, grain storage, and distributor registration, to product delivery—is logged to ensure traceability and data integrity. On top of this infrastructure are the Stakeholder Layers, which include distinct user entities such as Suppliers, Farmers, Grain Elevators, Distributors, Vendors, and Consumers. The Supplier provides seeds to the Farmer, who accesses the platform via a web interface to select seeds and make payments. Once the farmer produces and stores grain in the Grain Elevator, a Smart Contract is triggered to facilitate the automated sale of the product. Distributors register on the platform to purchase grain, and then sell the products to Vendors, who ultimately distribute them to Consumers. Each of these user actions is mediated through the platform and logged on the blockchain. Smart contracts ensure trust and enforce terms without manual intervention. Consumers at the final stage of the architecture benefit from transparency, as they can view the product’s origin, handling, and transaction history. This modular and layered architecture promotes scalability, accountability, and security, creating a robust digital agricultural ecosystem.

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III. PROPOSED SYSTEM

The proposed blockchain-enabled agricultural supply chain system introduces a decentralized and secure digital framework to manage interactions between all stakeholders—ranging from seed suppliers to end consumers. At the heart of this ecosystem lies a centralized Platform Layer, which provides a user-friendly interface for farmers, distributors, and other entities to interact.

This layer facilitates core functions such as user authentication, product selection, payment processing using Ethereum cryptocurrency, and the creation and execution of smart contracts. The system is deeply integrated with a Blockchain Layer, which ensures that all transactions are stored immutably and transparently, enhancing data integrity and reducing the risk of fraud or manipulation. In the system's operational flow, Suppliers provide seeds to Farmers, who log in to the platform to select and purchase seeds using Ethereum. Once the crops are grown, they are transported and stored in Grain Elevators. At this point, Smart Contracts are automatically created to govern the relationship between the farmer and the Distributor, who registers on the platform to purchase stored grain. The distributor then sells the product to Vendors, who pass it along to Consumers. Throughout each stage, the system automatically handles the required interactions, logs every transaction on the blockchain, and ensures transparency in the supply chain lifecycle. The final stage benefits the Consumer, who can verify the entire history of a product—from seed sourcing to delivery—ensuring trust, safety, and authenticity. This transparency not only builds consumer confidence but also enhances supply chain accountability. With its modular design, the proposed system is scalable and adaptable to various agricultural products and market environments. The integration of blockchain, Ethereum, and smart contracts provides a tamper-proof, auditable, and efficient platform, revolutionizing traditional agricultural supply chains into a robust digital ecosystem.

A. Supplier of the Seed:

The seed supplier plays a crucial role in the agricultural supply chain by providing high-quality seeds that ensure better crop yield and resilience. In a blockchain-integrated system, the seed supplier registers on the platform, creating a transparent and tamper-proof record of seed origin, quality, and certification. This data, once stored on the blockchain, helps traceability throughout the supply chain. Suppliers may also upload details like seed batch number, germination rates, expiry dates, and any treatments or coatings applied. This not only boosts farmer confidence but also aligns with sustainable agricultural practices. A smart contract may automate verification checks, ensuring only certified suppliers are onboarded. The transparency of the blockchain reduces fraudulent activities and ensures farmers receive genuine seeds. Furthermore, this system can be expanded globally, enabling cross-border seed purchases with guaranteed authenticity and compliance with international standards. Integrating IoT with the blockchain can further enhance data accuracy by automatically logging storage conditions such as temperature and humidity. This initial step sets the foundation for a reliable, secure, and efficient farm-to-fork supply chain, ensuring trust and quality from the very beginning of the agricultural process.

B. Farmer Log into the Website:

Farmers are the backbone of the agricultural supply chain, and enabling them to log into a blockchain-based platform provides them with access to a transparent and decentralized ecosystem. After successful registration, farmers gain a secure digital identity, allowing them to access services such as purchasing seeds, fertilizers, or farming equipment directly from verified suppliers. This eliminates the need for intermediaries, reducing costs and improving efficiency. Through the platform, farmers can also access information about best agricultural practices, weather forecasts, and government subsidies. Logging into the website also allows farmers to participate in smart contracts, where terms of transactions (like delivery timelines, price, and quantity) are predefined and executed automatically upon fulfillment. This provides security against fraud and ensures timely payments. Additionally, data such as land size, previous harvest records, and pesticide usage can be voluntarily stored by the farmer, building a verifiable farming history that can help in getting loans or insurance. By integrating digital access with blockchain technology, this step empowers farmers by giving them control over their data and business decisions, promoting a more inclusive and sustainable agricultural economy.

C. Select the Seed from the Supplier and Payment Using Ethereum Coin:

Once logged into the system, the farmer can browse available seed varieties listed by different certified suppliers. Each seed batch is linked with a blockchain entry detailing its characteristics, such as growth period, yield potential, and resistance traits, which helps the farmer make informed decisions. Upon selecting the desired seed, the farmer initiates payment using Ethereum (ETH), a decentralized cryptocurrency. This mode of payment ensures secure, fast, and borderless transactions, eliminating traditional banking delays and associated fees.

The transaction is recorded on the blockchain, creating a permanent, tamper-proof record of the purchase, including time, quantity, and pricing details. The use of Ethereum also enables the execution of a smart contract, which ensures that the seed is dispatched only after payment is confirmed. This safeguards both the farmer and supplier against fraud. Smart contracts can include refund clauses in case of defective seeds or delays. By adopting Ethereum, the system brings financial inclusion to rural farmers, enabling participation in the global digital economy while ensuring trust, efficiency, and automation in the seed procurement process.

D. Grain Elevator:

A grain elevator is a facility where harvested grains are collected, stored, and graded before further processing or distribution. In a blockchain-based system, the use of grain elevators becomes more transparent and traceable. Each transaction—from the moment the farmer delivers the grain to the elevator, to the time it's stored or dispatched—is recorded on the blockchain. This includes data such as weight, moisture content, and quality grade. Blockchain integration ensures that the farmer is compensated fairly based on these metrics, with smart contracts triggering instant payments once the grain quality is verified. The elevator facility can also provide real-time updates about storage conditions, like temperature and humidity, which are recorded immutably, guaranteeing the integrity of the stored grain. This traceable chain of custody reduces the chances of contamination, mixing, or fraud. Moreover, it helps regulatory authorities monitor food safety standards and allows distributors and consumers to trace the product back to its origin. The grain elevator thus becomes a critical point of trust and data collection within the agricultural supply chain, ensuring transparency, quality assurance, and fairness in post-harvest handling.

E. Grain Production:

Grain production involves the cultivation, harvesting, and initial processing of cereal crops such as wheat, corn, rice, or barley. When integrated with blockchain technology, every stage of grain production—from seed sowing to harvest—is meticulously documented. Farmers or IoT devices can input data related to planting dates, fertilizer and pesticide application, water usage, and environmental conditions. This creates a digital record that adds value to the final product by enhancing transparency and traceability. Smart contracts can manage agreements between farmers and buyers, ensuring that the product is produced following agreed-upon standards. If a buyer demands organic or non-GMO grains, blockchain can help prove compliance through immutable records. Furthermore, quality checks and yield assessments during harvest are also logged, giving the product a verified history. This approach not only increases consumer trust but also helps farmers command better prices for higher-quality, traceable produce. Blockchain in grain production also assists in compliance reporting and facilitates more accurate forecasting of supply and demand, helping stabilize markets and reduce food waste. Ultimately, blockchain empowers grain producers with data ownership and market access while enhancing supply chain accountability.

F. Distributor Registration:

Distributors play a pivotal role in connecting producers to vendors and eventually to consumers. In a blockchain-enabled ecosystem, distributors must first register on the platform to ensure authenticity and traceability. During registration, detailed business credentials, licenses, and certifications are uploaded and verified using smart contracts or third-party auditors. Once validated, the distributor receives a unique digital identity stored immutably on the blockchain. This identity allows transparent tracking of all future transactions, helping to build trust across the supply chain. Registration also enables access to verified product listings, including grains and other farm produce, where distributors can review information about product origin, quality, and previous handling. This improves procurement decisions and ensures supply chain integrity. By integrating with smart contracts, distributors can enter into automated agreements with farmers or vendors, which are enforced without intermediaries. The blockchain also records delivery confirmations, quality checks, and payment statuses. This eliminates fraud, reduces paperwork, and ensures legal compliance. In essence, the distributor registration process ensures that only credible participants are part of the supply chain, increasing transparency, efficiency, and accountability across agricultural commerce.

G. Create Smart Contract:

A smart contract is a self-executing program stored on a blockchain that automatically enforces the terms of an agreement without requiring intermediaries. In the agricultural supply chain, smart contracts facilitate secure, automated, and transparent transactions between farmers, distributors, and vendors. For example, a smart contract can be set up between a farmer and a distributor stipulating conditions such as delivery timelines, grain quality, quantity, and payment terms.

Once the farmer meets the conditions—like delivering a specific quality of grain—the contract executes and releases payment automatically in cryptocurrency or fiat equivalent. This removes the possibility of delayed or disputed payments. Smart contracts can also include dispute resolution clauses, quality assurance steps, and penalty clauses for non-compliance. Every action taken under the contract is logged immutably on the blockchain, making it auditable and trustworthy. This ensures that all parties are held accountable and that the rules of engagement are enforced uniformly. By automating agreements, smart contracts reduce administrative overhead, enhance trust, and significantly streamline operations in the agricultural supply chain.

H. Distributor Buy Product from the Farmer:

After successful registration and smart contract creation, the distributor can now purchase agricultural products directly from the farmer. This transaction is facilitated through the blockchain platform, which offers complete transparency regarding the quality, quantity, and history of the produce. Before the purchase, the distributor reviews the product profile, which includes data like harvest date, pesticide usage, and grain grade—information logged by the farmer or IoT systems. The payment, typically in Ethereum or another supported cryptocurrency, is then initiated through the platform. Once confirmed, the smart contract automatically updates the inventory and ownership records on the blockchain, signaling a successful transaction. The grain is then scheduled for pickup or delivery, with logistics information also logged for tracking. This direct purchasing model cuts out unnecessary middlemen, ensuring farmers receive fair compensation and distributors gain access to verifiable products. It also builds a chain of trust and enhances traceability, as the product's journey from farm to distribution is securely documented and visible to all stakeholders.

I. Distributor to Vendor:

Following the purchase from the farmer, the distributor coordinates the sale and delivery of agricultural products to various vendors such as retail shops, supermarkets, or food processors. In a blockchain-based system, this transaction is also recorded immutably, ensuring transparency in pricing, product quantity, and delivery timelines. Vendors can review the product's blockchain trail, including its origin, handling conditions, and certifications, before accepting the delivery. Smart contracts are again utilized to enforce agreed terms like delivery schedules, quality checks, and payment milestones. Once the vendor receives and verifies the product, the contract automatically releases payment to the distributor. This automation reduces delays and eliminates the need for third-party verification. Real-time updates on logistics and delivery status are visible on the blockchain, enhancing trust and reducing miscommunication. Moreover, this traceable system helps vendors assure their customers of product quality and origin, contributing to brand trust. The transparency and efficiency of this process benefit all parties involved, enabling faster turnover, minimized risks, and a more resilient supply chain.

J. Store Transaction In Blockchain:

Every transaction in the seed-to-consumer journey—seed purchase, grain delivery, distributor sales, vendor transfers, and consumer purchases—is securely stored on the blockchain. Each transaction is recorded as a block containing critical details such as time, date, quantity, quality parameters, payment verification, and stakeholder identities. Once verified, the block is added to the immutable blockchain ledger, ensuring the data cannot be altered or deleted. This system offers unparalleled transparency and accountability, allowing every stakeholder to audit past transactions without the need for central authority or third-party validation. It prevents fraud, double-spending, and misrepresentation, especially in sectors like agriculture where trust and verification are crucial. This immutable ledger also helps in policy formulation, market forecasting, and compliance checks by regulators. The decentralized nature of blockchain ensures data resilience even during system failures or cyberattacks. Ultimately, storing transactions on the blockchain establishes a foundation of trust, supports data-driven decisions, and paves the way for a more sustainable, secure, and efficient agricultural supply chain.

IV. RESULT AND DISCUSSION

The implementation of a blockchain-based agricultural supply chain system has shown promising results in enhancing transparency, traceability, and trust among all participants—from seed suppliers to end consumers. The system allows farmers to log in securely and purchase seeds from registered suppliers using Ethereum, ensuring secure and verifiable payments. Once the crops are harvested, the grain production data is recorded and uploaded to the blockchain, where it becomes tamper-proof and accessible. Distributors, after registering on the platform, can view this data and use smart contracts to directly purchase products from farmers, eliminating the need for intermediaries and ensuring fair trade practices

As the product moves from distributor to vendor and eventually to the consumer, each transaction is stored in the blockchain. This provides a clear, unalterable history of the product's journey. Consumers can scan or access the product data to verify its source and quality. The results highlight that blockchain enhances the integrity of agricultural supply chains by reducing fraud, ensuring timely payments, and enabling product authenticity. The discussion confirms that the integration of smart contracts automates processes, reduces manual errors, and builds trust among stakeholders. Ultimately, this system promotes a more efficient, secure, and sustainable agricultural ecosystem.

A. Stake Weight Formula:

In a blockchain-based supply chain management system, the Stake Weight Formula is used to determine which stakeholder—such as a farmer, distributor, or vendor—can validate the next block of transaction data. These stakeholders may stake tokens (e.g., Ethereum or a custom coin) to participate as validators. The probability of a stakeholder being selected to validate and add a new block is proportional to the amount of tokens they have staked. This is calculated using the formula:

$$P_i = \frac{S_i}{\sum_{j=1}^{n} S_j}$$

Where P_i is the probability that validator i is selected, S_i is the amount staked by validator i, and $\sum_{j=1}^{n} S_j$ is the total stake across all validators.

This system ensures that participants who are most invested in the supply chain's transparency and integrity are more likely to be chosen as validators. For example, a trusted distributor or vendor who stakes more tokens has a higher chance of validating transactions—such as seed purchases, grain sales, or product movements—thereby maintaining accurate and secure records. This incentivizes honest behavior, reduces fraud, and fosters a reliable, decentralized trust model throughout the supply chain network.

B. Reward Formula:

The Reward Formula in a Proof of Stake (PoS) blockchain-based supply chain management system is used to determine how much a participant (such as a farmer, distributor, or vendor) earns for validating a block in the network. In PoS systems, validators are rewarded for their participation in maintaining the integrity and security of the blockchain. The reward is typically distributed based on the amount of cryptocurrency or tokens a participant has staked, as well as the share of the network they represent. The formula to calculate the reward for a validator is:

$$R_i = R_{\text{total}} \times \frac{S_i}{\sum_{j=1}^{n} S_j}$$

Where R_i is the reward for validator i, R_{total} is the total reward allocated for the block, S_i is the amount staked by validator i, and $\sum_{j=1}^{n} S_j$ is the total stake from all validators. This formula ensures that validators with a larger stake in the network receive a larger share of the reward, reinforcing their commitment to maintaining the system's integrity.

The reward system promotes fairness and encourages validators to maintain honest behavior. Since validators are financially invested in the blockchain by staking tokens, they have a vested interest in ensuring the accuracy and reliability of the data recorded. By receiving a portion of the block reward proportional to their stake, they are incentivized to continue participating in the validation process. For example, in a supply chain system, validators could include trusted vendors, distributors, and even consumers, who validate each transaction from seed purchases to final product deliveries.In addition to the financial incentive, the reward formula also helps maintain network security. By aligning the interests of participants with the overall success of the blockchain, the system ensures that validators are motivated to act in the best interests of the network. This can reduce fraud, as participants have a direct stake in the blockchain's success. Furthermore, as the system grows and more stakeholders join, the reward distribution ensures that those who contribute more resources (e.g., tokens staked) receive a fair and proportional share, creating a balanced and efficient supply chain ecosystem.

C. slashing penalty:

In a blockchain-based supply chain management system, slashing penalties are applied to discourage malicious behavior, such as double-signing, inactivity, or fraudulent transactions. Validators who act dishonestly or fail to fulfill their duties face a reduction in the amount they have staked as a penalty. The slashing mechanism ensures that validators are incentivized to act in the network's best interests, as malicious actions result in financial losses. The formula for slashing is: In a blockchain-based supply chain management system, slashing penalties are applied to discourage malicious behavior, such as double-signing, inactivity, or fraudulent transactions. Validators who act dishonestly or fail to fulfill their duties face a reduction in the amount they have staked as a penalty. The slashing mechanism ensures that validators are incentivized to act in the network's best interests, as malicious actions result in financial losses. The formula for slashing is:

$$S_{\text{remaining}} = S_i \times (1 - p)$$

Slashing ensures that validators are not only financially motivated to act honestly but also face significant consequences for malicious activities. For instance, in the context of a blockchain supply chain system, a vendor or distributor who submits false information about product deliveries or quality could face slashing penalties. This creates an environment where honesty is rewarded, and bad actors are penalized, helping to maintain the integrity of the system. Furthermore, slashing discourages validators from becoming inactive or neglecting their validation duties, as this could also result in penalties.Beyond financial penalties, slashing also acts as a deterrent to collusion between malicious actors in the supply chain. It ensures that participants who stake more tokens, and thus have a larger responsibility in the system, are less likely to engage in harmful activities, as the penalty disproportionately impacts their financial stake. This provides additional security and trust within the system, ensuring that all participants—whether farmers, distributors, or consumers—are protected from fraud and misrepresentation. Through slashing, the blockchain ensures that the supply chain remains transparent, secure, and efficient.

*D. Time Comparison for Proof of Stake (PoS) and **Hyperledger Fabric:***

When comparing the time efficiency of Proof of Stake (PoS) and Hyperledger Fabric, it is important to consider how each consensus mechanism handles transaction validation and block creation. In PoS, the process is dependent on the amount of cryptocurrency a validator has staked, and validators are chosen to create new blocks based on their stake. This reduces the computational burden compared to Proof of Work (PoW), allowing for faster block times. The time to validate and create a new block in PoS can be estimated with the following formula for block creation time:

$$T_{\text{PoS}} = \frac{T_{\text{total}}}{N} \times S_i$$

In contrast, Proof of Stake (PoS) does not require complex puzzle solving. Instead, it selects validators based on the amount of cryptocurrency they have staked. The time to add a block in PoS is determined by the stake weight of the validators and the time it takes to select a validator. The time taken for block creation can be simplified as:

$$T_{\text{HF}} = T_{\text{commit}} + T_{\text{endorsement}} + T_{\text{network}}$$

In terms of transaction speed, PoS generally has a faster throughput compared to Hyperledger Fabric, as PoS does not require the same level of consensus participation as Fabric's PBFT, which needs several rounds of endorsement and agreement. However, Hyperledger Fabric excels in permissioned use cases where privacy and transaction control are paramount. Its modular architecture allows for optimized configurations depending on the specific use case (such as supply chain management), balancing speed and security. In practice, the efficiency of PoS in public blockchains is often higher for high-volume transaction systems, while Hyperledger Fabric offers a more secure and flexible environment for business and enterprise use cases, though at a slightly slower pace.

*E. Energy Comparison For Proof Of Stake (Pos) And **Hyperledger Fabric:***

Proof of Stake (PoS) is known for being an energy-efficient consensus mechanism compared to Proof of Work (PoW). In PoS, validators are selected based on the amount of cryptocurrency they have staked in the network rather than performing computationally expensive work, as in PoW. As a result, the energy consumption for validating transactions and creating blocks is significantly reduced. The energy consumption for PoS can be expressed using the formula:

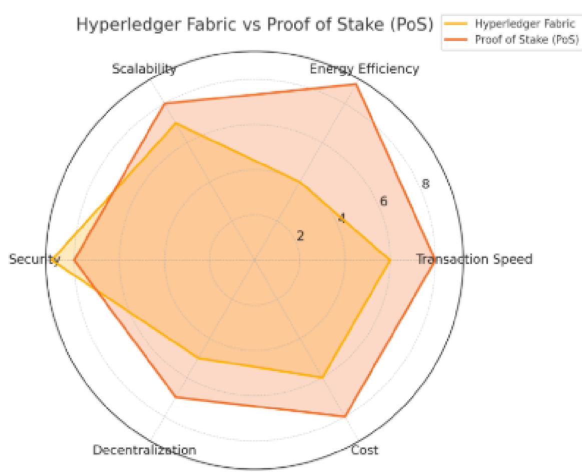
$$E_{\text{PoS}} = C_{\text{validator}} \times N$$

Hyperledger Fabric, on the other hand, operates as a permissioned blockchain that uses consensus algorithms like Practical Byzantine Fault Tolerance (PBFT) or Raft in addition to other mechanisms. The energy consumption of Hyperledger Fabric is driven by factors such as network size, consensus process complexity, and the number of nodes in the system. The formula to estimate energy usage in Hyperledger Fabric is:

$$E_{\text{HF}} = C_{\text{node}} \times P_{\text{endorsements}} \times N$$

Energy Efficiency Comparison: PoS significantly outperforms Hyperledger Fabric in terms of energy consumption, especially in large-scale systems where high transaction throughput is required. PoS systems, with their low computational overhead, consume far less energy per transaction than Hyperledger Fabric, which requires multiple rounds of endorsement and validation from distributed nodes. This makes PoS more suited for public blockchain applications where scalability and energy efficiency are critical. On the other hand, Hyperledger Fabric's energy consumption, while higher, is justified in enterprise environments where security, privacy, and governance are more important, and energy cost is less of a concern compared to the need for controlled access and permissioned transactions. Thus, PoS offers a more energy-efficient solution for decentralized applications, while Hyperledger Fabric excels in controlled, permissioned blockchain environments with stricter performance requirements.

F. Comparison Graph Of Pos Vs Hyperledger Fabric:



The comparison between Hyperledger Fabric and Proof of Stake (PoS) can be effectively illustrated through a radar chart that evaluates them across multiple dimensions such as Transaction Speed, Energy Efficiency, Scalability, and Cost. This visual representation helps highlight the core strengths and trade-offs between a permissioned enterprise blockchain like Hyperledger Fabric and a consensus mechanism used in many public blockchains like Ethereum 2.0, Cardano, and Solana. In the radar chart, PoS consistently scores higher across all key performance metrics. For transaction speed, PoS-based blockchains can process thousands of transactions per second (TPS) due to parallel processing and minimal consensus overhead, while Hyperledger Fabric, though relatively fast for a permissioned system, is limited by its ordering service and endorsement policies. In terms of energy efficiency, PoS dramatically outperforms Fabric. PoS does not require intensive computational work like Proof of Work (PoW), and its validator selection mechanism is inherently more power-efficient than Fabric's modular consensus, which still demands network resources for managing identities and permissions. Scalability is another area where PoS shines. PoS networks are designed for horizontal scaling and can accommodate a large number of validators without significant throughput degradation. Hyperledger Fabric, while scalable within a private consortium, encounters complexity and performance bottlenecks as the network size increases. Cost is a crucial differentiator. PoS operates with lower infrastructure and operational costs due to its lightweight consensus model, whereas Hyperledger Fabric incurs costs related to identity management, certificate authorities, and more complex setup.

V. CONCLUSION

In conclusion, the proposed blockchain-enabled agricultural supply chain system represents a transformative leap toward digitizing and securing the agricultural ecosystem. By integrating blockchain technology, Ethereum-based payments, and smart contracts, the system ensures end-to-end transparency, trust, and automation across all stages—from seed suppliers to end consumers. The centralized platform interface simplifies user engagement, while the underlying blockchain layer guarantees data immutability and transaction traceability. Every interaction, whether it's purchasing seeds, storing grain, or distributing produce, is securely logged and governed by smart contracts, minimizing human error and fraud. This not only streamlines operations but also empowers all stakeholders—farmers, distributors, vendors, and consumers—with reliable and verifiable information. Ultimately, the system enhances consumer confidence, boosts accountability, and lays the foundation for a scalable, adaptable, and future-ready agricultural supply chain. Future work could focus on integrating IoT sensors for real-time crop and logistics monitoring, expanding the system to support multi-currency and fiat payment options, and incorporating AI-driven analytics for demand forecasting and supply chain optimization. Additionally, mobile app development could enhance accessibility for rural farmers.

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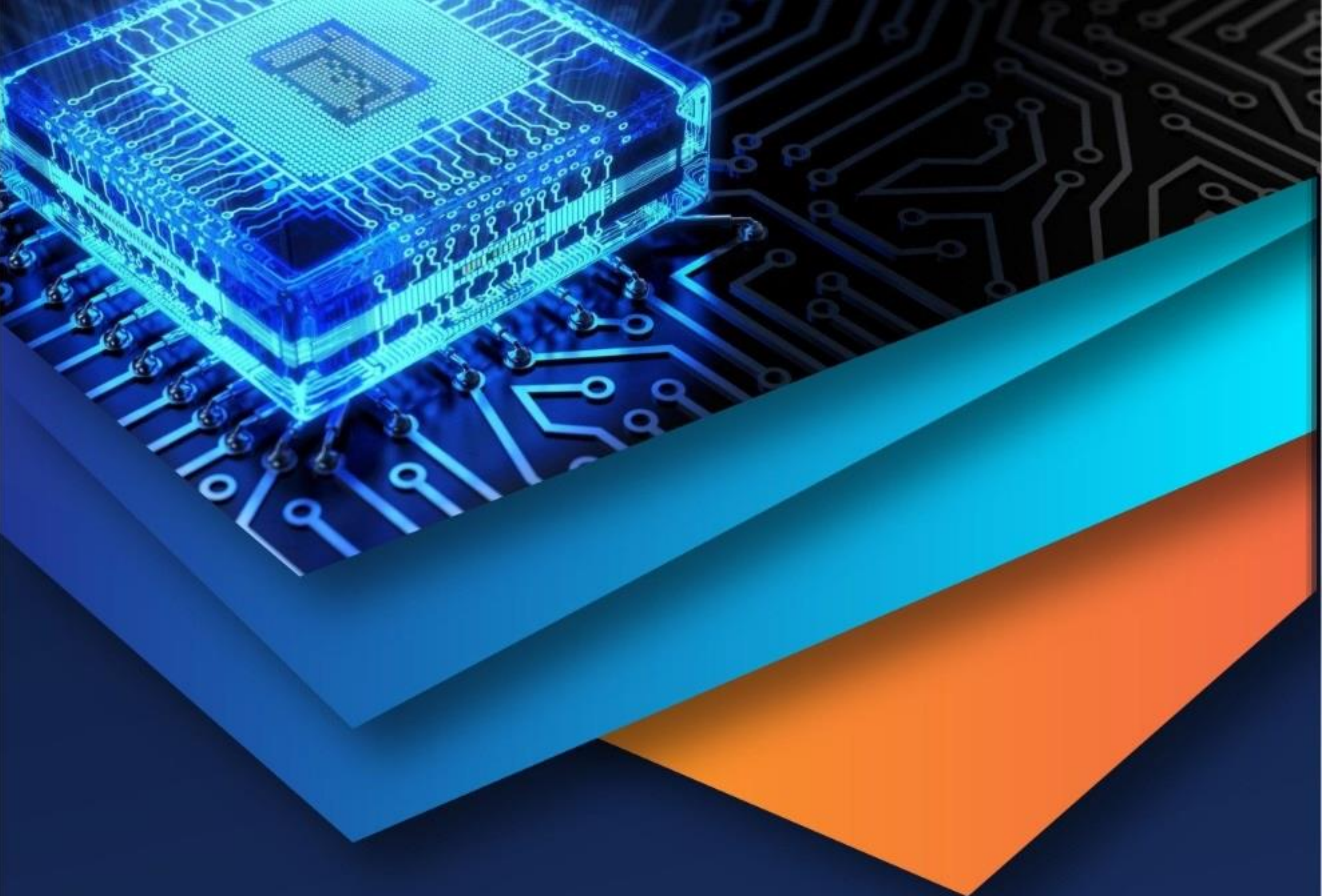

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