Revolutionizing Agriculture by Enhancing Supply Chain Management Through Blockchain Technology

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***Abstract*-In the intricate landscape of today's global agricultural supply chains, challenges in traceability, safety, quality, and overall efficiency have emerged. Traditional storage methods lack real-time monitoring, leaving farmers uncertain about perishable goods' status. This chapter proposes leveraging Blockchain technology to reshape agriculture supply chain management. By integrating Blockchain, a transparent and traceable platform is established, fostering stronger links between producers and consumers, enhancing relationships, and building trust. Blockchain's advantages, such as increased capacity, security, immutability, quick settlement, and full transaction traceability, create a resilient supply chain. Stakeholders, including farmers and government personnel, gain real-time insights into shipping phases, enabling streamlined operations and informed choices. This implementation offers a transformative solution, providing a secure, transparent, and visible platform that bolsters collaboration and empowers the agricultural sector for heightened productivity and sustainability.**

Keywords- Agri Supply Chain Management, Blockchain technology, Traceability, Farmers

I. Introduction

Agriculture plays the significant role in the GDP of many countries, particularly in developing nations like India, where it employs a substantial workforce and serves as the primary income source for a significant slice of the population. During the fiscal year 2020–21, 54.6% of the Indian population was employed in agriculture and related industries, which contributed 19.9% to the GDP of the nation. (MoAFW, 2022).

As globalization and market competition have intensified, food supply networks have grown more complicated. The food supply chain multiple stakeholders, including farmers, processors, distributors, retailers, and consumers. The supply chain is responsible for ensuring that safe and high-quality food products are delivered to consumers.

These supply chains are responsible for ensuring the delivery of safe, high-quality food products. A number of pervasive issues in these food supply chains, including as food traceability, safety, quality, trust, and inefficiency, pose further risks to society, the economy, and human health.

From a producer's viewpoint, building consumer trust and enhancing brand reputation are two benefits of using blockchain technology. Transparent, distinctive product data is made available on the blockchain. This approach allows enterprises to realize the full value of their products, boosting competitiveness. As a result, it is more difficult for dishonest or poor-quality goods to remain on the market, putting pressure on all suppliers to improve product quality across the agricultural and food sectors.

II. Literature Review

Blockchain gives consumers access to precise information on food Production as well as on transactions, addressing concerns about safety, quality, and environmental impact. Consumers can conveniently and comprehensively understand the food production process, facilitating interaction with producers and strengthening trust and confidence in food safety.(Ge et al., 2017).

From a regulatory agency perspective, blockchain ensures the availability of reliable and precise data, enabling more informed and efficient regulation efforts. Blockchain technology helps build trustworthy food supply chains and fosters trust between farmers and customers by tracing the provenance of food. It is simpler to use data-driven technology to enhance farming because it is a dependable data storing approach. When combined with smart contracts, it also makes it possible for stakeholders to make timely payments that may be initiated by data changes that emerge on the blockchain. (Chen, 2018).

Blockchain, which Satoshi Nakamoto, the creator of Bitcoin, popularized in the beginning, has the potential to transform many industries and various contemporary processes, including supply chain management and the protection of copyrights and ownership rights, resulting in time and cost savings.

A blockchain serves as a digital ledger for recording transactions, maintained by a decentralized network of computing machines, eliminating the need for a central, trusted third party. Every transaction is distributed across this network of machines operating on the blockchain procedure, requiring validation from all participating computer nodes. The pivotal feature of blockchain lies in its ability to uphold a consistent and universally agreed-upon record among participants, often referred to as consensus. (Bano 2017)

While some participants may not act honestly, even in this context (Castro and Liskov 1999), the issue of achieving consensus has been a well-explored subject in the past. However, its adaptation within the blockchain domain has stimulated fresh thinking and motivation, leading to inventive concepts for blockchain system design.This technology offers a trustworthy source of information because it is frequently prohibitively expensive to collect correct data about farms, inventories, and contracts in the agricultural sector.

As per Zheng et al. (2017), the blockchain architecture comprises three primary components: the network, the consensus mechanism, and the data structure. The network component is responsible for linking nodes and facilitating data transmission among them. The consensus mechanism ensures unanimous agreement among nodes regarding the blockchain's state, typically achieved through proof-of-work or proof-of-stake algorithms. The data structure component outlines how data is stored and organized within the blockchain, commonly utilizing a Merkle tree or hash-linked list.

In essence, blockchain architecture is designed to establish a secure, transparent, and decentralized infrastructure for transactions and data storage. This technology allows all participants in the network to access each other's records, preventing the dominance of any central authority. Transactions are broadcast to the network, where computer programs validate their legitimacy. Once validated, the new transaction is linked to the previous one, forming a series of transactions known as the blockchain. This technology functions on a decentralized network, operating akin to a peer-to-peer system.

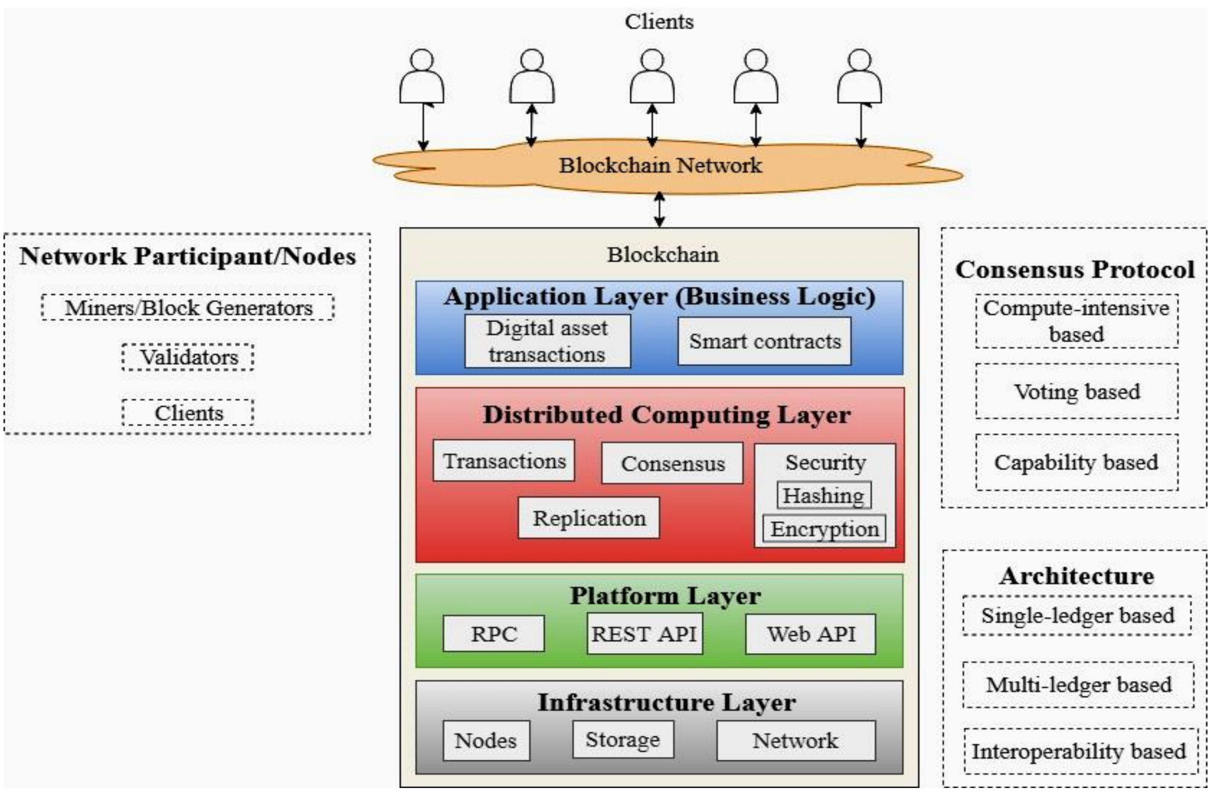

Fig. 1. Block Chain Architecture

A. *Key Characteristics of Block Chain Technology*

A blockchain network derives its effectiveness from four fundamental characteristics:

- Ledger: Blockchain employs an append-only ledger, ensuring a comprehensive transaction antiquity. Unlike traditional databases, which overwrite earlier data, blockchain transactions and values preserve them.
- Secure: Blockchains are cryptographically secure, safeguarding the integrity of the ledger's data against tampering. The data within the blockchain is verifiable and tamper-resistant.
- Shared: Multiple parties can view the ledger, which promotes transparency among node participants in the blockchain network.
- Distributed: Blockchain has the potential to be distributed, enabling the network to grow by adding more nodes. This scalability improves resilience to possible attacks from malicious parties and reduces their capacity to influence the blockchain's consensus system.

B. *Interpreting the Operations of Blockchain*

How blockchain-based distributed ledger technology operates to make this feasible with the aid of middlemen-free, secure transactions between members.Here is a succinct explanation of how it operates.

- Transaction Initiation: The blockchain process begins with a transaction, such as a cryptocurrency transfer.
- Validation by Nodes: This transaction is shared with a network of computers known as nodes. These nodes employ complex algorithms to verify the authenticity and legitimacy of the transaction.

- Block Creation: Validated transactions are bundled into a new data block.
- Chain Addition: This new block is added to the existing chain of blocks, creating an immutable transaction record.
- Hash Linking: Each block contains a unique hash code that securely links it to the previous block, ensuring system integrity.
- Decentralized Maintenance: A decentralized network of nodes collaborates to validate transactions and maintain the system's overall integrity.

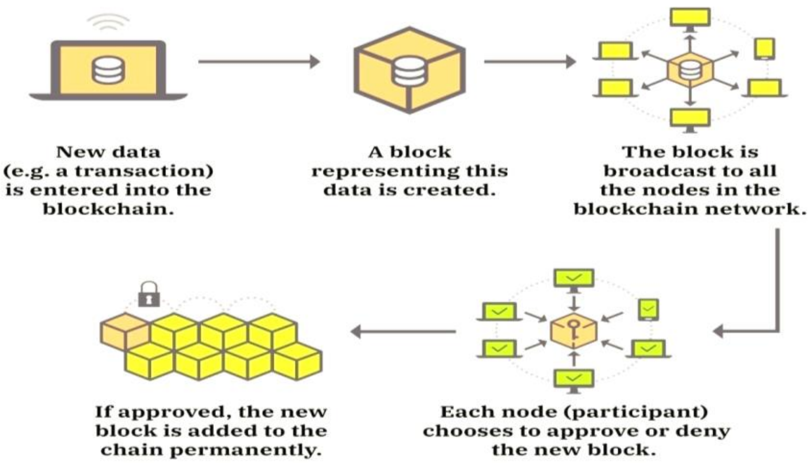

Fig. 2. Block chain Process

III. Blockchain Application in Agro- Commodity Supply Chain Management

Supply chain management has long posed challenges for global companies, necessitating substantial resource allocation to address inefficiencies and reduce costs. However, the advent of blockchain technology has spurred a forward-thinking approach in addressing these issues. Analysts suggest that blockchain can revolutionize supply chain operations by bolstering effectiveness, faith, and transparency (Meidute et al., 2021). Many supply chain leaders believe that blockchain solutions represent the future of supply chain management.The survey performed by PwC in 2019 has revealed that more than 24% of the manufacturing business is looking to implement blockchain know-how in supply chain management (PwC, 2019).

A 2019 survey by PwC revealed that over 24% of the industrial manufacturing industry is actively exploring blockchain implementation in supply chain management (PwC, 2019). Although not a novel internet infrastructure, blockchain is a relatively recent entrant in the realm of supply chain networks, offering promising prospects for the future of business.

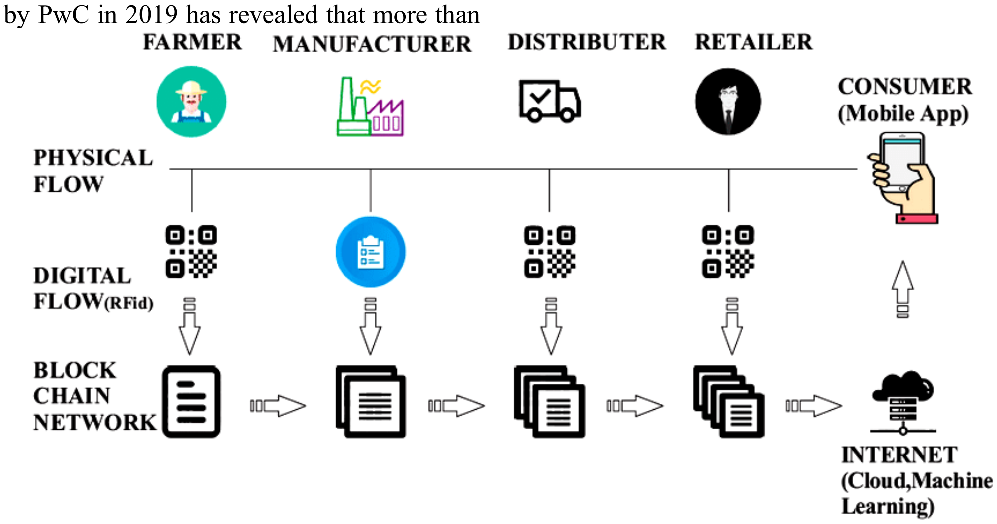

Fig. 3. Block chain- based Supply Chain Management

Supply chain management varies in its specifics, but as per Moosavi (2021), it entails the comprehensive coordination of material flow from raw material suppliers to production, warehousing, transportation, and ultimately, the end-users. Identifying its boundaries, as emphasized by Xu et al. (2021), is a crucial aspect of this complex process.

Blockchain technology has the potential to contribute significantly to attaining the seven key points of supply chain management: cost optimization, value enhancement, speed improvement, dependence reduction, risk mitigation, sustainability promotion, and flexibility augmentation, as outlined by Kshetri (2018).

To enhance efficiency and reliability in agricultural applications, blockchain applications can be categorized into four distinct groups. The first category involves tracing the provenance and authenticity of food products. The second pertains to the efficient management of smart agricultural data. The third focuses on financial transactions within the supply chain management process. The fourth category encompasses other information management systems (W. Lin et al., 2020).

Additionally, importance should be placed on continuing to provide consumers with information after food is purchased, for example, via smart packaging technologies that aid consumers in knowing the expiration status of food products. Today, massive potential exists to implement new technologies within food supply chains to establish transparency, thereby gaining consumer trust and aiding approval from regulatory bodies. Food industry actors and regulators among others in the United Kingdom, Australia, and New Zealand identified transparency as the most crucial strategy in building, or rebuilding, consumer trust in existing food systems (Wilson et al., 2017).

IV. ADVANCING TRANSPARENCY AND TRACEABILITY

The capacity to authenticate and follow the movement of both goods and information along the whole supply chain is referred to as transparency in the context of supply chains. Access to impartial, correct, timely, and relevant information regarding supply chain products is what is meant by this type of transparency. (Wognum, Bremmers, Trienekens, Van Der Vorst, & Bloemhof, 2011), has evolved into a pivotal element within contemporary food supply chains.

To effectively follow the movement of food products across the supply chain, comprehensive information should be accessible from the point of origin ("farm to fork") and beyond. Information on agricultural farming practices is also included, and extends to particulars about transportation, packaging, and storage conditions, up to the point of consumer acquisition. Furthermore, it involves the provision of post-purchase information to consumers, potentially through smart packaging technologies that keep consumers informed about the status of food product expiration.

In the current landscape, there is immense potential for the integration of novel technologies in food supply chains to establish transparency. This, in turn, fosters consumer trust and garners approval from regulatory authorities. Transparency has been identified by various stakeholders in the food industry, including regulators and organizations in the Considering the UK, Australia, and New Zealand is the greatest way to promote and strengthen consumer trust in the current food systems. (Wilson et al., 2017).

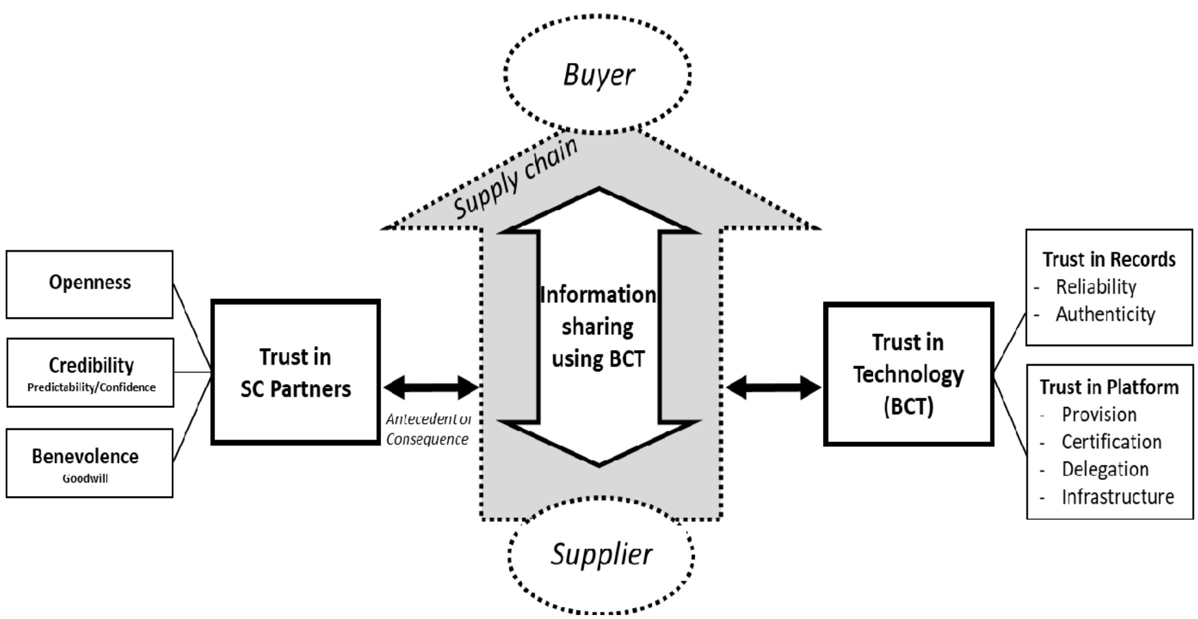

Fig. 4. Block chain and Trust in participants

The information sharing in the supply chain process has many important factors that drive bloat block chain technology; development is regarded as the most crucial factor. In block chain technology, the transactions are identified in a time-stamped and observable manner and then confirmed, there is no point in changing the transaction once the right parties approved the name. Talking about data integrity and security, block chain technology is much more secure, traceable, efficient, and transparent in the field of supply chain transactions (Kamble et. al, 2021). There is no way of changing the record on the block chain hence the supply chain members' transactions and decisions are properly recorded and documented on the block chain technology. The supply chain members are well aware of the transaction accuracy and the activities. If any situation arises where it can lead to controversial business results, the members of the supply chain can easily monitor the name and take necessary action and adjust the activities accordingly at the time of finalizing the future transaction (de Giovanni, 2020).

Blockchain distributed ledger technology could be used in the food chain to store valuable information digitally such as food production data, ingredients, origin, shipment and storage data, expiry, etc. This will facilitate the prompt identification of foodborne outbreaks and the authenticity of the food (Huang, H.; Zhou, 2019).

Blockchain technology enables a distributed ledger system that is transparent and resistant to manipulation. The following are some ways that blockchain enhances supply chain transparency:

Traceability: Blockchain technology enables comprehensive end-to-end traceability by meticulously documenting each transaction, ownership change, and product movement inside the blockchain ledger. This data is accessible and verifiable by all supply chain participants, promoting transparency and accountability.

Provenance Verification: Blockchain enables the validation of a product's origin and authenticity. By recording data like batch numbers, production information, and certificates on the blockchain, consumers and businesses can monitor a product's entire history and confirm its validity and ethical sourcing.

Real-time Visibility: A shared, synchronized, and decentralized database that provides real-time visibility into supply chain operations is made available to allowed parties by blockchain technology. Transparency increases supply chain decision-making and collaboration while reducing informational inequities.

The proliferation of blockchain technology in the supply chain hinges on various crucial factors, with development being paramount. In blockchain technology, transactions are time-stamped and observable, and once approved by the relevant parties, they are immutable. This provides robust data integrity and security, ensuring transparency in supply chain transactions (Kamble et al., 2021). With blockchain, records cannot be altered, assuring that supply chain members' transactions and decisions are accurately recorded and documented. This offers members a clear understanding of transaction accuracy, and in case of any discrepancies, they can swiftly identify and rectify issues when finalizing future transactions (de Giovanni, 2020).

The utilization of blockchain's distributed ledger technology in the food chain allows for the digital storage of valuable data, including food production details, ingredient information, origin, shipment and storage records, and expiration dates. This aids in rapid detection of foodborne outbreaks and assures food authenticity (Huang, H.; Zhou, 2019).

The traceability system encompasses exhaustive information on food production, processing, transportation, and storage conditions. Consumers should have precise access to all stages of the process and even individual ingredients of the final product.

A. *Smart Contracts in Agricultural Supply Chain Management*

Smart contracts, a component of blockchain technology, play a pivotal role in establishing trust within the supply chain process. The applicability of blockchain and smart contracts extends across diverse domains, encompassing insurance claims, financial transactions, and corporate dealings. Consequently, the proliferation of blockchain and smart contract applications has surged over time.

The smart contract functionality within blockchain can seamlessly find application in complex supply chains that involve multiple tiers of suppliers and subcontractors.

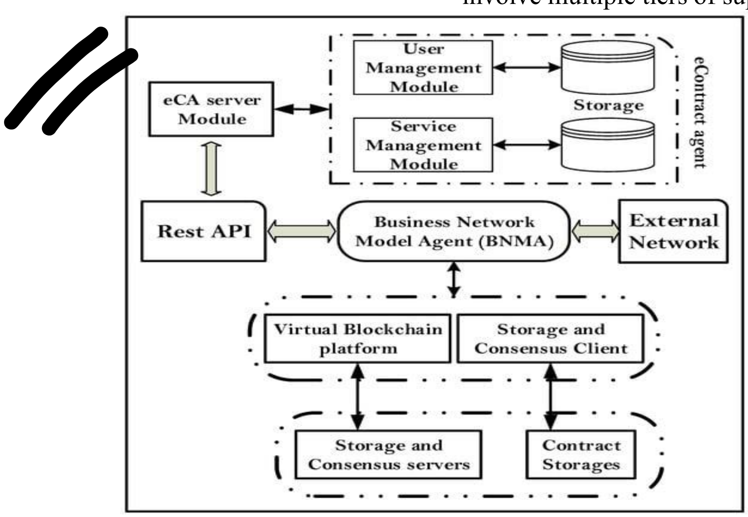

Fig. 5. Agri Smart Contract System

The agri-food supply chain system is a complex network involving multiple levels of transactions, each with varying terms and conditions (Nguyen et al., 2019). This system integrates various functions, such as food processing, transportation, storage, and distribution. At each level, detailed records are maintained throughout the lengthy and intricate processes, from processing to packaging, transportation, storage, and distribution.

Smart contracts offer a solution to streamline these processes and enhance transparency across the entire supply chain. When integrated with IoT devices, blockchain-based smart contracts facilitate real-time tracking of product location, inventory, and changes in ownership rights, allowing companies to proactively respond to disruptions or incidents. Additionally, smart contracts empower companies and consumers to assess food product quality by enabling traceability of all relevant information. The versatile nature of smart contracts makes them suitable for diverse applications (Haiwu et al., 2018).

A typical blockchain smart contract system features various functional blocks, including user management and service management modules responsible for overseeing user accounts, services, and smart contracts. The business network module acts as an intermediary, while APIs provide interfaces for external components. A virtual blockchain platform, such as the Ethereum virtual machine, is employed for deploying, implementing, and supervising the smart contract state machine. Blockchain and distributed ledger technologies guarantee the security of business transactions, and real-time data from various distributed sources is used to dynamically enforce the terms and conditions of smart contracts. (Showkat et al., 2022).

B. *Quality Control involving IoT and Data Analytics*

Quality control is a pivotal element in agro-commodity supply chains, ensuring that agricultural products meet the requisite standards and are safe for consumption. This rigorous process involves continuous monitoring, testing, and management of agro-commodity quality at various stages within the supply chain, spanning from production to distribution. Blockchain technology offers a secure and transparent solution for overseeing and ensuring the quality of agricultural commodities throughout the entire supply chain process. This comprehensive monitoring encompasses the evaluation of farming conditions, production processes, as well as the transportation and storage of agricultural products.

Sensor technology and the Internet of Things (IoT) effectively address challenges in precision agriculture by providing surveillance services to optimize plant growth and anticipate potential disease outbreaks. Wireless sensor networks-based agricultural monitoring systems aid in early detection and forecasting of plant diseases (Khattab et al., 2019; Ibrahim et al., 2019). Moreover, smart irrigation systems, incorporating IoT and sensor technology, facilitate the efficient utilization of water resources, a critical consideration in the context of dwindling clean water resources in precision agriculture (Huong et al., 2018).

Data analytics assumes a central role in quality assurance, as it involves the analysis of collected data to identify patterns or anomalies that could impact crop quality. The application of machine learning and deep learning techniques enables the development of automated fruit detection systems, facilitating fruit yield estimation and automated harvesting (Kamilaris and Prenafeta-Bold, 2018). Deep learning finds application in weed detection and control in precision agriculture (Kounalakis et al., 2019).

The integration of IoT devices and data analytics empowers real-time monitoring and analysis, enabling farmers to make up-to-date decisions and take appropriate actions to safeguard crop quality. By harnessing advanced analytics techniques, farmers can optimize farming practices, enhance crop yields, and mitigate the risk of crop failure.

V. BLOCK CHAIN IMPLEMENTATION IN FOOD SUPPLY CHAIN

Many companies have made the commitment to look into using blockchain technology. in food safety management and are actively implementing it in practice (Tian, 2016). For instance, industry giants like Wal-Mart, Alibaba, and JD.com are actively engaged in blockchain food traceability projects, using blockchain technology to comprehensively track the entire journey of food production, processing, and sales. Here are some notable implementations and their implications (Pareek, 2022):

- **IBM Food Trust™:**Food authenticity and safety are improved by this platform's ability to track items back to their source and provide food traceability.
- **Transparent Path**: Offers real-time tracking of the farm-to-distributor journey, acting as a chain of custody to enhance food safety and provide consumers with insight into a food's origins.
- **Ripe.io**: leveraging blockchain to promote transparency in the food supply chain, offering tools for mapping the food journey, quality verification, secure data aggregation, and integration with sensors and IoT devices.
- **Trace-Harvest Network**: Developed in partnership with Bayer Crop Science, this system enhances supply chain efficiency, transparency, compliance, and sustainability, setting new standards in the agricultural sector.
- **Trace X**: The food and agriculture supply chain is connected by a next-generation digital agriculture platform that uses blockchain to provide secure, verifiable, and auditable data exchange.
- **Agri-Digital**: a blockchain-based commodity management system that uses smart contracts to simplify complicated agricultural transactions for the world's grain business.
- **Agri-Ledger**: uses blockchain and distributed ledger technology to enhance the agricultural supply chain's traceability, authenticity, transparency, and

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trustworthiness, offering digital identity and financial inclusion tools.

- **Agri-Chain**: Focuses on enabling peer-to-peer agricultural transactions and processing, removing intermediaries and enhancing management software solutions for traditional agricultural supply chains.
- **Ag-Unity**: A platform connecting farming communities with organizations and businesses, reducing operational risks in transactions with rural communities and improving project efficiency in emerging markets.
- **Grain-Chain**: Provides innovative solutions to address challenges across the global agricultural industry's supply chain, benefiting producers, storingoperatives, buyers, and the agribusiness supply chain.
- **HARA**: A blockchain-based data exchange for the food and agriculture sector, offering valuable data to farmers and other stakeholders, making data-driven decisions across Indonesia's agricultural sector.

These implementations showcase the diverse ways blockchain technology is enhancing transparency, trust, and traceability in food supply chains.

VI. Challenges in Implementation of Bock Chain in Food Supply Chain

The application of blockchain technology in the food supply chain is still in its infancy, characterized by various areas of immaturity and imperfection in its implementation process. Additionally, For the effectiveness of the food supply chain's stakeholders must work together and engage widely for blockchain technology to realize its full potential.

A. Security Challenges in Centralized Systems:

Centralized systems are susceptible to numerous security vulnerabilities, and the integration of IoT systems has introduced fresh concerns related to security and privacy.

Lack of Global Standards: There is a noticeable absence of global standards and uniform theoretical frameworks when it comes to implementing traceability within the food supply chain.

Diverse Stakeholder System Architectures: Various stakeholder system architectures exist, encompassing both centralized and distributed storage for data sharing.

Concerns of Farmers and Small Businesses: Farmers and small-scale businesses often grapple with concerns regarding their privacy, profit-sharing arrangements, and the commercial use of their data.

Incomplete Linkage to Raw Ingredients: There is a shortage of data linking finished food products to their raw ingredients, impacting transparency in the supply chain.

Drawbacks of "One Size Fits All" Traceability Techniques: A universal "one size fits all" approach to traceability may prove detrimental in certain contexts.

Complexity of Multiple Granularity Levels: The adoption of traceability granularity levels at multiple stages can be hindered by complex procedures and the involvement of various key participants.

Challenges of Centralized Data Exchange: Centralization along the supply chain network can impede the efficient exchange of traceability-related data.

Addressing these challenges and fostering collaboration among all stakeholders is essential to advance the maturity and effectiveness of blockchain technology within the food supply chain.

VII. Conclusion

The global blockchain trendy agriculture and food market is projected to experience substantial growth, with an estimated market size of USD 1.4 billion by 2026, compared to the current market size of USD 200 million in 2021. This growth is expected to be driven by a robust compound annual growth rate (CAGR) of 47.5%. Stakeholders within the agriculture ecosystem are increasingly recognizing the potential of emerging technologies like blockchain in bolstering data management capabilities. Blockchain holds the promise of creating supply chain efficiencies, reducing transaction friction, fostering trust among stakeholders, simplifying compliance procedures, and diminishing the costs associated with contract execution.

Blockchain technology stands to benefit not only agribusinesses and government bodies but the entire agricultural sector, including farmers and food consumers. Its capacity to streamline processes and logistics while cutting costs and timelines associated with transactions, augment tracking and traceability, and elevate food safety and sustainability is precisely what the agriculture sector needs to ensure its sustainability.

Despite the promise of blockchain, AI, and IoT in agriculture, it's important to note that their application is still in the developmental stage. Existing work predominantly comprises exploratory and prescriptive studies, with only a handful of concrete systems having been designed and implemented, often at the prototype level. There's a pressing need to implement a multitude of real-time use cases to empirically evaluate the claimed benefits of these technologies, which include improved performance, intelligent decision support, enhanced security and privacy throughout the supply chain, elevated food safety, and eco-friendly practices.

Additionally, the development of optimization tools is necessary to effectively implement the existing solutions of these technologies in agricultural applications. This research and development endeavor is vital for the continued progress of technology-driven advancements in the agriculture sector.

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