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Article

Blockchain in Agriculture to Ensure Trust, Effectiveness, and Traceability from Farm Fields to Groceries

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Abstract: Despite its status as one of the most ancient sectors worldwide, agriculture continues to be a fundamental cornerstone of the global economy. Nevertheless, it faces obstacles such as a lack of trust, difficulties in tracking, and inefficiencies in managing the supply chain. This article examines the potential of blockchain technology (BCT) to alter the agricultural industry by providing a decentralized, transparent, and unchangeable solution to meet the difficulties it faces. The initial discussion provides an overview of the challenges encountered by the agricultural industry, followed by a thorough analysis of BCT, highlighting its potential advantages. Following that, the article explores other agricultural uses for blockchain technology, such as managing supply chains, verifying products, and processing payments. In addition, this paper examines the constraints and challenges related to the use of blockchain technology in agriculture, including issues such as scalability, legal frameworks, and interoperability. This paper highlights the potential of BCT to transform the agricultural industry by offering a transparent and secure platform for managing the supply chain. Nevertheless, it emphasizes the need for involving stakeholders, having clear legislation, and possessing technical skills in order to achieve effective implementation. This work utilizes a systematic literature review using the PRISMA technique and applies meta-analysis as the research methodology, enabling a thorough investigation of the present information available. The results emphasize the significant and positive effect of BCT on agriculture, emphasizing the need for cooperative endeavors among governments, industry pioneers, and technology specialists to encourage its extensive implementation and contribute to the advancement of a sustainable and resilient food system.

Keywords: smart agriculture; blockchain technology; distributed ledger; agriculture

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1. Introduction

Blockchain is a decentralized digital ledger system that utilizes cryptography to secure and verify transactions [1]. The initial application, Bitcoin, was developed by Satoshi Nakamoto using blockchain technology (BCT) and served as the foundation for cryptocurrencies like Bitcoin while offering potential applications in various contexts [2]. One of these applications is in smart agriculture, where BCT has the potential to enhance transparency, traceability, and productivity within supply chains [3].

Agriculture plays a crucial role in the global economy, being a source of both food and raw materials. With the growing global population, there is a pressing need to develop methods for enhancing agricultural efficiency and efficacy [4]. BCT emerges as a viable solution to address challenges in the agricultural industry, particularly in the areas of trust, efficacy, and traceability, which have become more pronounced due to recent technological advancements [5].

BCT, as a secure and immutable database employing cryptographic methods, offers advantages such as traceability, immutability, transparency, and security [6]. These attributes are particularly significant in the agricultural sector, where trust and transparency are essential for building a sustainable and secure food supply system [7].

The implementation of BCT in agriculture has the potential to promote confidence and transparency throughout the entire food supply chain. It can enable more efficient monitoring and tracing of goods, minimizing risks associated with foodborne diseases and food fraud [8]. The establishment of a system for the accurate tracing of the origin, quality, and safety of food items is crucial for consumers, regulators, and industry stakeholders, and BCT can provide a more accurate and reliable solution to meet these requirements [9].

"Smart agriculture" refers to a forward-thinking farming approach that utilizes modern technology to maximize crop production, reduce waste, and improve environmental sustainability [10]. The incorporation of sensors, drones, and other technologies to gather data on soil conditions, weather patterns, and crop health allows for more informed decision-making in planting, fertilizing, and harvesting [11].

The use of BCT in environmentally conscious farming holds great promise. It can establish a more transparent and efficient supply chain, preventing food fraud and ensuring consumers are informed about the actual origin of the food they purchase [12]. Furthermore, blockchain can be employed in precision agriculture to make better-informed decisions on the planting, fertilizing, and harvesting of crops [13]. Despite being in its early stages, blockchain has considerable potential to enhance smart agriculture [14], emphasizing the importance of monitoring progress in this area. This study aims to investigate the applicability of BCT to the agricultural industry, particularly in promoting trust, efficiency, and traceability along the supply chain.

1.1. Identification of the Research Gap

This study commences by addressing a notable deficiency in the agricultural industry, which is marked by challenges such as inadequate trust, inefficiencies in supply chain management, and difficulties in traceability. The existence of this disparity underscores the necessity for novel approaches to improve efficacy and transparency across the entire agricultural supply chain.

1.2. Definition of the Objective of the Research

The principal aim of this study is to investigate the potential of blockchain technology (BCT) in alleviating the challenges that have been identified in the agricultural sector. From farm fields to grocery stores, ensuring trust, efficiency, and traceability is of paramount importance. The objective of this research is to utilize blockchain technology (BCT) in order to create an agricultural supply chain management platform that is both secure and transparent.

1.3. Methodology Applied

The applied methodology examines the multifaceted effects of BCT on agriculture through a comprehensive lens. An analysis of the pertinent literature, case studies, and a critical evaluation of BCT applications across multiple domains of the agricultural supply chain are all encompassed within this report. Combining conceptual frameworks and concrete illustrations, this study utilizes a PRISMA approach and meta-analysis approach to illustrate the potential benefits and obstacles associated with the adoption of BCT in agriculture.

1.4. Contribution Accomplished

By examining a variety of application domains, including supply chain management, product verification, and payment processing, this study offers a more thorough understanding of the ways in which BCT can be used to address the issues that have been identified in the agricultural industry. This paper highlights the difficulties and limitations that come with using BCT in the agricultural industry, including issues with regulatory frameworks and interoperability. The overall goal of this research is to provide information that will motivate stakeholders—technologists, business executives, and governments, among others—to work together to advance the use of blockchain technology for a safe and sustainable agricultural system.

2. Research Contributions

This research paper aims to investigate the use of BCT in the agricultural industry to ensure trust, effectiveness, and traceability from farm fields to groceries. This paper will make the following contributions to the existing literature:

2.1. Literature Review

A full assessment of the recent literature on BCT in the agricultural industry will be carried out as part of the next step, which is the "literature review". The purpose of this study is to investigate the many applications of BCT in the agricultural sector, as well as the advantages and disadvantages of putting it into practice.

2.2. Framework Development

The creation of a framework for the use of BCT in the agricultural sector will be the primary focus of this study. Participants in the food supply chain will have access to a guide that will help them deploy BCT efficiently thanks to the framework. Small-scale farmers and other participants in the food supply chain will have their difficulties, such as infrastructural, technical, and financial limitations, taken into consideration throughout this process.

2.3. Future Research Directions

This article will highlight the gaps in the current literature on BCT in agricultural business and make suggestions for future research areas. Also, this study will identify the breaches in the present works. The need for additional empirical studies, the potential for the integration of other technologies like the Internet of Things (IoT) and Artificial Intelligence (AI), and the ethical considerations of applying BCT in the agricultural industry will all be taken into account with the recommendations.

The organization of this article is as described below. The technology known as blockchain will be broken down in more detail in the next section. The subsequent part delivers an outline of the available research on how BCT may be used in the agricultural sector. In the next part, we will talk about the many application areas of BCT that may be employed in the agricultural industry. The following section presents a framework according to the different application areas that were discussed in the previous section. The next two sections discuss the possible advantages and difficulties that might arise from using BCT in agricultural settings. Last but not least, the examination of the prospective applications of BCT in agriculture, as well as the future research paths, brings this article to a close.

3. BCT: An Overview

BCT emerged following the introduction of the cryptocurrency named "Bitcoin". It functions as a distributed ledger technology, consisting of a series of blocks that form a decentralized and distributed peer-to-peer network [15]. Blockchain is utilized to record information about all operational activities, and this data is stored across the distributed ledger of each node in the network. Each node within the structure has its own individual Distributed Ledger Technology (DLT) [16]. The decentralization of BCT provides inherent strength in addressing security issues, authentication, confidentiality, integrity, and authorization—challenges that centralized systems may struggle to handle. Figure 1 illustrates that blockchain is a sequence of hashed blocks.

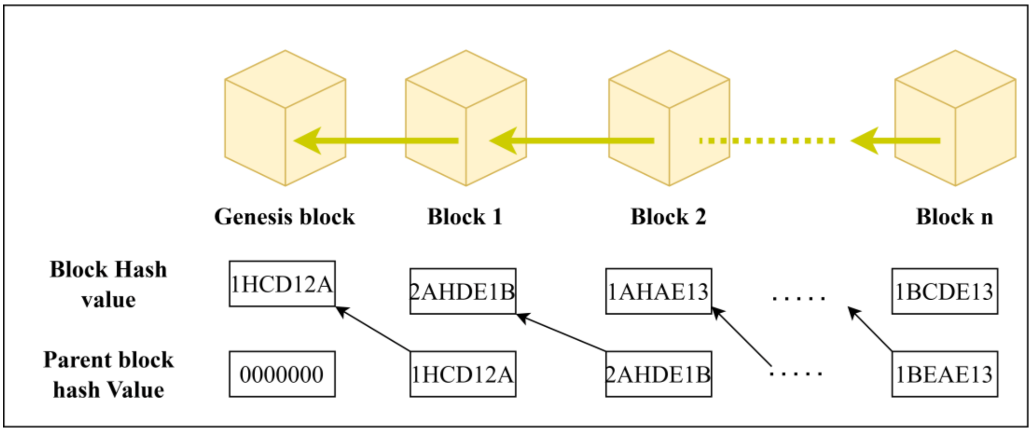

Figure 1. Blockchain as a sequence of hashed blocks.

3.1. Types of Nodes in Blockchain

3.1.1. Normal Nodes

These nodes are classified as ordinary nodes, possessing comprehensive knowledge about the blockchain within their ledger. Normal nodes are responsible for conducting transactions, and these transactions may undergo validation by miner nodes.

3.1.2. Miner Nodes

These nodes are highly specific and are considered special nodes. These superior nodes are nominated based on certain protocols. Miner nodes play a crucial role in the authorization and authentication of blocks containing transactions conducted within the network.

3.2. Basic Elements of a Blockchain Network

Every network requires some fundamental components to form a functional system. In blockchain, several essential components contribute to the structure of the network. These include nodes, smart contracts, consensus mechanisms, blocks, chain, and transactions, each of which is explained as follows:

3.2.1. Nodes

Initially referenced simply as computers, these entities are commonly known as nodes. Over time, these nodes may also be referred to as miner nodes, and their primary responsibility lies in the authentication and authorization of transactions, facilitated via the application of consensus mechanisms [17].

3.2.2. Consensus

Consensus is an agreement reached by the diverse nodes within the blockchain system. Various types of consensus mechanisms are employed to gain approval from different nodes in the blockchain network. These mechanisms include proof-of-work, proof-of-activity, proof-of-stake, proof-of-space, Ripple, and others.

3.2.3. Smart Contract

It is a set of rules utilized to validate and authorize the operational status of devices within a blockchain network. These rules verify the working limits of devices, ensuring the secure and automated execution of predefined actions based on predetermined conditions.

3.3. Block Structure in Blockchain

Figure 2 illustrates the structure of a block in the blockchain. A block is a fundamental element in the blockchain, contributing to the formation of a chain by storing the hash rate of the preceding block. The generation of the hash value for each block is achieved via the application of a consensus mechanism. In the blockchain, each block is equipped with a header used to store comprehensive information about the requester. Additionally, the block holds other information as outlined below:

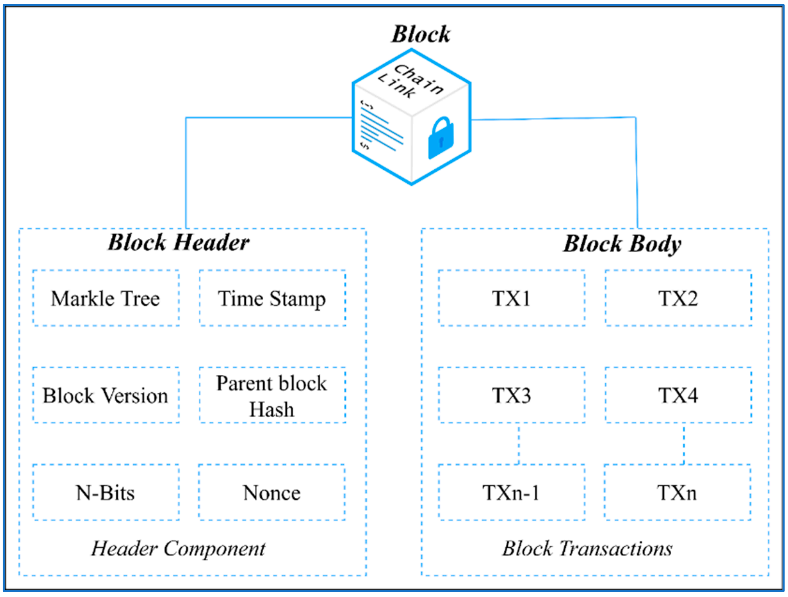

Figure 2. Structure of a block.

- *Time stamp:* It is used to define and track the period of formation and update of each block to maintain the integrity of the block.
- *N-bits:* These bits are used to define the marked threshold value of the hash code of the validated and authorized block.
- *Block Version:* This is a 4-byte value used to have knowledge about the consensus mechanism currently used.
- *Nonce:* This is a 4-byte number used only once for a valid block.
- *Markle Tree:* It forms a structure that looks like a binary tree to minimize the hash of transactions associated with it, and it does not break the hash of the transaction to reduce the storage data.
- *Parent block Hash:* This value is 256 bits and is used as an address of the previous block. This hash value is responsible for making a connection between the blocks.

3.4. Working of Blockchain

Blockchain gained significant popularity following the discovery of the cryptocurrency "Bitcoin" by Satoshi Nakamoto in 2008 [18]. Bitcoin, built on ledger technology, derives this feature from BCT. Blockchain implements a decentralized and distributed ledger system, where ledgers serve as authorized operating nodes storing duplicate records of all transactions. The distributed ledger technology ensures that records cannot be manipulated administratively [19]. This decentralized system takes advantage of exposing information disclosure matters, eliminating the need for a single authority to hold information. The decentralized nature of blockchain eliminates the necessity for establishing trust between nodes [20]. Both the concepts of decentralized and distributed ledgers are crucial for data manipulation. In the event of any attempt to change transactional data, errors during data admission, or any unauthorized manipulation, the connectivity breaks down [21]. The recovery of lost data is addressed by the distributed peer-to-peer (P2P) network. Figure 3 illustrates the working of blockchain. An example is presented below to illustrate the process of storing transactions in blocks and how these blocks become part of the chain:

- *Step 1:* In the first step, the address of the payee is generated, which is further used by the payer to make a payment. After the completion of the payment, the transaction is accepted by both parties (i.e., payee and payer) and broadcasted to every node or peer existing in the network.

- *Step 2:* The broadcasted transaction is further authorized and validated by Nodes or participants to be collected in the block. Then, cryptocurrency is rewarded to these nodes for the proof-of-work. All the nodes collect the transaction data in the block for a period of time and work hard to add the block to the current blockchain.
- *Step 3:* After the uploading of the new block with the current chain, the information will be broadcast to all the other nodes or participants existing in the network. Then, they receive the block, and the nodes verify all the transaction records held by that block to maintain data integrity. The participant accepts this block by using its hash value for the creation of the next block.

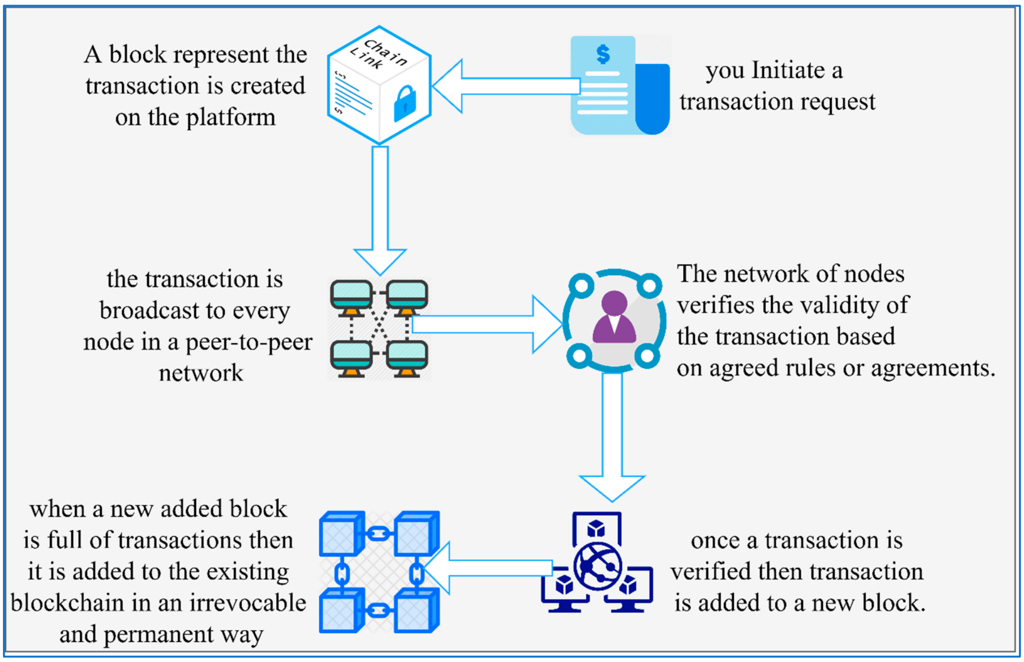

Figure 3. Working of blockchain.

All the transaction records or data are stored in a distributed and decentralized manner with the repetition of these defined steps.

4. Research Methodology

We took care to adhere to the precise and comprehensive methodology outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines while conducting our systematic literature review. This guaranteed the accuracy and dependability of our results. A particular research issue served as the foundation for our rigorous examination, which got underway with this study. The performing of thorough searches across a range of reputable academic databases, including PubMed, IEEE Xplore, and Google Scholar, was the initial stage in the methodology. We laboriously compiled a list of search terms that included crucial elements from our investigation, such as "Food Safety", "Traceability", and "Blockchain Technology". This made it possible for us to ensure the thoroughness of our approach.

Following an initial search of the body of literature, the papers that were found underwent a stringent screening process. We closely scrutinized the paper titles and abstracts to determine their pertinence to the objectives of our investigation. Only after it was established that the articles had passed the first screening were their complete texts subjected to a more thorough evaluation. We initially utilized a set of previously stated inclusion and exclusion criteria to assess whether each manuscript satisfied the requirements. The selected databases were shown as rectangles, and the search terms that were utilized were represented by the direction of the arrows. The decision-making processes for selecting an item for inclusion or exclusion were shown in a diamond-shaped graphic representing the screening phase. Decision routes, which are shown in Figure 1, were used to decide whether a paper was included or excluded throughout the screening process and were symbolized by a diamond shape.

After the screening process was finished, the chosen articles were subjected to a step that included laboriously extracting data and, if applicable, analyzing it. We were able to draw significant conclusions as a result. The papers that met our stringent conditions were highlighted in the final selection, denoted by a decision diamond. The synthesis and review step, shown by a rectangle, included a thorough analysis of the chosen body of literature, the identification of the most significant findings, and the arrangement of those conclusions into cogent themes. This comprehensive procedure, which follows the PRISMA principles, safeguards the reliability and integrity of our systematic literature evaluation. The insights obtained as a result of this strict approach, which forms the basis of this article, give a strong basis for our research study on the technique for risk traceability using blockchain technology in monitoring, tracing, and authenticating food commodities. Figure 4 shows the flowchart of the research methodology.

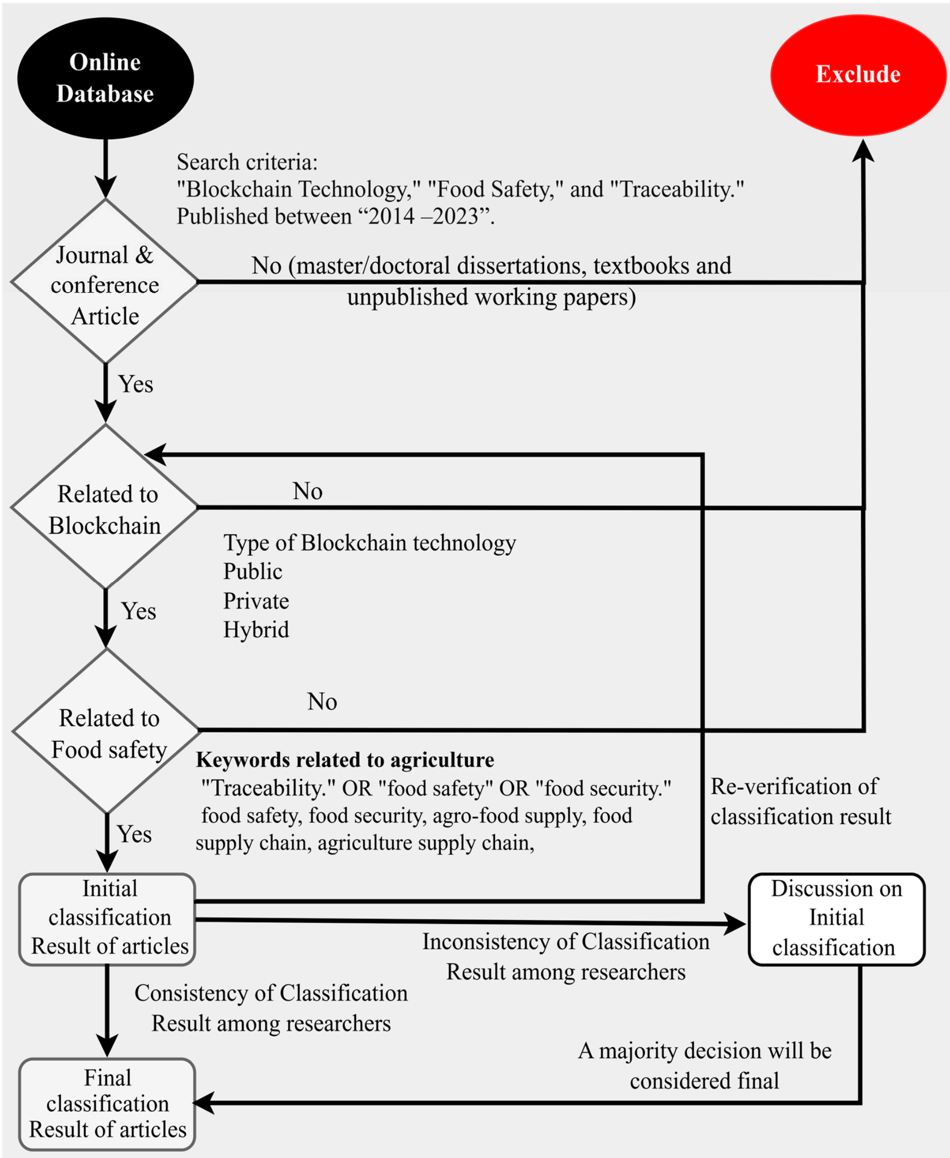

Figure 4. Research methodology.

5. Literature Review

The literature review on BCT in agriculture will be extensive. The evaluation will examine the pros and drawbacks of BCT in agriculture. BCT may increase supply chain transparency, traceability, food safety, and food fraud and waste, according to the literature assessment [22]. The evaluation will also investigate technological, financial, and infrastructural impediments to BCT in agriculture.

These articles introduce agricultural BCT. Feng [23] found blockchain-based food traceability technologies may improve safety and transparency. From this, BCT may increase traceability, making agriculture more ecologically friendly. No study explicitly tackles the question, "How may blockchain help develop a more sustainable agriculture industry?" Consequently, further research is needed to resolve this problem. Bermeo-Almeida [24] found that Asian academics, notably Chinese, led 50% of BCT studies in agriculture. This means Western research on this area is scarce.

These papers suggest that BCT might help green the agricultural industry. Sendros [25] found that BCT may be utilized to create a more sustainable agricultural industry. Najjar [26] found that BCT may increase supplier visibility and predictability and create robust and sustainable supply networks. Nguyen [27] found little research on BCT's potential usage in Vietnam's agricultural sector. Bux [28] found that blockchain might increase Halal meal legitimacy and traceability. The trustworthiness and traceability of food are crucial to an ecologically friendly system, but Halal meals are not.

"How may blockchain aid in developing a more sustainable agriculture industry?" is not addressed in various research. Upadhyay [29] found that BCT could help the circular economy by reducing transaction costs, improving supply chain performance and communication, protecting human rights, improving healthcare patient confidentiality and welfare, and reducing carbon footprint. This suggests that BCT might help green the agricultural industry. Al-Jaroodi [30] found that blockchain technologies had several industrial uses and both pros and cons. Table 1 illustrates the contributions of previous studies.

Table 1. This table shows the previous studies.

Authors	Abstract Summary	Year	Main Findings	Outcomes Measured
G. da S. R. Rocha et al. [2]	The investigation into the possibilities of BCT in the agricultural sector is just getting started.	2021	• The management of financial, livestock, environmental, agricultural, energy, logistical, and industrial concerns have been documented in the literature. These concerns include agriculture, livestock, and industry. • Using blockchain in agribusiness has the potential to deliver various advantages, including increased informational dependability and agility at a lower cost.	• blockchain applications in agribusiness
Wei Liu et al. [7]	ICT (Information and Communication Technology) methods are employed increasingly for manufacturing improvement.	2021	• The agricultural production, logistics, and supply chain are three areas in which ICTs and BTs have applications that are comparable to one another. • Information and communications technologies are used more for the enhancement of production. • With regard to consumption, ICTs concentrate on achieving market stability by striking a balance between supply and demand, while BTs research the impact of various factors on the buying choices of consumers.	• application design • socio-demographic factors • production improvement • transparency • transaction efficiency • market stability
S. S. Kamble et al. [9]	The visibility of the supply chain and the resources available within the supply chain are the major driving power behind the development of data analysis.	2019	• Developing a competency for data analytics and attaining sustainable performance is primarily driven by increasing visibility across the supply chain. • Practitioners in the agri-food supply chain use an application framework as a guide to assist them in planning their investments in order to construct a strong data-driven supply.	• social, environmental, and economic objectives attained
Y. Wang et al. [16]	Technologies based on blockchain have the potential to cause disruptions in the provisioning of traditional supply chains.	2019	• Numerous obstacles, voids in knowledge, and possibilities for more study have been found. Additionally, prospective design considerations for a supply chain that is enabled by BCT have also been uncovered.	• trust being the primary element that drives their acceptance in such technologies.

Table 1. *Cont.*

Authors	Abstract Summary	Year	Main Findings	Outcomes Measured
M. Kouhizadeh et al. [17]	Academics and industry professionals agree that the supply chain and technology constraints are the most important obstacles.	2021	• The technology, organization, and environmental framework, as well as force field theories, were used in order to study the constraints that prevented widespread blockchain implementation. • Supply chain and technology hurdles are generally considered to be the most significant impediments by academics as well as industry professionals. • This exploratory research indicates fascinating relative relevance and interrelationships of obstacles that are essential, both conceptually and practically, for further acceptance and diffusion of BCT in a sustainable supply chain environment.	• BCT can be used to overcome the obstacles in order to manage sustainable supply networks
V. Varriale et al. [21]	The use of BCT results in an increase in both a company's profitability and its reputation.	2020	• Because of the environmental, economic, and social consequences of BCT, it may be possible for this technology to make supply chains more sustainable. • Businesses that use BCT in their supply chains may see a rise in their earnings as well as an improvement in their reputation. • To quantify the effects of BCT on environmental sustainability in supply chains, there are still research gaps that need to be investigated.	• three dimensions of sustainability: environmental, economic, and social
M. P. Kramer et al. [23]	The selection of a particular BCT platform type is one of the most important factors that will determine the level of commercial success achieved by the planned use case.	2021	• BCTPTs are differentiated from other types of training by the coordination mechanisms that are used to exercise authority, share information, make decisions, and profit from collective learning. • Use cases with a high success rate often take place inside a vertical ecosystem, and the actions within the supply chain network are typically coordinated by a central company.	• the impact on coordination mechanisms in vertically cooperating agri-food networks that are the consequence of the adoption of various kinds of BCT platforms (BCTPTs)

Table 1. *Cont.*

Authors	Abstract Summary	Year	Main Findings	Outcomes Measured
O. Bermeo-Almeida et al. [24]	The use of BCT is increasing both the speed and reliability of financial transactions.	2018	• The food supply chain is the subject of sixty percent of the publications. • Researchers from the Asian community, particularly from China, account for fifty percent of all of the studies. • Fifty percent of the research looked at how BCT may help address concerns about the Internet of Things' impact on users' privacy and safety.	• Wholesome food • Transaction durations • Present-day research areas • Significant inputs
C. Bux et al. [28]	The use of BCT has become a fascinating tool for improving the reliability and traceability of Halal meals.	2022	• The use of BCT could be able to assist in the formulation of protocols and standardized processes for the purpose of guaranteeing sanitary and authorized items. • It is possible that sustained growth will result from improvements made to the Halal certification and blockchain tool.	• the challenges that Halal food sustainability faces, as well as the possibilities that are presented by certification and BCT
R. L. Rana et al. [29]	The use of BCT, also known as BCT, together with the Internet of Things makes agri-food production more environmentally friendly.	2021	• BCT that is assisted by ICT/IoT makes a contribution to the environmentally friendly production of agri-food. • The usage of BCT may provide a number of challenges, including issues with scalability and privacy leaks, as well as high costs and connection issues. • Due to the inherent qualities of BCT, it finds widespread use in a variety of agri-food supply chains.	• the benefits derived from the ethical applications of blockchain offered by the abovementioned supply chain
J. Al-Jaroodi et al. [30]	The use of technology based on blockchain provides a wide variety of applications in the industrial sector by increasing both efficiency and security.	2019	• Technologies based on blockchain have the potential to be beneficial for an extensive variability of areas, counting the safe recording and dissemination of transactional data, the establishment of automatic and effective supply chains, and the enhancement of transparency. • Industries have a great number of potential applications; nevertheless, there are still a few obstacles that need to be overcome before this technology can be utilized more effectively.	• Many commercial application areas have been suggested.

Table 1. *Cont.*

Authors	Abstract Summary	Year	Main Findings	Outcomes Measured
B. Esmaeilian et al. [31]	The creation of incentive systems and tokenization that encourage environmentally responsible behavior on the part of consumers may lead to an increase in sustainability.	2020	• BCT can improve sustainability in four main areas: incentive mechanisms and tokenization to encourage consumer green behavior; enhanced accessibility across the entire product lifecycle; and supply chain sustainability monitoring and reporting. • Using blockchain for sustainable supply chain management should be evaluated for its drawbacks and research gaps.	• the creation of incentive systems and tokenization to encourage environmentally responsible behavior on the part of consumers
Y. Zheng et al. [32]	The implementation of blockchain technology in agriculture is examined in this article, with a particular emphasis on farmers, processors, and governments. It recommends that in order to enhance brand image and reap advantages, producers and processors should control the costs associated with traceability, and that the government should incentivize agents to participate by enacting a system of rewards and penalties.	2023	Maintaining agricultural commodities' safety and quality requires blockchain-based traceability, and controlling traceability expenses is critical for producers and processors looking to enhance their reputation and reap additional rewards. Incentives and punishments are also required to accelerate the deployment of blockchain traceability.	decision-making behavior of the main participants in the blockchain traceability of agricultural products
G. da S. R. Rocha et al. [33]	The paper evaluates blockchain's pros, cons, obstacles, and prospects in agriculture. Blockchain technology enhances governance and information flow, but eliminating middlemen and high implementation costs are drawbacks. Lack of a popular platform is rising. Opportunities for blockchain integration with new technologies and competitiveness are emerging.	2023	The advantages and prospects linked with the use of blockchain technology in the agricultural industry surpass the obstacles and drawbacks, signifying the growing significance of blockchain technology in this domain.	Expert evaluation of the perceived significance of the advantages, drawbacks, difficulties, and prospects of blockchain applications in agriculture using a Likert scale questionnaire

Table 1. *Cont.*

Authors	Abstract Summary	Year	Main Findings	Outcomes Measured
G. K. Akella et al. [34]	This comprehensive analysis looks at the factors that encourage and hinder blockchain use in intelligent and sustainable agriculture. Adoption is hampered by constraints including a lack of international standards and industry best practices, while major facilitators like stakeholder engagement and the development of consumer trust are identified.	2023	Stakeholder cooperation, shared responsibility, consumer value, quality of service, trust, sustainable supply chains and value chains, democratization, and data usability allow blockchain technology adoption. Key results include lack of government legislation, resource capital needs, security and privacy concerns, lack of standards, trust, scalability challenges, knowledge, and simplicity of use as hurdles to blockchain technology adoption in smart and sustainable agriculture. The research emphasizes analyzing blockchain technology adoption hurdles and enablers for smart and sustainable agriculture.	Barriers and enablers of blockchain technology adoption for smart and sustainable agriculture
S. Padhy et al. [35]	This research combines software-defined networking, fog computing, and blockchain technologies on an open-source Internet of Things platform to provide a secure architectural framework for agriculture 4.0. The system holds up effectively against DDoS assaults.	2023	With the effective use of natural resources, smart agriculture technology may improve farming practices and raise production. For Agriculture 4.0 to create safe and scalable systems, the right security mechanism is needed. The suggested security architecture has worked effectively, integrating fog computing, software-defined networking, and blockchain technology.	Production volume, production quality, agricultural techniques' efficacy, and resource use, optimal cultivation costs, cutting down on waste, sustainable in terms of the environment, Making the Most of Your Time
A. Adimabua Ojugo et al. [36]	It is possible for the framework to immediately access and obtain data without having to go through the whole ledger.	2023	The suggestion of a trace-support system based on blockchain technology to guarantee food quality, consumer security, and food asset trade. The model's fast response times for https sites and queries, averaging 1101 transactions per second. Historical data on all beef produced, delivered, purchased, and eaten throughout the chain is provided by the framework.	Tracer management model performance metrics based on blockchain, such as transaction throughput and application response time
M. Fiore et al. [37]	An area of study that needs to be addressed is the deficiency of training for both industry and stakeholders.	2023	Blockchain technology may streamline food supply chain tracking, enhancing efficiency, safety, and customer confidence. It may build food product digital identities to help customers make educated selections and monitor sustainable and ethical manufacturing.	enhanced customer confidence and producer visibility in the agri-food supply chain via the use of blockchain-based traceability solutions

Table 1. *Cont.*

Authors	Abstract Summary	Year	Main Findings	Outcomes Measured
E. P. Kechagias et al. [38]	As a possible option for increasing traceability, a distributed application for table olives' traceability on the Ethereum network has garnered a substantial amount of interest.	2023	The use of blockchain technology in the food supply chain has greatly enhanced the traceability of products, reduced processing times, increased data accuracy and dependability, enhanced supply chain efficiency, and assisted producers in adhering to global norms and laws.	improvement of traceability in the food supply chain
M. srikanth et al. [39]	Smallholder farmers may control demand and supply with P2P blockchain technology. Installing auction algorithms in a hybrid peer-to-peer system for smallholder farmers, government crop forecast and smallholder farmer advice, estimating crop growth and managing demand and supply.	2023	The findings imply that the paper's main focus is on how blockchain technology—specifically P2P and PoA—may assist smallholder farmers in managing supply and demand, as well as how auction algorithms can be used in this setting.	Blockchain technology and machine learning can help agribusiness companies make better supply and demand projections.

6. Application Areas

This section will explore agricultural applications where companies have implemented BCT. The application areas encompass small-scale farmers, processors, distributors, and retailers. This study aims to spotlight both the advantages and drawbacks of BCT for each participant. The examination of application areas will delve into how BCT can augment supply chain transparency, traceability, and food safety. Additionally, it will assess its potential to reduce food fraud and waste, enhance overall efficiency and profitability, and improve traceability in the agricultural sector.

6.1. Application Area 1: Production of Crops and Foods

Numerous food companies are leveraging BCT to enhance trust, transparency, and traceability. The distributed and immutable nature of the blockchain's ledger allows for comprehensive tracking of the supply chain, spanning from the farm to the end consumer [40]. This capability is particularly valuable in tracking the origin and preparation of crops and meals, contributing to the assurance of their safety and quality. The implementation of smart contracts within the supply chain can automate various processes, while BCT ensures the verification of crop and food quality [41]. The automation facilitated by blockchain technology has the potential to streamline tasks, ultimately improving productivity in the food supply chain. Moreover, BCT has the capacity to reduce instances of fraud and food waste, thereby enhancing both food security and overall quality.

6.2. Application Area 2: Food Supply Chain

BCT holds the potential for diverse applications in the cultivation and preparation of food. By rendering the supply chain transparent and traceable from the farm to the end consumer, BCT ensures a heightened level of accountability [42]. The technology is adept at verifying the authenticity of crops and commodities, while smart contracts bring automation to various processes within the supply chain. Beyond supply chain management, financial transactions can also benefit from the implementation of BCT. The utilization of BCT in the food industry contributes to improved supply chain management, a reduction in fraud, and a decrease in food waste, ultimately enhancing the safety and security of food [43]. The transparency, efficiency, and safety that BCT can bring to food and agriculture production have the potential to boost industrial productivity significantly.

6.3. Application Area 3: Farmers Should Be Paid More Fairly

BCT has the potential to revolutionize the payment structure for farmers by introducing transparency into the supply chain. With blockchain, every stage of the supply chain can be meticulously recorded, creating an indisputable record of the source and quality of crops. This transparency ensures that farmers are fairly compensated for their crops, taking into account the quality and effort invested. Blockchain also plays a role in removing intermediaries from the supply chain, reducing costs, and increasing incomes for farmers [44]. Via the implementation of blockchain, the entire process of crop production and distribution gains transparency and accountability, guaranteeing that farmers receive the rightful compensation for their efforts. In summary, the use of BCT in ensuring fair payments for farmers has the potential to foster more equitable and sustainable agricultural practices.

7. Proposed Framework

This section will present and explore a BCT framework for agriculture based on application areas covered in this paper. The framework will let food supply chain participants use BCT. Small-scale farmers and other food supply chain actors confront infrastructural, technical, and financial constraints. The framework will address data governance, interoperability, scalability, and sustainability and provide solutions.

7.1. Framework for Application Area 1: Production of Crops and Foods

Figure 5 shows the proposed architecture for application area 1. The following four actions may be taken to alter the way crops or food products are produced using BCT:

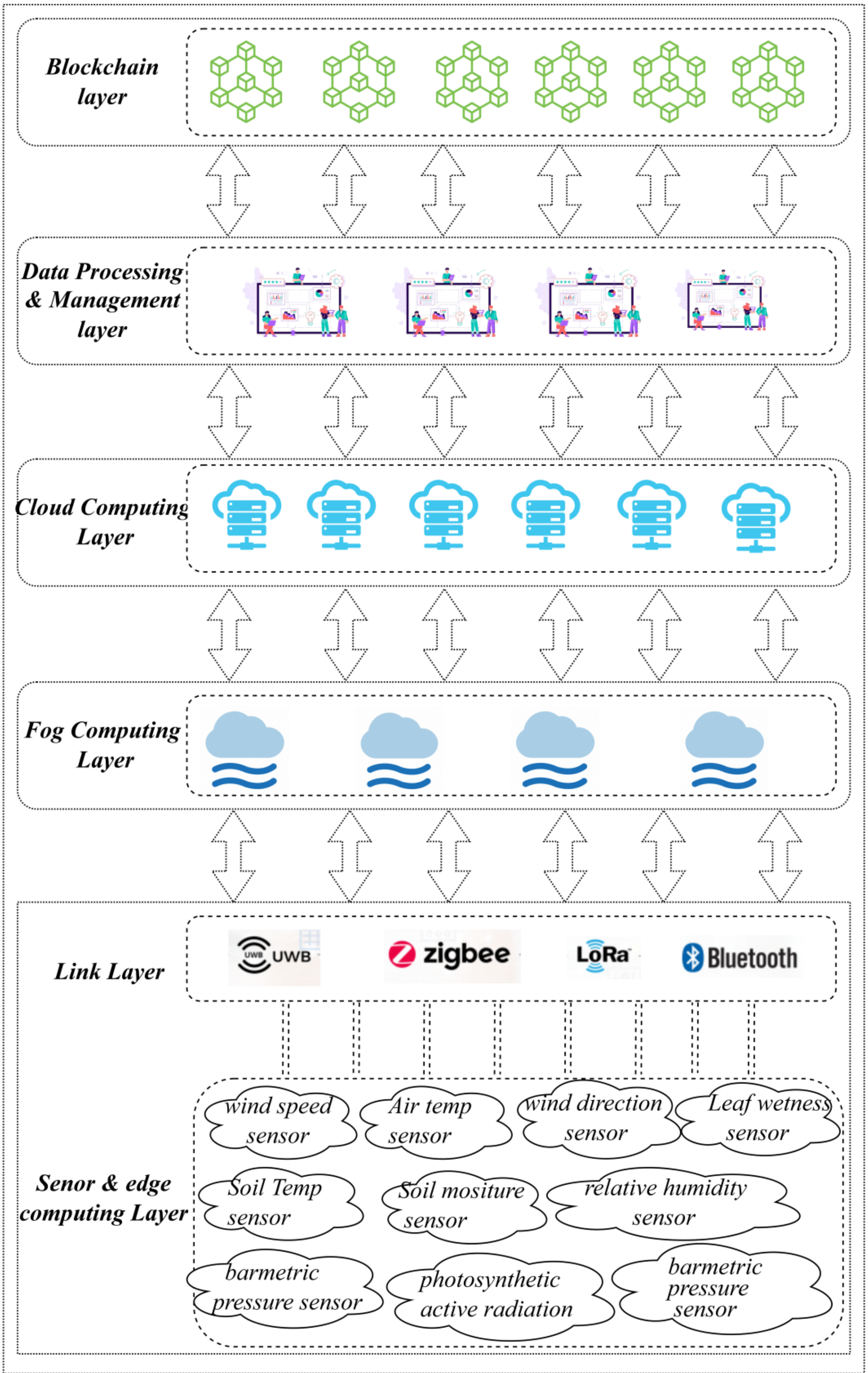

Figure 5. Proposed framework for application area 1.

7.1.1. Step 1: Internet of Things Devices Generate Data

According to forecasts, the total number of people living on our planet will have increased to 9.6 billion by the year 2050. As a consequence of this, in the agricultural industry, gadgets and sensors that are connected to the Internet of Things are being used so that a growing population can be fed.

In the context of Internet-of-Things-enabled smart farming:

- In the building of a system to monitor an agricultural field, sensors play an important role as part of the construction process (soil moisture, temperature, humidity, pH, light, etc.).
- The data generated by sensors and other devices linked to the Internet of Things (IoT) may provide farmers with valuable information that can aid them in making educated decisions on the growth of their crops.
- The information that is collected from Internet of Things devices must be organized before it can be saved into a data storage device.

7.1.2. Step 2: Cleansing and Enhancement of the Data That Has Been Gathered

The information that has been acquired must first be arranged in a manner that is user-friendly and understandable before it can be saved on the blockchain. The goal of the process known as "data enrichment" is to improve the overall quality of the information that has been gathered as well as to add more value to the information that has been gathered. Before the data is stored on the distributed storage platform, they are first cleaned.

To effectively organize data, it is crucial to include metadata encompassing details such as the type of timestamp, demographics, and data structure type. This facilitates a systematic arrangement of information. Additionally, preparing data for regulatory compliance is streamlined by leveraging blockchain capabilities. Storing data on the blockchain simplifies the enforcement of compliance, ensuring adherence to regulations. Meeting these requirements not only safeguards any personally identifiable information linked to data from Internet of Things devices but also ensures the implementation of necessary safety measures.

7.1.3. Step 3: Machine Learning Algorithms Are Being Used to Make the Data More Informative

In order to provide insights into the situation that can be put into action, machine learning is applied to the data that were acquired by the sensors. The following are some examples of high-value application areas that predictive models might potentially drive:

- Commendations for Optimal Harvest Quality
- Identification of the Harvest
- Predictions of Harvest Yield
- Predictions of Harvest Demand

Machine learning algorithms will provide growers and other parties with the knowledge they need to make adjustments to their irrigation systems on a regular basis. Growers, inventors, producers, service providers, and merchants should be able to access valuable information by storing it on the blockchain and making it available to them in a transparent manner [45].

7.1.4. Step 4: The Blockchain Is Used to Store Information

We are able to obtain high-value data by using machine learning, and these data have the potential to be stored in IPFS (Interplanetary File System), which is a decentralized storage network whose addresses are hashed and retained on the blockchain. The present strategy, which involves storing vital data on a single server in a centralized location, runs the risk of making the system susceptible to experiencing a breakdown at a single point. On the other hand, while using blockchain, the data are disseminated throughout all of the nodes that are part of the network. Because of this, it is hard for a centralized authority to exercise control over the system because of the way it is set up. The data that are stored on the blockchain will bring about the activation of smart contracts, which will then bring about the execution of the rules that are included within them. By the use of smart contracts, it is possible to simplify the process of exchanging data that are stored on the blockchain with the many stakeholders who are involved in the system. As a result of the fact that information will be accessible to every participant in the agricultural market, it would be simple to enhance the productiveness of crops or the production of food [46].

7.2. Framework for Application Area 2: Food Supply Chain

Figure 6 shows the proposed architecture for application area 2. The agribusiness supply chain, like that of any other industry, begins with crop loading and continues all the way to stocking the shelves of retail stores and foodservice operations. However, since it is connected to food, the procedure is much more crucial in this case. How can you guarantee that the food that has been provided is safe to consume? Except if the food supply chain is well controlled, everyone from the food producers to the merchants will be unable to determine if the food being given is of high quality. By being a viable option, blockchain in agriculture helps to provide transparency to the agricultural industry. With precision agriculture, blockchain may be used to record information about the crop, such as crop quality, seed kind, and the weather circumstances whereby the crops were planted, among other things [47].

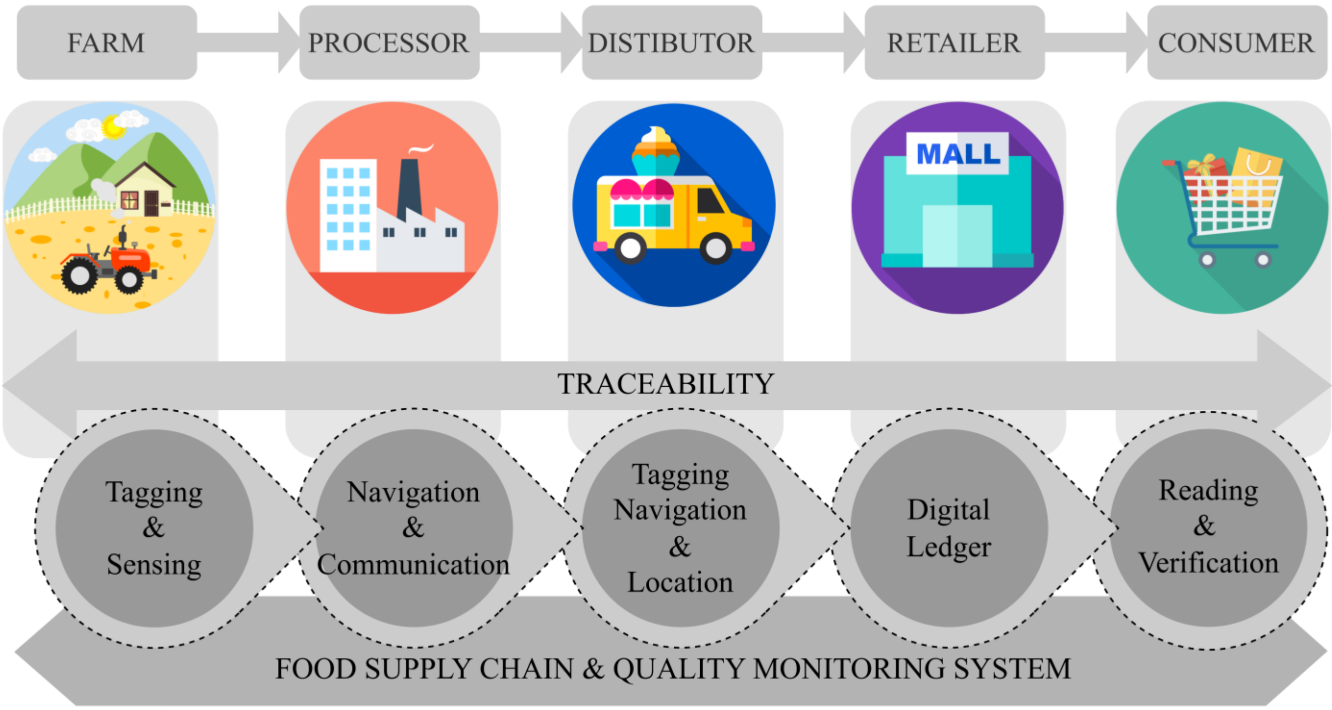

Figure 6. Proposed framework for application area 2.

The same is true if the crops have been delivered to the refineries using IoT-enabled trucks, since it is simpler to record the temperature at which they have been exposed. This is important when food-processing firms are competing for contracts. At the very same time, it checks to see whether the food item being delivered is of high quality or not. In the provision of processed foods to wholesalers and retailers, the same procedure might be followed.

This traceability method is equally applicable to the end user, the consumer. They may retrace the information in the following ways:

- Information from farm origination;

- Information from transportation;
- Information about batch numbers;
- Information about food processing;
- Information from factory;
- Information from expiry.

At the same time, when the transparency of the supply chain improves, it will have a significant influence on the following areas:

- Reducing fraudulent food issues;
- Removing mislabeled food;
- Removing intermediaries from the process;
- Ensuring food producers get paid on time;
- Allowing consumers to understand what they are paying for;
- Recording and updating the status of crops by the farmer;
- Tracking farmers through the process of planting, harvesting, and delivery.

For the purposes of conclusion, we can say that blockchain has significant potential in the supply chain industry in terms of cost-cutting, seamless interaction and handling orchestration between various involved parties related to global supply chain and logistics business, as well as in terms of cost-savings. The involvement of the public, on the other hand, is a significant obstacle to large-scale blockchain deployment. Multiple actors collaborate in the supply chain, and in order to use BCT to improve efficiency and transparency in supply chains, all participants must work together. BCT is a collaborative effort. What exactly do we understand by collaboration in this context? They must agree to participate on a shared platform and adopt the set of criteria that have been agreed upon.

7.3. Framework for Application Area 3: Farmers Should Be Paid More Fairly

Figure 7 shows the proposed architecture for application area 3. It is a well-known truth that farmers often have difficulties in receiving payment on time. Traditional payment procedures require farmers to wait weeks before receiving their complete payments, and they sometimes comprise a significant portion of the farmer's revenue [48]. A blockchain-based smart contract is an excellent match in this situation. As soon as a certain and previously described condition is met, smart contracts initiate automatic payments on a pre-determined schedule. This is accomplished without the imposition of hefty transaction costs. Farmers should theoretically get compensated for their commodities as soon as they are delivered to the customer. There is absolutely no danger that their money will be taken away as a result of this procedure. Many farmers also have difficulties throughout the sale process at a reasonable price since middlemen get the majority of the earnings despite performing a comparatively little amount of effort. Smart contracts would reduce the need for middlemen because they would enable growers to directly connect with merchants, eliminating the need for intermediaries [49]. As a result, they would be able to get a more equitable price for their commodities.

7.3.1. Key Components of the System

The key components of the system are:

- *Smart contracts:* Self-executing contracts that are kept on the blockchain are known as smart contracts. They may be used to guarantee that each party is treated equally and to automate transactions.
- *Cooperatives for agriculture:* Cooperatives for agriculture are associations of farmers that collaborate to increase their negotiating position and resource availability.
- *Financial institutions:* Farmers may be able to get loans and other financial services from financial institutions.
- *Technology suppliers:* These companies are able to provide the assistance and infrastructure required for the setup and upkeep of the blockchain network.

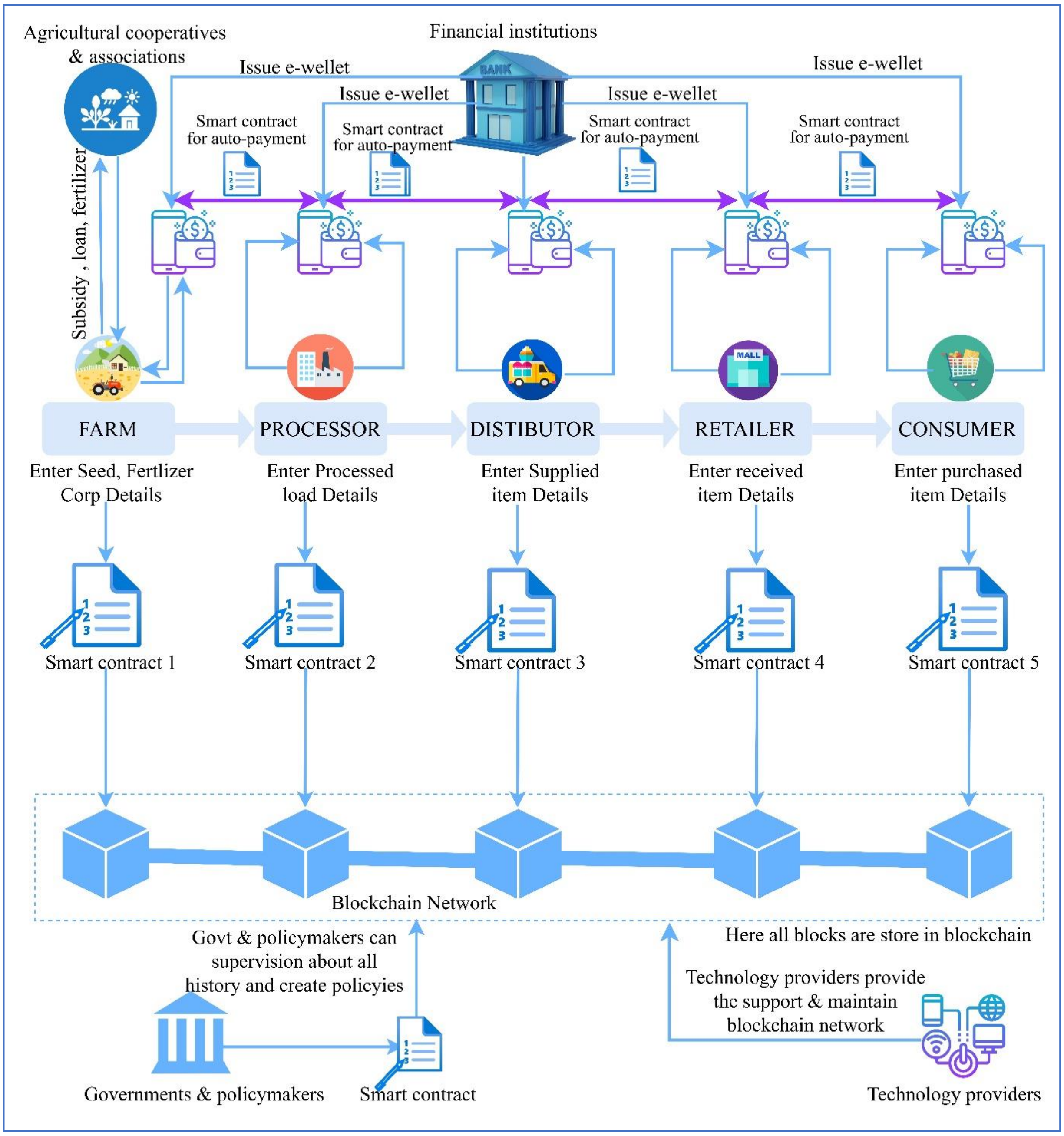

Figure 7. Proposed framework for application area 3.

7.3.2. The System Works as Follows

- For every crop they plant, farmers who join an agricultural cooperative establish a smart contract.
- The price, quantity, and delivery date are among the conditions of the sale that are specified in the smart contract.
- Members of the agricultural cooperative get e-wallets.
- E-wallets are distributed by financial institutions to processors, distributors, merchants, and end users.
- The agreed-upon sum is deposited into the farmer's electronic wallet by the processor once the farmer sells their harvest to them.
- After that, the harvest is immediately released to the processor via the smart contract.
- After that, the crop is sold by the processor to a distributor, who then sells it to a retailer.

- The smart contract automatically delivers the money to the preceding party at each stage of the supply chain when the current party has completed their duties.
- The customer uses their e-wallet to make the payment when the vendor sells them the produce.

7.3.3. Advantages over Traditional Payment Systems

There are many benefits that blockchain technology offers over conventional payment methods.

- *Transparency:* The blockchain is a public ledger that contains records of every transaction. This facilitates the tracking of money and product transfers across the supply chain.
- *Security:* The blockchain technology is quite safe. Since all of the data are encrypted and kept in several places, they are incredibly impossible to hack or alter.
- *Efficiency:* Many of the laborious processes required in conventional payment methods may be automated by the blockchain technology. All parties concerned may save money and time by doing this.
- *Fairness:* All participants to a transaction are guaranteed to be treated equally by the smart contracts. The contracts are automatically executed as soon as the predetermined criteria are satisfied and cannot be altered or interfered with.

Agricultural cooperatives may help guarantee that farmers get a fair price for their produce by using blockchain technology. The agricultural supply chain's efficiency and transparency may both be enhanced by blockchain technology.

7.4. Shortcomings Addressed with the Help of the Proposed Framework

Our suggested blockchain architecture for the agricultural supply chain solves significant flaws in conventional solutions. We specifically address issues with efficacy, traceability, and confidence from the farm to the grocery store. Traditional supply chains often have issues with opacity, stakeholder mistrust, and product-origin tracking. Our blockchain-based system helps to address these problems by offering an unchangeable transparent record that promotes confidence, increases supply chain efficiency, and permits tracking all the way from farm to customer. This section describes the inadequacies that have been found and shows how our approach successfully tackles these issues to create a more reliable and resilient agricultural environment.

8. Discussion

8.1. Impact of Blockchain Technology on Performance Matrices

The use of blockchain technology in agriculture will have a major impact on key performance metrics, including supply chain throughput, latency, cost, scalability, security, and trust.

- *Throughput:* By improving the effectiveness of transaction processing, blockchain technology, with its decentralized and distributed ledger design, may favorably improve throughput. Consensus mechanisms and the removal of middlemen facilitate quicker and more efficient data transfers, which raises the agricultural supply chain's total throughput.
- *Latency:* By offering an open and unchangeable record of data, the use of blockchain technology may lower transaction latency. Smart contracts, a crucial component of blockchain technology, allow for the automatic and immediate execution of predetermined actions, reducing processing times and enhancing system responsiveness.
- *Cost:* The agricultural supply chain might see cost optimization thanks to blockchain technology. Operational expenses may be greatly decreased by doing away with the need for middlemen, automating record-keeping, and increasing automation thanks to smart contracts. This may result in agricultural practices that are more economical and resource-efficient.

- *Scalability:* The decentralized structure of blockchain enables better scalability in the agricultural industry. The need for supply chain solutions that are transparent and traceable is growing, and blockchain technology can readily expand to handle higher transaction volumes without sacrificing performance. The technology's capacity to scale guarantees that it can be adjusted to the ever-changing needs of the agricultural sector.
- *Security:* Cryptographic encryption and consensus procedures, two of blockchain's built-in security features, make the agricultural supply chain more secure. Data integrity is guaranteed by the blockchain's immutability, and the decentralized structure lessens the possibility of a single point of failure. The agricultural ecosystem is more resilient to fraud, manipulation, and unauthorized access thanks to this increased protection.
- *Trust:* The improvement of trust is perhaps one of blockchain's most important effects on agriculture. A product's validity and provenance may be confirmed by stakeholders across the supply chain using transparent unchangeable ledgers. In the end, this openness benefits both producers and consumers by fostering confidence among participants and resolving issues with food safety, authenticity, and ethical sourcing.

8.2. Technical Considerations

- *Interoperability:* Smooth interoperability between various blockchain systems is necessary due to the varied stakeholder profiles in the agricultural supply chain. Technical factors should take into account how well different systems work together, making it possible for data and transactions to be effectively shared and comprehended across the ecosystem.
- *Data Standards:* For blockchain technology to be used in agriculture successfully, consistent data standards must be established. All participants can accurately read the information stored on the blockchain thanks to consistency in data formats, structures, and coding rules. In order to create a consistent and unified system, this factor becomes crucial.
- *Integration with Current Systems:* A wide range of current databases, technology, and systems are necessary for agriculture. One technological obstacle that has to be overcome is the seamless integration of blockchain with these older systems. For a seamless transition to blockchain solutions, existing agricultural technology must be compatible and work well together.
- *Scalability:* Making sure blockchain solutions are scalable is essential since the agricultural supply chain includes a large number of transactions and data. When developing systems, technical considerations should be directed towards creating solutions that can meet the increasing needs of the agricultural sector without sacrificing functionality.

8.3. Need for Standardization

- *Uniform Protocols:* The smooth cooperation of many stakeholders in agriculture is hampered by the lack of established protocols. Creating consistent standards for the use of blockchain technology guarantees that all parties function under the same framework, promoting consistency, interoperability, and confidence.
- *Regulatory Compliance:* There are a number of regulations that apply to the agricultural industry. To guarantee that blockchain solutions follow these rules and enable compliance and legal recognition, standardization is required. The navigation of regulatory environments with more clarity and assurance is made easier by using a standardized strategy.
- *Data Security and Privacy:* Ensuring a consistent level of data security and privacy across the agricultural supply chain requires standardization. Defined standards may include data ownership, access restrictions, and encryption techniques, guaranteeing that private agricultural data are always safeguarded.

- *Smart Contract Standards:* Standardized coding techniques are required for the use of smart contracts in agriculture. Having a standardized set of smart contract requirements improves their auditability, security, and dependability, which raises the overall efficacy of blockchain-based solutions.

8.4. Potential Regulatory Challenges

Although the use of blockchain technology in agriculture has the potential to greatly improve supply chain traceability, efficacy, and trust, there may be regulatory obstacles. Decentralized systems provide a challenge to conventional hierarchies and structures, making it difficult for governments to create flexible and unambiguous regulatory frameworks. Important regulatory obstacles consist of:

- *Data Access and Control:* Regulators that tackle issues with data access and control may find it easier to impose laws. It becomes essential to strike a balance between promoting openness and safeguarding confidential information since agricultural data are sensitive. Finding this balance needs thought and attention in order to keep blockchain's benefits for traceability and trust intact.
- *Legitimacy of Smart Contracts:* The use of smart contracts in agricultural operations presents a new regulatory obstacle. Legislative adaptation may be necessary to determine the legal validity and enforceability of smart contracts, particularly in areas with strict contract rules. To ensure that smart contracts are enforceable under the law, governments may need to set up frameworks that acknowledge the validity of contracts carried out via blockchain.
- *Interoperability Standards:* As the use of blockchain technology spreads, interoperability may be hampered by the absence of uniform legal frameworks in many countries. The establishment of international standards that guarantee compliance with various regulatory contexts and enable the smooth integration of blockchain technology into the global agricultural supply chain may provide a challenge to governments.
- *Protection of consumers:* Ensuring the security and legitimacy of agricultural goods is a major factor in the deployment of blockchain technology. Governments, nonetheless, need to create laws to protect the interests of consumers. In order to solve issues with misleading claims or misleading information, this entails establishing standards for labelling, certification, and quality assurance inside the blockchain.
- *Environmental Impact:* Blockchain networks' energy usage, particularly for those that use proof-of-work consensus processes, has sparked worries about the environment. Governments may try to control how blockchain technology affects the environment in agriculture. This might have an influence on the consensus algorithms used and encourage the creation of blockchain solutions that are environmentally benign.

The blockchain community, agricultural stakeholders, and regulatory agencies must work together to address these possible regulatory obstacles. Achieving compliance with legal and ethical norms while realizing the full potential of blockchain technology in agriculture will need the establishment of clear, flexible, and internationally harmonized regulatory frameworks. Our paper's examination of these issues seeks to further the current conversation around blockchain regulation in the agricultural industry.

8.5. Potential Applications of the Proposed Framework

Blockchain has a plethora of potential uses in agriculture that span the whole food supply chain. Blockchain has the potential to completely transform the production and distribution of food, from safe and efficient transactions to farm management and resource optimization. The digitization of land records and guaranteeing ownership transparency is one potential use. By giving farmers—especially smallholders—secure and substantiable documentation of their land title, this may help them get access to financial services and loans. Furthermore, by generating an unchangeable record of each step of a product's journey from farm to fork, blockchain might improve food traceability. This may lessen food fraud and guarantee consumer food safety by enhancing accountability and transparency across the supply chain. Furthermore, by facilitating quick and safe payments across different agri-food industry players, blockchain helps expedite financial transactions. By automating payments based on pre-established criteria, smart contracts may save transaction costs and do away with the need for middlemen. These are just a few instances of how blockchain technology has the ability to revolutionize the agricultural industry. The technology will probably have a significant influence on how food is produced and distributed in the future as it develops and becomes more widely used.

8.6. Contrasting Viewpoints

It is critical to compare blockchain-driven strategies with conventional ways when thinking about BCT integration in agriculture. Conventional supply chain systems frequently have manual record-keeping, information silos, and a lack of transparency. BCT, on the other hand, overcomes these drawbacks and promotes a more reliable and efficient supply chain by introducing a decentralized and transparent ledger. On the other hand, divergent opinions can surface regarding BCT's scalability in large-scale farming operations and possible opposition to technological integration into conventional farming methods. A balanced viewpoint arises from recognizing and resolving these issues, allowing for a more thoughtful and nuanced conversation about the use of BCT in agriculture.

9. Drawbacks to the Use of Blockchain in Agriculture

BCT may improve trust, efficiency, and traceability in several sectors, including agriculture [50]. Like every technology, it has drawbacks. This study examines the downsides of adopting BCT in agriculture.

While decentralization and more transparency are possible benefits of using blockchain techniques in agriculture, it is important to be aware of the potential obstacles presented by governmental and corporate institutions. Because of the revolutionary potential of blockchain technology, governments and large businesses may want to create legal frameworks that address their worries over data access and control. This is because blockchain technology threatens the conventional supremacy of central authority. The main challenge is to strike a careful balance between the advantages of decentralization and the rules that these organizations impose. The maintenance of the integrity of protected data while fostering an atmosphere that supports the dramatic changes brought about by blockchain in agriculture requires striking this balance. We explore these issues in detail in our essay, providing a nuanced view on how to work within the regulatory framework to fully use blockchain technology in the agricultural industry.

BCT's intricacy is a drawback. Farmers and other stakeholders struggle to grasp and apply the technology's complex algorithms and encryption. Small-scale farmers may not have the means or technical know-how to deploy the system due to its complexity [51]. Second, BCT's decentralized nature might be a drawback. Decentralized systems are subject to malicious attacks, fraud, and other security problems because they lack central regulation. If the blockchain system is hacked or interfered with, agricultural yields, pesticide consumption, and soil health might be jeopardized [52].

Finally, BCT in agriculture may be expensive. Blockchain implementation needs major hardware, software, and staff investments. Small-scale farmers and other stakeholders may not be able to afford this technology. BCT might cause data overload. The blockchain stores all transactional data, which might be difficult to analyze and comprehend. Growers and other stakeholders may struggle to utilize data to make educated choices due to this overburden.

10. Limitations and Implications of Research

10.1. Limitations of This Research

Although the goal of this study is to provide an extensive analysis of the applications of blockchain technology (BCT) in agriculture, it is important to recognize certain limitations. First off, the paper's theoretical approach mostly draws on conceptual frameworks and previously published research, which may not adequately represent the nuances of practical applications. Furthermore, the dynamic and ever-changing landscape of blockchain technology demands ongoing modifications and adjustments, potentially impacting the enduring relevance of the suggested frameworks.

10.2. Managerial Implications

This study has significant management ramifications, particularly for stakeholders in the agricultural industry. Managers and decision-makers may investigate ways to boost supply chain transparency, increase traceability, and expedite payment procedures by realizing the promise of BCT. The results enable management groups to choose blockchain technologies wisely, resulting in an agricultural ecosystem that is more reliable and efficient.

10.3. Theoretical Implications

This study makes a theoretical contribution by providing conceptual frameworks for the use of BCT in agriculture. By laying the groundwork for understanding how blockchain might solve trust, efficacy, and traceability challenges in the agricultural supply chain, this article encourages further scholarly investigation. The theoretical frameworks that have been suggested initiate conversations on the incorporation of decentralized technologies into conventional agricultural methods, hence providing opportunities for further investigation into the wider domain of agricultural technology and innovation.

11. Future Scope

This study examines the possible advantages, application areas, technical elements, constraints, and obstacles of using BCT in agriculture. Nevertheless, blockchain use in agriculture is still in its infancy, and there are other areas that need more study. Future studies should concentrate on finding practical solutions for using BCT in agriculture, and solving technological obstacles such as scalability, interoperability, and energy usage. Also, additional studies might investigate the potential of blockchain for encouraging sustainable agricultural practices and enhancing the industry's openness and accountability.

The establishment of legislative frameworks that allow the broad implementation of blockchain in agriculture while preserving data privacy, security, and interoperability might be another subject of future study. In addition, studies might be conducted on the socioeconomic effects of BCT in agriculture, such as its ability to empower small-scale farmers, minimize food waste, and enhance farmers' lives. Implications for the future of this work include greater exploration of the potential of blockchain in agriculture, overcoming technological, regulatory, and socioeconomic issues, and advocating for the wider implementation of blockchain to establish a sustainable and resilient food system.

12. Conclusions

In conclusion, BCT may address several agricultural industry challenges. BCT's transparent, irreversible, and decentralized platform for recording and validating transactions might improve food supply chain trust, efficiency, and traceability from farms to grocery shops. BCT can manage supply chains, verify goods, and execute payments in agriculture. BCT in agriculture requires collaboration, legal clarity, and technological expertise. Interoperability, scalability, and regulatory frameworks must be addressed to make BCT widely used in agriculture. Hence, politicians, industry leaders, and technical experts must work together to promote BCT in agriculture and create a sustainable resilient food system.

The agricultural industry needs fundamental transformation to tackle its issues. BCT might increase food supply chain trust, efficiency, and traceability. Many parties will need to work together to overcome the various social, legislative, and technical barriers to BCT in agriculture. BCT in agriculture might provide a more open, effective, and resilient food delivery network, which is vital for our planet's future.

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