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Review

Survey on the Applications of Blockchain in Agriculture

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Abstract: Dating back many millennia, agriculture is an ancient practice in the evolution of civilization. It was developed when humans thought about it and concluded that not everyone in the community was required to produce food. Instead, specialized labor, tools, and techniques could help people achieve surplus food for their community. Since then, agriculture has continuously evolved across the ages and has occupied a vital, synergistic position in the existence of humanity. The evolution of agriculture was based on a compulsion to feed the growing population, and, importantly, maintain the quality and traceability of food, prevent counterfeit products, and modernize and optimize yield. Recent trends and advancements in blockchain technology have some significant attributes that are ideal for agriculture. The invention and implementation of blockchain have caused a fair share of positive disruptions and evolutionary adoption in agriculture to modernize the domain. Blockchain has been adopted at various stages of the agriculture lifecycle for improved evolution. This work presents an intense survey of the literature on how blockchain has positively impacted and continues to influence various market verticals in agriculture, the challenges and the future.

Keywords: blockchain; blockchain in agriculture; agriculture digitization; information technology in agriculture; Agriculture 5.0

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1. Introduction

1.1. Blockchain

Blockchain consists of an electronic system that allows electronic recordkeeping, validation, and verification without the need for an intermediary. Data are available to all participants, all information is made transparent and available, and the records are immutable and cannot be tampered with or deleted. It follows the principles of governance, accountability, transparency, flexibility, availability, usability, manageability, and sustainability.

Improving agriculture is not a single-solution task. In [1], the authors explore the factors influencing young Irish farmers to adopt cloud computing technologies for smart farming. In another study [2], the authors presented a study on machine learning and big data. ICT in the agriculture domain requires continuous collaboration among multifaceted technologies. These continuous, cyclic, and multiattribute improvements make agriculture a highly researched area. Blockchain is a recent invention with practical feasibility, and the quest to find applicability for blockchain in agriculture has motivated researchers in various verticals in the agriculture domain.

1.2. Branches of Agriculture and Their Respective Processes

On a high level, the branches of agriculture, including horticulture, comprise the cultivation of plants, fruit, and vegetables and the sciences agronomy, soil management, crop production, animal husbandry, and raising livestock. Figure 1 presents various branches and subbranches of agriculture.

Agronomy	Horticulture	Plant Breeding and Genetics	Soil Science	Entomology	Agriculture Engineering	Agriculture Economics	Forestry	Animal Husbandry	Environmental Sciences	Food Science and Technology	Land and Water Management
Weed Sciences	Pomology	Seed Science	Chemistry	Ecology	Mechanization	Agrarian System	Agro-Forestry	Dairy	Energy	Nutrition	Ecotourism
Organic Farming	Olericulture	Crop-Physiology	Biology	Morphology	Machinery	Agribusiness	Rangeland	Sericulture	Meteorology	Production	Conservation
Farm management	Floriculture	Plant Protection	Mineralogy	Pathology	Structures	Extension	Wildlife	Aquaculture		Post-harvest	Irrigation
	Arboriculture	Biotechnology	Pedology	Physiology		Marketing	Analog	Mariculture		Transporting	
	Landscaping	Plant Pathology	Physics	Toxicology		Custom Harvesting	Gardening	Nematology			
	Viticulture		Fertility	Taxonomy		Development	Farming	Beekeeping			
	Oenology		Salinity	Entomology		Rural		Poultry			
	Microbiology		Survey	Medical				Nomadic			
			Conservation	Control				Piggery			
				Post-Harvest							
				Forest							
				Forensic							
				Crop							

Figure 1. Disciplines and subdisciplines in agriculture [3].

1.2.1. Conventional Steps in Horticulture

Horticulture, both art and science [4], has conventional steps. The first step is to select the type of plant to grow. Once the plant is selected, the soil must be prepared. Preparation involves tilling the soil and adding fertilizers and irrigation. After the soil is prepared, seeds or seedlings are planted. Once the plants have grown, the crop can be harvested. Figure 2 represents the steps as a flow.

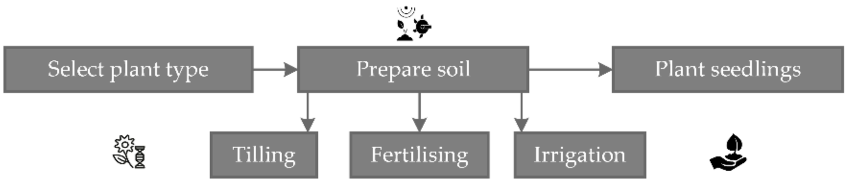

Figure 2. Conventional steps in horticulture.

1.2.2. The Steps in Conventional Agronomy

Agronomy is the science of soil and crop management [5]. Figure 3 presents the steps in agronomy. The first step is soil testing to determine its composition and decide which fertilizers and amendments need to be added. The next step is to till the soil, aerate it, and prepare it for planting. The next step is to plant seeds or seedlings. Once the plants have grown, the crop can be harvested.

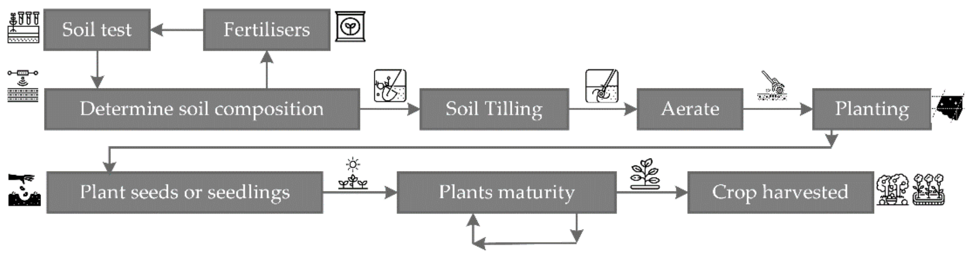

Figure 3. Conventional steps in agronomy.

1.2.3. Conventional Processes in Animal Husbandry

The art of livestock raising and selective breeding [6] forms a key annexure to agriculture. Figure 4 presents the steps in livestock management. The first step is to select the type of animal to raise. The next step is to build a shelter for the animals, which is essential to protect them from the elements. Next, the animals are provided with food and water. Once the animals have been adequately cared for, they can be bred. After the animals have given birth, their offspring must be cared for. Finally, once the offspring have grown, they can be sold.

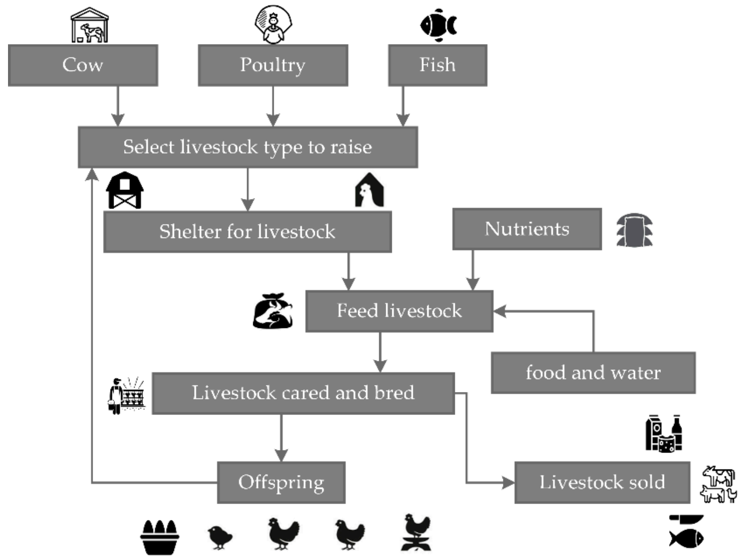

Figure 4. Conventional processes in animal husbandry.

1.3. Major Challenges in Agriculture and Possible Blockchain Solutions

The inherent challenges in agriculture are tabulated in Table 1 and mapped to the solution that can be provided with the attributes of blockchain technology.

Table 1. Agriculture challenges mapped to blockchain-based solutions.

Agriculture Challenges [7–10]	**Blockchain Solutions [11]**
Connectivity among suppliers, procurement, retailers, and consumers	Distributed ledger and data integration with transparency in the supply chain
Lack of transparency of provenance	Traceability to customers
Financial sources and industrialization	Financial options: crypto/token economy Payment: cross-border settlement
Middlemen/agents	Direct access, pricing transparency, competitive transaction pricing
Access to real-time data for smart farming	Complete security and data freedom

Blockchain acts as a distributed, immutable, tamper-proof ledger [12] in which participants of the ecosystem store transactions. This data store is a source of truth about the state of the ecosystem. In an agriculture ecosystem, the essential data about the state of farms, inventories, contracts, and management are collected and stored in the blockchain. This trusted form of data storage helps farmers achieve a higher degree of decentralization, provenance, nonrepudiation, payment, and commodity exchange automation.

1.4. Motivation

Observing the quantum importance of agriculture and the challenges they inherently pose motivates this survey to find past solutions employed to solve the challenges. Table 1 shows the major challenges in agriculture. Blockchain is radically taking shape in the domain, where trust, transparency, and traceability are key attributes. Blockchain, with its key attributes of immutability, integrity, and tamper resistance, is a viable candidate of choice to solve the problems in agriculture involving supply provenance, traceability, finical integrity, and process decentralization. The table shows the mapping of the challenges of concern in the agriculture domain and the benefits of using blockchain to provide a viable solution. The next section presents the research method and questions raised in the existing work to find the benefits, scrutinize the challenges, and present the open challenge and research direction for future researchers.

The rest of this survey is organized as follows. Section 2 describes the research method, while Section 3 presents the curated literature review. Section 4 presents a detailed discussion and finally the last section concludes the survey.

2. Research Method

Literature-based analyses of past work based on the standard requirement to observe typical patterns in the application of blockchain in agriculture and allied domains focus on finding the applications, challenges, gaps, and future directions. These steps allowed us to identify and collect all the literature related to agriculture, where blockchain was used to solve conventional problems. Each subsection summarizes and tabulates the findings and problems that were solved. This method could help in identifying prospective applications, problems, and challenges that were solved in the agricultural domain using blockchain technology, followed by an exploratory study on the state-of-the-art implementation of blockchain technology in the agriculture domain to consolidate the case studies that non-government and governmental agencies worldwide used to solve agricultural challenges. Finally, all the literature was combined to discuss the predominant applications, current open issues, and best practices.

2.1. Research Questions

1. What potential vertical markets in the agriculture domain could benefit from using blockchain technology?
2. What are the possible blockchain-based applications that could be used to address the identified vertical markets in the agriculture domain and were used in past research?
3. What are the open issues and challenges in deploying blockchain for agriculture?

2.2. Preliterature Review Results

This section discusses the collected literature and the filters used to narrow down the results to the use of blockchain in agriculture as presented in reports, articles, and review findings. The initial query yielded 300 papers. Applying the criteria to the primary studies, the final list of papers included in this study was obtained. Paper selection followed, as presented in Figure 5.

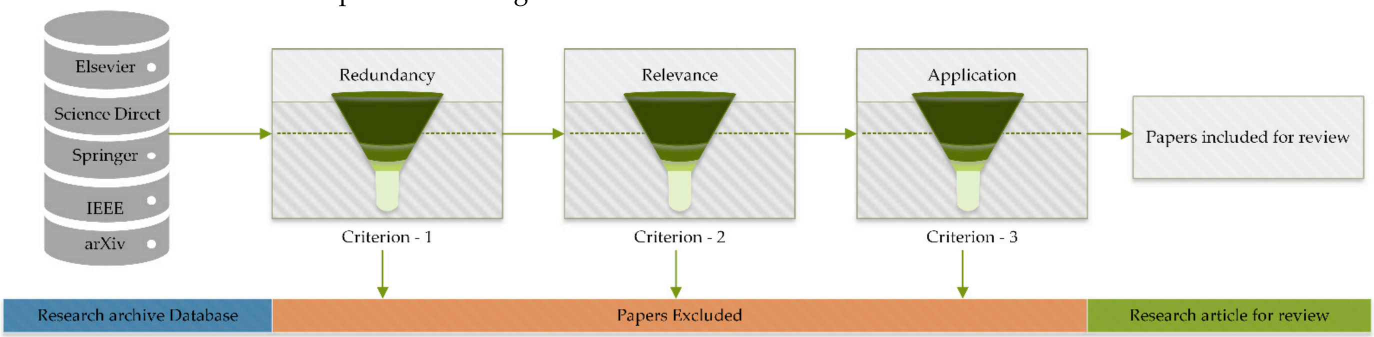

Figure 5. The representative flow of data curation, with criterion filters and final list.

2.3. Structure of This Paper and the Contributions

This paper has three parts. Part 1 describes a comprehensive search of the current literature and presents a summary of the work done thus far. Part 2 provides an inventory of existing work on critical subdomains/subfields of agriculture and reference case studies implemented. Parts 1 and 2 are presented in Sections 2 and 3. Finally, Part 3 presents a discussion and a conclusion that is presented in Sections 4 and 5.

3. Literature Review

Based on the outcome of the research method, the broadly identified verticals as in Figure 6 across agriculture are survey and review, smart agriculture based on IoT and sensors, finance, supply chain, livestock, commercialization, governance, limitations, and challenges. This section elaborates briefly on the research impact in each vertical direction.

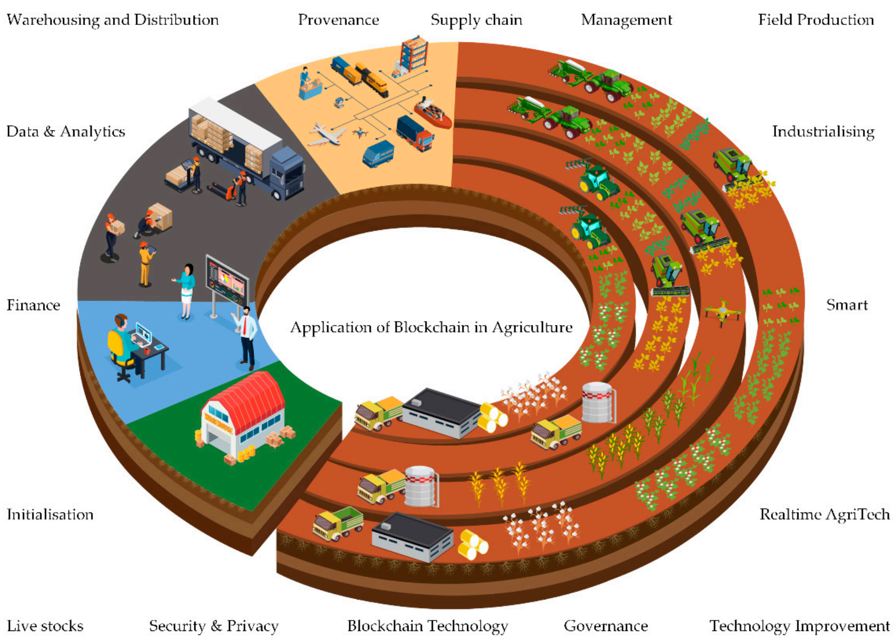

Figure 6. Application of blockchain in various verticals of the agriculture domain.

3.1. Survey and Review of Blockchain in Agriculture

This subsection presents past surveys and a review of the literature, as presented in Table 2. The broad classification of papers includes the following domains: prospective applications, future overview, smart trends, green and sustainable initiatives, enabling technology, mitigating challenges and issues, providing solutions, optimizing supply chains, fortifying security mechanisms, and modern-day finance.

A review of Agriculture 4.0 and the future of the industrialization of agriculture is presented in [13]. Applications of blockchain in agriculture are discussed in [14]. Case studies of solution built on blockchain platforms for IoT are covered in [15]. In [16], the authors show how blockchain can solve privacy and security challenges in conjunction with green IoT. A review of traceability systems built on blockchain for agriculture is presented in [17]. In [18], the author discusses the need for novel privacy-preserving techniques based on a survey on smart agriculture. A review of blockchain-based applications from the food sector is presented in [19], and traceability systems are presented in [20]. A list of future and smart technologies in agriculture is given in [21]. In [22], the authors discuss the application of blockchain in other fields beyond cryptocurrency. The research in [23] contributes to the advancement of smart agriculture, emphasizing security and privacy challenges. An aspect of financial governance in the agriculture domain is presented in [24] with a review of agriculture insurance applications on the blockchain. In [25], the authors present a brief review of applications of IoT in smart agriculture. Cases of ICT and blockchain use for precision farming are presented in [26]. Ideas on using blockchain in Agriculture 4.0 are presented in [27]. A technological review of the food industry and blockchain is presented in [28].

A case study is presented in [29] as part of Canada's policy and research agenda evaluating the importance of blockchain. In [30], the authors showcase security challenges in smart cities and agriculture. The authors of [31] discuss data management in e-agriculture. A business perspective on agriculture applications in the blockchain is described in [32]. The authors of [33] discuss the convergence of IoT and blockchain for agriculture. A review of blockchain-based solutions for pest problems is presented in [34]. Blockchain technology for agriculture and the food sector is presented in [35], and a review of future technology in transformative agriculture is presented in [36].

Table 2. Survey and review of blockchain in agriculture.

Re	A	T	So	F	C	Sp	Si	Tr	Fi	Gs	R
[13]				√			√				
[14]	√									√	
[15]		√									
[16]			√		√	√	√			√	
[17]	√										
[18]						√	√				
[19]	√										
[20]								√			
[21]				√			√				
[22]	√										
[23]					√	√	√				
[24]	√	√	√						√		
[25]							√				
[26]	√										
[27]	√	√		√							
[28]	√	√									
[29]											√
[30]					√	√	√				
[31]										√	
[32]	√										
[33]							√				
[34]							√				
[35]		√									
[36]				√						√	
A	Application			F	Future, 4.0			Si	Smart, IoT		
T	Technology			C	Challenges			Tr	Traceability		
So	Solutions			Sp	Security, privacy			Fi	Finance, insurance		
Gs	Green, sustainable			R	Regional			Re	References		

The common observation was that most surveys and reviews are vertical-specific and not comprehensive. Therefore, the remaining part of this work presents vertical-specific coverage over a wide range of studies in all sections.

3.2. Application of Blockchain with IoT, Smart Technology, and Sensors in Agriculture

Blockchain is an emerging technology that can be applied to improve the food supply chain's security, transparency, and traceability, as presented in Table 3. IoT can be used to collect data from sensors, which can be used to improve the efficiency of agricultural production. A combination of blockchain and IoT can be used to create a smart and secure agricultural system. Applying blockchain in agriculture with IoT, smart technology, and sensors can help ensure food safety and quality, trace food origins, and optimize agricultural production.

Table 3. Application of blockchain with IoT, smart technology, and sensors in agriculture.

Re	It	Sa	Se	Re	It	Sa	Se	Re	It	Sa	Se
[37]		√		[38]		√		[39]	√	√	
[40]	√			[41]			√	[42]	√	√	
[43]	√	√	√	[44]	√			[45]	√	√	√
[46]	√	√	√	[47]	√			[48]	√		
[49]	√			[50]		√		[51]	√		√
It	Internet of Things						**Se**	Sensors			
Sa	Smart technology						**Re**	References			

The work presented in [37] shows that a farmer's credit scheme can be managed using a smart contract in a blockchain. Various uses of blockchain technology, such as supply chain management, food safety and provenance, and digital identification of livestock and land registry processes, are presented in [40]. Collection, storage, and sharing are described in [43]. The authors of [46] explore how IoT sensors and blockchain can create an autonomous greenhouse environment. The authors of [49] discuss how IoT sensors can help supply chain management, food safety, and traceability. In [41], the authors interpret data from sensors to demonstrate big-data analysis. Studies have also been conducted on food supply chain management [44], a data management platform [47], a decentralized marketplace for agricultural products and services [50], improved transparency, security, and quality of the supply chain [39], decentralized big data and knowledge [42], data related to climate, weather and agricultural production [45], and work on protection against intellectual property theft [48]. The authors in [51] went further by proposing a new provenance improvement framework.

3.3. Application of Blockchain in Agriculture for Finance

Blockchain technology is being applied in various industries, such as supply chain and finance, as presented in Table 4. The technology has the potential to revolutionize the agriculture industry by providing autonomous financial settlement, audit, and reconciliation mechanisms with greater transparency by preventing fraud. Blockchain technology thus could be used to create a secure system for payments and transactions in the agriculture industry.

Table 4. Application of blockchain in agriculture for finance.

Re	Py	Fi	In	Ln	Cr	Re	Py	Fi	In	Ln	Cr	Re	Py	Fi	In	Ln	Cr
[37]	√				√	[52]	√					[53]		√			
[54]	√					[55]				√	√	[56]		√			
[57]			√			[58]	√					[59]	√				
Py	Payment					**Fi**	Finance					**Ln**	Loan				
In	Insurance					**Cr**	Credit					**Re**	References				

A blockchain-based farmer's credit scheme called KRanTi that was launched in India is discussed in [37]. The scheme was designed to help small and marginal farmers in the country access credit more quickly. The authors further discuss how the scheme works and hope that it will help improve the efficiency of India's agriculture–food supply chain. The authors of [54] discuss how smart contracts can be used to improve farmers' income in the agricultural supply chain. They present a model for how this can be done and discuss the benefits of using this approach. AgriOnBlock, a blockchain-based data harvesting solution for the agriculture sector, is described in [57]. It enables farmers to securely collect and store data related to their crops and livestock and access relevant information and services from government and private sector partners. The platform also allows for the creation of digital identities for individual farmers, which can be used to access financial services and other benefits. The authors of [52] explore the potential of using blockchain technology in the agricultural supply chain to create a more efficient and transparent system. They suggest that by utilizing smart contracts, the various actors in the supply chain would be able to share information and coordinate their activities more effectively. This would lead to improved traceability of food items, reduced costs, and improved efficiency. The authors of [55] discuss how the agricultural sector's loan distribution process can be simplified. Information and communications technology (ICT) could make the process more efficient and less time-consuming. According to the authors, the quality of information available to lenders can be improved by using ICT, which would improve the decision-making process. BIoT, a blockchain-based IoT platform for agriculture, is described in [58]. The platform uses blockchain to secure data from sensors and other devices used in agriculture. This will help farmers track data and manage their farms more efficiently. The authors of [53] discuss a new food supply chain finance model based on the Internet of Things and blockchain technology. The model is intended to improve the efficiency and transparency of the food supply chain. The authors explain how the model works and how it can benefit both food producers and consumers. A new sustainable supply chain finance model based on blockchain technology is described in [56]. The model is intended to assist small and medium enterprises (SMEs) in obtaining financing while reducing costs and increasing supply chain transparency and traceability. In [59], the authors describe how the system would work and how it could benefit farmers and other stakeholders in the agriculture sector. They also discuss how blockchain and smart contracts can be used to create an IoT-enabled smart agriculture system.

3.4. Application of Blockchain in Agriculture for Supply Chain Management

Blockchain technology can be used to create a secure, transparent, and efficient supply chain for agriculture and food, as presented in Table 5. It can help to track the origins of products and ensure food safety.

Table 5. Application of blockchain in agriculture for the supply chain.

Re	**Sc**	**Tr**	**Pr**	**Fc**	**Re**	**Sc**	**Tr**	**Pr**	**Fc**	**Re**	**Sc**	**Tr**	**Pr**	**Fc**
[37]	√	√	√	√	[65]	√				[66]		√		√
[60]	√			√	[10]	√	√	√	√	[67]				√
[54]	√	√	√	√	[68]	√	√		√	[69]				√
[61]	√				[70]	√	√		√	[71]		√		
[62]	√				[72]	√	√			[73]		√		
[63]	√				[74]	√			√	[75]		√		
[64]	√	√			[76]	√	√			[77]		√		
[78]	√				[79]	√				[80]		√		
[81]	√				[82]	√			√	[83]		√		
[84]	√				[85]	√			√	[86]		√		
[87]	√	√	√	√	[88]	√				[89]		√		
[90]	√				[91]	√		√	√	[92]		√		
[93]	√				[94]	√			√	[95]		√		
[96]	√				[97]	√				[98]		√		
[99]	√				[100]	√				[101]		√	√	
[102]	√				[103]	√				[104]		√		
[105]	√	√			[106]	√	√		√	[107]		√		
[108]	√				[109]	√			√	[110]		√		
[111]	√			√	[112]	√		√	√	[113]		√		
[114]	√				[115]	√				[116]			√	
[117]	√	√	√		[118]	√				[119]			√	
[120]	√				[121]	√			√	[122]			√	
[123]	√				[124]	√				[43]			√	
[52]	√				[56]	√				[125]			√	
[126]	√				[127]	√			√	[31]			√	
[128]	√	√			[129]	√	√			[130]			√	
[131]	√			√	[132]	√			√	[55]			√	
[133]	√	√		√	[134]	√				[135]			√	
[136]	√			√	[46]			√	√	[47]			√	
[137]	√				[38]		√	√	√	[42]			√	
[138]	√		√		[139]		√		√	[140]			√	
[141]	√		√	√	[50]		√		√	[142]	√		√	
[44]	√	√	√	√	[143]		√		√	[48]			√	
[144]	√	√			[145]		√		√	[146]			√	
[25]	√			√	[147]		√		√	[148]			√	
[53]	√			√	[149]			√	√					

Sc	Supply chain management	**Pr**	Provenance
Tr	Traceability	**Fc**	Food chain
Re	References		

Traceability is the capability to track the life cycle, movement, or location of an item or product through its supply chain. In a supply chain-management system built on blockchain technology, traceability is achieved through the use of digital signatures and tamperproof timestamps. Each item or product is assigned a unique digital identifier, and each time the item or product changes hands, a new digital signature and timestamp are added to the blockchain. This creates an immutable record of the item's or product's journey through the supply chain, which can be used to track its location and verify its authenticity. A blockchain-based provenance system is used to track and verify the origins of a product or service. This system can track the provenance of anything from food and wine to art and antiques. By tracking the provenance of products or services, businesses can ensure that they are providing their customers with the highest-quality products and services. Additionally, this system can help businesses avoid fraud and counterfeiting.

Blockchain-based food traceability is a system that enables the tracking of food items throughout the supply chain, from farm to table. Tracking the movement of food items is accomplished through the use of blockchain technology. It provides a transparent and secure way to track food items as they move through the supply chain. This system can be used to track the provenance of food items and to ensure food safety and quality.

In [37], the authors discuss a blockchain-based farmers' credit scheme called KRanTi that was launched in India. The scheme is designed to help small and marginal farmers in the country access credit more easily. They further discuss how the scheme works and how it is expected to improve the efficiency of the agriculture and food supply chain in India. The potential benefits of using blockchain technology to manage food supply chains are presented in [60]. The study highlights how blockchain could help to reduce costs associated with traditional supply chain-management systems and provide new opportunities for data-driven decision-making. The authors also highlight the challenges in practical scenarios. A model for improving farmers' income in the agricultural supply chain using smart contracts is presented in [54]. In [61], the authors studied the impact of transparency and traceability, reducing transaction costs, and improving data quality and security to support sustainable blockchain initiatives.

The authors of [62] propose a case study-based justification for applying blockchain technology in agricultural supply chains to achieve sustainable development. In [63], the authors discuss the potential benefits for consumers and producers of creating an agricultural supply chain that would allow for greater transparency and traceability of organic food products. A reconciliation scheme to improve consumer trust in beef supply chain traceability is proposed in [64]. The mechanism would improve consumer confidence in the safety and quality of beef products and increase transparency and traceability throughout the supply chain.

The authors of [78] show how blockchain would be beneficial for overseas market expansion in a cross-border agricultural supply chain adopted by suppliers. In [81], researchers looked at how blockchain technology could help make agricultural supply chains more transparent and trustworthy. They created a model for how this could work using Ethereum and then made a prototype system to show that it could work in real life. Their tests showed that this system would effectively reduce transaction costs and increase trust between farmers and buyers.

The authors of [84] conducted research on a blockchain-based agricultural supply chain system with double-chain architecture. They built the architecture using two distinct forms of blockchain, public and private, and automated several supply chain operations using smart contracts. The findings indicated that the proposed method was more effective than the current one and that it could enhance transparency and traceability in the agriculture sector. In addition, the authors of [87] investigated whether blockchain technology could be reliably used to identify the sources of agricultural products and guarantee their safety. The study also showed that using a traceability system built on a blockchain could help reduce fraud in the agricultural supply chain. According to [90], the blockchain maturity model has four levels: basic, intermediate, advanced, and expert. Each level involves a set of capabilities that a company must have to achieve that level. Therefore, the model can be used to see how well a company is doing with blockchain and find areas that need improvement.

The authors of [93] proposed a new way to manage trust in agricultural green supply chains using blockchain technology. They used game theory to model and analyse the trust-management problem and showed that their proposed approach could achieve efficient and secure trust management in agricultural green supply chains. The authors of [96] discuss how blockchain can be used to promote the development of green energy in smart agriculture and argue that doing so would create an innovative ecosystem of clean energy. They conclude that developing such an ecosystem is crucial to promoting green energy and achieving sustainable development. The study goal in [99] was to create a system that tracks the journey of food from farm to table. This would help quickly identify and contain contaminated products, reducing the spread of foodborne illnesses. In addition, it would create a more efficient and cost-effective system for recall procedures.

In [102], the authors studied how the COVID-19 pandemic has caused problems for farmers trying to get their products to consumers. Blockchain technology can help solve some of these problems by keeping a secure record of transactions. This could help reduce waste, ensure food is safe, and help farmers obtain better product prices. Blockchain technology can also help the agricultural sector reduce its carbon footprint. The use of blockchain technology in agricultural supply chains to improve traceability and transparency and create a more efficient and fair system is discussed in [105]. However, challenges need to be addressed before this can be achieved. Another study [108] concluded that the main barriers to adopting blockchain technology in the agricultural supply chain in India are a lack of awareness and knowledge and associated high costs. The study also found that the benefits of blockchain technology include increased transparency, traceability, and trust.

In [111], blockchain is presented as an opportunity to increase transparency and traceability, reduce costs, and increase efficiency. However, challenges remain in terms of scalability, interoperability, and governance. The authors of [114] report that blockchain can help to improve transparency and traceability, reduce costs and eradicate time delays, ensuring the quality of food products and protection from fraud. The authors of [117] discuss how blockchain technology could improve supply chains for agricultural products and how BigchainDB could help with this. BigchainDB is suitable because it enables data sharing in a secure and transparent way and allows people to interact without needing to trust one another. However, there are some difficulties with this kind of solution, such as ensuring that everyone agrees with the rules. In [120], the authors discuss how blockchain technology can be used to help with agriculture and supply chain management and how it can facilitate tracking food and ensuring that it is safe. They also discuss some of the challenges of using blockchain technology in agriculture, such as making sure everyone can use it and that it meets safety standards.

The authors of [123] discuss how blockchain technology can help build trust in agricultural product supply chains by providing a system to track the provenance of products and ensure that they are coming from trusted sources. In addition, blockchain can also be used to create transparency in the supply chain, which establishes trust between enterprises. In [52], the authors explore the potential of using blockchain technology to create a more efficient and transparent agricultural supply chain. They suggest that smart contracts help various supply chain actors share information and coordinate their activities more effectively. This would lead to improved traceability of food items, reduced costs, and improved efficiency. Another study [126] found that blockchain technology could make agricultural supply chains more efficient and transparent. However, the study had a constraint in that it could be applied only in a fast-growing economy. The authors of [128] discuss how blockchain technology can be used to improve soybean traceability in the agricultural supply chain. They explain how blockchain works and how it can be used to track the provenance of soybeans. They also discuss the benefits of using blockchain for soybean traceability, including improved transparency and efficiency in the supply chain.

In [131], the authors discuss how blockchain technology can help improve the food supply chain by creating a complete end-to-end solution, which can help with aspects such as transparency, traceability, and food safety. They also highlighted that some companies are already using blockchain in their agri-food supply chains. A system to track and manage food supply chains using blockchain technology and smart contracts is presented in [133]. The system includes a web-based interface to track the progress of food products from farm to table and a mobile app to allow farmers and producers to track the progress of their products in real time. The authors of [136] discuss how blockchain-based agri-food supply chains can be effectively managed using deep reinforcement learning. This is a technology that can be used to track and trace food items, as well as to manage and optimize supply chains. They presented a case study on how the technology has been used to improve agri-food supply chain management in China.

Another study [137] looked at how blockchain technology can be used in agricultural supply chain management. The study found that it had the potential to improve transparency and traceability in the supply chain, as well as reduce costs. This means that blockchain technology could be helpful in ensuring that food is safe and that farmers are paid sufficiently for their products. Another study [138] focused on the need to enhance supply chain management with desirable characteristics, such as checkpoints at every level. The argument for this criterion is made by demonstrating that poorly managed farms existed in an ancient nation with a long history of agriculture. Poor supply chain management or the lack of a mechanism for monitoring the flow of products at various stages of transportation was the main cause. According to [141], blockchain technology can help make the food supply chain safer and more efficient. Research shows that blockchain technology can improve food safety and customer satisfaction by deploying blockchain technology to increase transparency and traceability in the agricultural food supply chain [44].

In [144], the authors show that using IPFS technology with blockchain could help make the supply chain for agricultural products more transparent and secure and that it could help consumers easily trace the origins of products. The authors of [25] discuss how the Internet of Things (IoT) and blockchain could be used together in agriculture and food supply chains. They explain how these technologies can help to improve transparency (the ability to see what is happening), traceability (the ability to follow an item's journey), and efficiency (the use of resources in the best way possible) in the supply chain. They also highlight some of the challenges that need to be addressed for the technology to succeed, such as ensuring everyone involved has access.

The authors of [53] discuss a novel food supply chain for finance based on the Internet of Things built on a blockchain ecosystem. The model is designed to improve efficiency and transparency and has the potential to benefit both food producers and consumers. The potential for blockchain technology in agricultural governance under a big-data platform is discussed in [65]. The authors suggest that blockchain and smart contracts could help track agricultural products' origins and ensure food safety and quality.

A system that uses blockchain technology to keep track of food as it goes through the supply chain from farm to store is described in [10]. The system has four main parts: a blockchain platform to manage information and transactions, a digital ledger to keep track of everything, smart contracts to make sure everyone does their part, and an application layer for users to interact with the system. The authors of [68] explore how food supply chain traceability can be improved with the application of blockchain. The system would have such benefits as improved transparency and data security. They also argue that blockchain technology has the potential to help reduce food waste and improve food safety. IoT systems help farmers and manufacturers increase their competitiveness in the global market. In [70], the authors proposed that by using blockchain, the system could be further improved in a secure and transparent way to track the provenance of agricultural products from farm to table. In addition, the system would help to reduce fraud and counterfeit products in the supply chain.

In another study [72], a traceability system for agricultural supply chains based on blockchain technology in and around Indonesia was designed. In particular, the authors observed the chili commodity supply chain. The results showed a drastic improvement in traceability. The authors of [74] proposed a smart blockchain-based certification solution for agri-food and supply chain management [76]. They discussed the potential for using blockchain technology to create a secure traceability system for the ginger supply chain in Nepal. The technological potential of blockchain technology to optimize the supply chain on a digital platform is described in [79]. Blockchain technology can help create an efficient and transparent supply chain that can provide such benefits as improved security, reduced costs, and traceability. In addition, blockchain technology can also help to reduce fraudulent activities and improve customer satisfaction.

The authors of [82] present a SWOT analysis of the use of blockchain technology in sustainable agri-food supply chains in Vietnam. They found that blockchain technology has great potential to improve the traceability and transparency of agri-food supply chains, reduce transaction costs, and enable new business models. However, the authors also identified several challenges that need to be addressed for blockchain technology to be successfully implemented in Vietnam, including the lack of awareness and understanding among stakeholders, regulatory support, and technical capabilities. A system that allows users to connect with food suppliers and purchase food items directly from them is proposed in [85]. The system is based on blockchain technology, which makes it secure and transparent. It also has a mobile app, which makes it convenient for users to purchase food items.

Another study [88] examined the adoption of blockchain technology in supply chains between 2010 and 2020. The findings showed that blockchain adoption grew steadily during this period, with the number of related projects increasing from just a handful in 2010 to over 1000 by 2020. However, blockchain adoption remains relatively low, despite this growth, compared to other technologies, such as RFID and EDI. The study attributes this to the fact that blockchain is still a relatively new technology, and its potential applications in supply chain management are not yet fully understood. The authors of [91] discuss how blockchain and IoT can be used in agriculture and food supply chain management to improve interoperability among enterprises. They also describe how these technologies can be used to trace food items throughout the supply chain and to provide transparency and accountability.

Another study [94] discusses how blockchain technology can be used to create a third-party certification system for agri-food supply chains. The system uses smart contracts and blockchain tokens to track the movement of food products and ensure that they meet certain standards. This would provide greater transparency and traceability in the supply chain and could help to reduce food waste and fraud. The authors of [97] describe how small and medium enterprises (SMEs) used blockchain technology to create a more efficient and secure agricultural chain. The study also explores how cooperative strategies can help SMEs compete in the global market. The authors of [100] review how blockchain technology can be used to improve sustainability in agricultural supply chains. They discuss how blockchain can track the provenance of food products, increase transparency and traceability, and reduce fraud and waste. They also discuss the potential benefits and challenges of adopting blockchain technology in agricultural supply chains. Future prospects and the state of the art of blockchain technology, which can be used for the betterment of the supply chain, are presented in [103].

A number of advantages that the technology offers are described in [106], including transparency, traceability, and reduced costs. The study also highlights some challenges that need to be addressed before blockchain can be widely adopted in agriculture, such as the need for standardization and regulatory clarity. Although blockchain is a promising technology with the potential to increase transparency and efficiency in the food supply chain, according to [109], there are still many challenges to overcome before it can be widely adopted, such as the lack of standardization and interoperability. In [112], the authors explore how upcoming technologies can be used to create a more efficient and sustainable food system. The authors of [115] discuss the potential for blockchain technology to be used for agricultural supply chain management to improve food security and safety. It could be used to track the provenance of food products and ensure that they are safe to consume. This would provide greater transparency and traceability in the food supply chain, which would ultimately benefit consumers.

Another study [118] describes how a permissioned blockchain model for end-to-end traceability works and how it can be used to design and help organizations manage their supply chains more effectively and improve supply chain management. According to [121], the potential for blockchain to transform food and agricultural supply chains is significant. By providing a secure, decentralized ledger for tracking the provenance of food products, blockchain has the potential to increase transparency and traceability throughout the supply chain, from farm to table. This could help to address many of the challenges faced by the food and agriculture industries, such as food-safety concerns, fraud, and waste. In addition, blockchain-based applications have the potential to streamline supply chain logistics and improve coordination among stakeholders.

Blockchain technology can help improve the risk management of agricultural product supply chains. It can serve as a decentralized platform for data sharing and information exchange, as stated in [124]. The advantages of using blockchain technology in the agricultural product supply chain are as follows: it can provide a decentralized platform for data sharing and information exchange, which can reduce the cost of data collection and information sharing; it can help build trust among participants in the supply chain and thus improve coordination; it can provide a transparent and traceable platform for tracking the movement of agricultural products and ensuring food safety, and it can help reduce fraudulent activities in the supply chain.

In [56], the authors designed a model based on blockchain that was intended to assist small and medium enterprises (SMEs) in obtaining financing, reducing costs, and increasing transparency and traceability. According to [127], farmers and food producers can use blockchain to track their products from farm to table, ensuring that consumers know exactly where their food comes from and that it has been handled safely and responsibly. This would create a more transparent and efficient food system, which would benefit both producers and consumers. As described in [129], RiceChain is a blockchain-based framework that enables secure and traceable rice supply chains. It was proposed by researchers at the National University of Singapore (NUS). The framework utilizes smart contracts and IoT technologies to provide end-to-end traceability of rice throughout the supply chain, from farmers to retailers. This allows for better management of the quality and safety of rice, and it can reduce fraudulent activities, such as adulteration.

The authors of [132] discuss how blockchain technology can be used along with the Internet of Things (IoT) to create a more efficient and effective food supply chain. They note that blockchain provides a secure and transparent way to track data, while IoT devices can provide real-time information on the condition of food products. By combining these two technologies, it is possible to create a system that can track food from farm to table and identify issues in the supply chain in near-real time. Such a system could potentially help to reduce food waste, improve food safety, and increase efficiency in the food supply chain. In [134], the authors showcase how blockchain can be used to devise a supply chain system for dairy and dairy products. A novel way to use blockchain technology to store and manage the data collected from greenhouse sensors securely is proposed in [46]. These data are then used to provide an optimal greenhouse environment. A comprehensive guide to the dynamic and rapidly evolving world of digital agriculture is presented in [38]. The study covers the history and origins of digital agriculture, the theoretical underpinning of blockchain technology, and practical usage in the agricultural sector. A blockchain service platform that uses IoT sensors to provide farm-to-fork traceability is presented in [139]. The platform is designed to help farmers and food producers track the provenance of their products and ensure food safety. The authors also describe how the platform works and how it can benefit farmers and food producers.

A decentralized sustainable agriculture architecture designed based on blockchain is described in [50]. The proposed system aims to create a decentralized marketplace for agricultural products and services and provide farmers with access to data and resources that could help them improve their operations. The authors also discuss the challenges associated with implementing such a system and the potential benefits it could bring to the agricultural sector. A novel application of technology that could help improve the quality and safety of food products is presented in [143]. By tracking the movement of food products from farm to table, blockchain and IoT can help to identify issues and contamination sources quickly, allowing for rapid recall of affected products. This traceability solution can also help to reduce food waste by providing data on where and when food is wasted.

Another study [145] explores the potential of using blockchain technology to create a food traceability system in agriculture. The paper discusses the various benefits of using blockchain technology, such as its ability to provide a secure and tamperproof system and its potential to reduce costs and increase efficiency. The paper also outlines the challenges associated with implementing such a system, including the need for interoperability among stakeholders and the lack of standardization in the agricultural sector. The potential of blockchain technology to improve food traceability in smart agriculture is explored in [147]. The authors developed a prototype system that uses blockchain to track food items throughout the supply chain, from farm to table. The system was tested and evaluated with real-world data to assess its feasibility and effectiveness.

Another paper [149] presents a blockchain-enabled provenance system for the food industry that uses advanced deep-learning techniques. The system is designed to optimize the food supply chain and improve traceability. The paper describes how the system works and how it can be used to improve food safety and quality control. The authors of [66] discuss how blockchain technology can create a decentralized system for tracking and tracing agricultural products in India. They proposed a system in which each farmer would have a unique ID and all transactions would be recorded on a blockchain. This would allow for full transparency and traceability of products, from farm to table. The authors also discuss the potential benefits of such a system and the challenges that need to be addressed before it can be implemented.

Blockchain technology lacks standardization and regulation, which could impede its adoption by agricultural producers. Agricultural producers who are considering using blockchain technology for food transparency should consider the advantages and drawbacks, as presented in [67]. An agriculture-based blockchain and food-chain network that can help farmers trace their products is presented in [69]. In [71], a system is designed to track the movement of agricultural products from farm to table, with their quality monitored throughout the supply chain using blockchain technology. In [73], the authors note that such a system would provide high data integrity and availability. A blockchain-based traceability system for vegetables and fruit was proposed in [75].

The system makes use of RFID tags and sensors to track the movement of products from farm to table, with the blockchain acting as a data store, providing an immutable record that can be used to verify the authenticity of products. The system also includes a mobile application that allows consumers to scan RFID tags. The application of blockchain technology in cold food chain logistics has broad prospects. Cold chain logistics and traceable systems for fresh agricultural products based on blockchain technology were researched in [77]. The authors noted that such a system could provide a technical guarantee for the whole process of food-safety tracking from source to table. Work on the application of the Vennia algorithm to achieve traceability for agricultural e-commerce using a dual-chain blockchain is reported in [80]. A blockchain-empowered data supervision, sharing, and privacy-protection scheme for a secure and trusted agricultural product traceability system is presented in [83]. The proposed scheme overcomes the single point of failure inherent in traditional traceability systems. It also provides fine-grained data access control to ensure that only authorized users can access the data. In addition, the scheme is designed to be resilient to Byzantine attacks.

Agricultural product traceability technology based on information supervision and cloud architecture is proposed in [86]. The authors believe that this technology could provide an effective way to improve the economic value of agricultural products. They suggest that a cloud-based agricultural product traceability system could be used to improve supply chain management efficiency and reduce costs. The authors of [89] designed a blockchain-based system that uses machine learning to improve the accuracy of sensing and tracking. The scheme discussed in [92] is based on the Hyperledger fabric, and it uses digital signatures and hashes to ensure data authenticity. The scheme also includes a mobile application that allows users to track the progress of their products through the supply chain.

According to [95], technology can provide a complete and reliable traceability system for agricultural products. This can improve the management of products and provide more information for consumers, improving the overall quality of agricultural products. A novel system that uses blockchain technology for the origin traceability of agricultural products is presented in [98]. The system consists of three nodes: farmer, buyer, and auditor. The farmer nodes are responsible for registering the information of agricultural products, buyer nodes for tracing the origins of the products, and auditor nodes are used to verify the authenticity of the information registered by the farmer nodes. Blockchain technology and its impact on agriculture are discussed in [101].

The potential application of blockchain technology in agricultural product traceability systems and the advantages of using blockchain technology in agriculture are discussed in [104]. In [107], the authors explore the use of blockchain technology to increase transparency and reduce information asymmetry in the perishable agricultural product supply chain. The authors develop a model to assign values to blockchain technology considering demand uncertainty and different levels of information asymmetry. The results show that blockchain technology can increase supply chain efficiency and improve market outcomes.

The authors of [110] discuss the potential application of blockchain technology in agricultural product traceability systems and highlight the key features that make it suitable for this purpose. A strategy for using blockchain nodes in an agricultural product traceability system is proposed in [113]. The system uses a permissioned blockchain, and the nodes are deployed on virtual machines in different data centers. The deployment process is described in detail, including the nodes' and network configuration. The authors also discuss how to optimize the system for performance and scalability. According to [116], cloud, blockchain, and IoT technologies can potentially enhance productivity and efficiency in the agriculture sector by providing greater transparency and traceability of food products, improving supply chain management, and reducing waste.

Another paper [119] presents a deep learning-based intrusion-detection system for distributed denial of service (DDoS) attacks in Agriculture 4.0. The proposed system uses a deep-learning algorithm to learn the features of normal and abnormal network traffic and then uses these features to detect DDoS attacks. The system was evaluated using a real-world dataset, and the results showed that it could effectively detect DDoS attacks with high accuracy. An app using blockchain technology to create a decentralized marketplace where buyers and sellers can connect and trade without the need for a third party is proposed in [122]. This would allow farmers to obtain better prices for their products and buyers to obtain access to fresh local produce. An integrated IoT–blockchain-based smart-agriculture system to achieve efficient and secure data collection, storage, and sharing among stakeholders is presented in [43]. The system has four major components: an IoT platform for data acquisition, a blockchain platform for data storage and sharing, a machine-learning platform for data analysis, and a mobile application for user interaction. The proposed system was implemented in a greenhouse in Taiwan, and the experimental results showed that it could effectively improve the efficiency of data collection, storage, and sharing and provide better security and privacy protection.

A system designed to provide a decentralized, tamperproof, and transparent data storage platform for collecting, analyzing, and sharing crop-breeding data is proposed in [125]. The system has three layers: data, application, and smart contract. The data layer is responsible for storing the raw data collected from field trials. The application layer provides an interface for users to access and query the data. The smart-contract layer defines the rules for data sharing and access control. The authors of [31] provide a comprehensive review of the use of blockchain technology in sustainable e-agriculture. They discuss the potential of blockchain for data management in agriculture, suggest a number of implications for research and practice, and describe how blockchain can support sustainable e-agriculture initiatives.

The authors of [130] discuss blockchain efficiency in the agricultural sector. They highlight how the technology can be used to track food supply chains, record land ownership and transactions, and manage agricultural data. They also discuss the potential benefits of blockchain technology for small-scale farmers, including increased transparency and traceability of food products and reduced transaction costs. The authors of [55] discuss how the process of loan distribution can be streamlined in the agricultural sector. They suggest that by using information and communications technology (ICT), the process can be made more efficient and less time-consuming. They also suggest that by using ICT, the quality of information available to lenders could be improved, which would, in turn, improve the decision-making process. Technology for the development of smart agriculture based on blockchain technology and dividing it further into stages is described in [135]. The first stage is the development of basic public infrastructure, which includes the construction of public chains, wallets, and exchanges. The second stage is the development of application-specific chains designed for such applications as smart contracts, decentralized applications (DApps), and decentralized autonomous organizations (DAOs). The third stage is the development of industry-specific chains designed for such processes as supply chain management, the Internet of Things (IoT), and big data. The fourth stage is the development of cross-chain interoperability, which allows different blockchain networks to communicate with each other.

The authors of [47] describe how blockchain can provide a secure and efficient data-management platform for the agricultural industry while reducing the costs associated with data breaches. In [42], the authors present a scheme that can be used to manage big data and knowledge in a decentralized manner. The scheme uses a directed acyclic graph data structure that can be used to track the movement of resources, information, and money in a transparent and secure way. The scheme also allows for the creation of smart contracts that can be used to automate transactions between parties. Another paper [140] proposes a control strategy for time-shifting agriculture loads and local consumption of photovoltaic power based on an energy blockchain. The strategy can ensure the effective use of renewable energy and optimize the allocation of renewable energy resources, reduce waste, and improve efficiency. A blockchain-based flexible double-chain architecture that can be used to optimize performance and sustainability in agriculture is described in [142]. The architecture consists of a primary chain and a secondary chain. The primary chain stores data and transactions, while the secondary chain validates and processes transactions. This architecture allows for more flexibility and scalability than traditional blockchain architectures. The paper also discusses how this architecture can be used to improve sustainability in agriculture by reducing waste, improving traceability, and increasing transparency.

Intellectual property theft is a major concern in the field of IoT-based precision agriculture [48]. Software-defined networking (SDN) can help mitigate this problem by providing a centralized way to manage and monitor network traffic. By identifying and blocking suspicious traffic, an SDN can help to prevent data theft and other attacks. The potential of blockchain technology to improve agricultural food product provenance is explored in [146]. The paper provides an overview of blockchain technology and its potential applications in food product manufacturing. The paper also discusses the challenges associated with implementing blockchain technology in manufacturing and provides recommendations for overcoming these challenges. A blockchain-based system that can be used to track the origin of chicken products is discussed in [148]. The system uses RFID tags to track the location of chicken products throughout the supply chain from farm to table. The system is designed to increase transparency and traceability in the food supply chain by helping consumers make well-informed choices about the products they purchase.

3.5. Application of Blockchain in Livestock Management

The application of blockchain technology in livestock management can help to improve the accuracy and efficiency of the stock-management process, as presented in Table 6. With blockchain, the entire process can be digitized and made transparent, making it error-proof and improving the accuracy of stock data. In addition, blockchain can help to streamline the stock-management process by automating the tracking and recording of transactions. All these in the framework make this more efficient and optimize the time required to complete transactions.

Table 6. Application of blockchain in livestock management.

Re	**Po**	**Be**	**Me**	**Fi**	**Ca**	**Re**	**Po**	**Be**	**Me**	**Fi**	**Ca**
[150]		√				[151]				√	
[152]				√		[153]					√
[64]		√				[148]	√				
Po		Poultry		**Be**		Beef		**Ca**		Cattle	
Me		Meat		**Fi**		Fish		**Re**		References	

In the United States, blockchain technology is used to increase the beef industry's transparency and traceability. A study [150] sought to understand how US consumers value these benefits when making purchasing decisions. The study found that US consumers are willing to pay a premium for beef that is sourced through a blockchain traceability system. Willingness to pay was highest among those who valued transparency and food safety and lowest among those who were concerned about privacy. These findings suggest that there is a market for blockchain-traced beef in the United States. In [152], the authors proposed a blockchain-based platform for fish farmers to store their data securely. The platform is aimed at providing farmers with secure and tamperproof storage of large agricultural data. The efficiency and usability of the system, demonstrated through a series of experiments, show exceptional benefits.

A blockchain-based reconciliation mechanism to improve consumer trust in beef supply chain traceability is proposed in [64]. The mechanism allows for the reconciliation of data among stakeholders in the supply chain, including farmers, processors, retailers, and consumers. This would provide a transparent and tamperproof record of the journey of beef from farm to table and ensure that all stakeholders have access to the same information. The authors argue that this would improve confidence in the safety and quality of beef products, as well as increase transparency and traceability throughout the supply chain. A quality-monitoring system for waterless transportation of live fish based on wireless sensors and blockchain technology is presented in [151]. The system monitors various parameters related to the quality of the water, such as temperature, pH, dissolved oxygen, and ammonia levels. Collected sensor data are stored on a blockchain, which allows for transparent and tamperproof data collection and analysis. The system was evaluated using a case study involving the transport of live fish from China to Japan. The results showed that the system was able to monitor the water quality throughout the journey effectively, and the fish arrived in good condition.

Blockchain technology can help improve animal and animal product traceability [153]. It can help improve the safety and quality of animal products and reduce the cost of animal production and health care. A blockchain-based system that can be used to track the origin of chicken products is discussed in [148]. The system uses RFID tags to track the location of chicken products throughout the supply chain from farm to table. The system is designed to increase transparency and traceability in the food supply chain and keep the consumer informed of the choices they make in purchasing a product.

3.6. Application of Blockchain in Agriculture for Industrialization and Commercialization

The application of blockchain technology in agriculture for industrialization and commercialization could revolutionize the sector, as presented in Table 7. The technology can help bring transparency and efficiency to the sector by tracking the movement of goods and crops from farm to table. It can help prevent food fraud and ensure food safety. The technology can also help reduce waste and improve logistics.

Table 7. Application of blockchain in agriculture for industrialization and commercialization.

Re	**In**	**Ec**	**Mr**	**Er**	**Tr**	**Re**	**In**	**Ec**	**Mr**	**Er**	**Tr**	**Re**	**In**	**Ec**	**Mr**	**Er**	**Tr**
[154]				√		[149]	√					[39]	√				
[155]					√	[158]		√				[119]	√				
[156]	√					[159]			√			[48]	√				
[157]	√			√	√	[160]			√			[161]			√		
[58]	√					[87]				√		[116]			√	√	
[106]	√		√	√		[162]				√		[163]				√	
[164]		√				[165]				√		[64]				√	
[166]		√				[167]				√		[96]				√	
[168]		√				[169]				√		[126]				√	
[170]			√			[52]					√	[171]				√	
[172]			√			[37]	√			√		[173]					√
[174]				√		[61]	√					[46]	√				
[38]	√					[49]	√					[91]	√				
[175]	√					[117]	√					[112]	√				
[176]	√					[138]	√					[80]		√			
[141]	√					[177]	√		√	√		[78]			√		
[178]	√	√				[135]	√					[179]			√		
												[86]				√	

In	Industrialization	**Mr**	Market
Ec	Economy	**Tr**	Trade
Er	E-commerce	**Re**	References

Studies report that the use of blockchain technology can provide socioeconomic security in the agriculture sector [154], improve supply chain management in Indian agriculture [155], and enable marketplace innovation and smart-contract performance evaluation [156]. Another study noted that an IoT blockchain network could help with optimal smart contracts for an autonomous greenhouse environment [157]. A dual-chain blockchain for agriculture e-commerce traceability is presented in [58].

The adoption of blockchain in a cross-border agricultural supply chain by an overseas supplier is described in [106]. The authors of [164] show that blockchain technology can promote the development of agricultural products using an e-commerce model in Jilin Province. With the help of blockchain technology, agricultural products can be easily traced, and the quality of the products can be guaranteed. In addition, blockchain technology can reduce transaction costs and improve the efficiency of agricultural product e-commerce. A three-in-one agricultural product e-commerce logistics model based on blockchain technology is discussed in [166]. The model includes information, logistics, and a service platform. The proposed model saves resources, improves efficiency, and can be used to create a trust system. The authors of [168] report that the development of agricultural product e-commerce in China is facing many challenges, such as the fragmented and scattered nature of the market, the lack of a unified standard for agricultural products, and the difficulty in tracing their source. However, with the help of blockchain technology, these problems can be effectively solved. Blockchain technology can provide a decentralized platform for agricultural product e-commerce, which can help to build a trustless and transparent trading environment. It can also help trace agricultural product sources and ensure food safety. In [170], the authors discuss an IoT based on distributed ledger technologies used in precision agriculture. The proposed system uses blockchain technology to manage data collected from sensors and devices deployed in the field and share the data among stakeholders in the supply chain. The system also uses smart contracts to automate decision-making and transactions.

A simulated organic vegetable production and marketing environment using the Ethereum blockchain is presented in [172]. The environment consists of three types of actors: farmers, distributors, and consumers. Farmers produce organic vegetables and sell them to distributors. Consumers purchase organic vegetables from distributors. The whole process is tracked and made transparent by the Ethereum blockchain. The data collected from a simulated environment showed that blockchain technology could improve the efficiency of organic vegetable production and marketing efficiency. According to [174], using blockchain technology in the agricultural sector can increase traceability and transparency in the food supply chain and improve the efficiency of agricultural production and logistics. However, the challenges are not small and need to be addressed before blockchain technology can be widely adopted in the agricultural sector, including the need for more research and development, regulatory clarity, and industry-wide collaboration. The authors of [38] collated a comprehensive guide to the dynamic and rapidly evolving world of digital agriculture. It covers the history and origins of digital agriculture, the theoretical underpinning of blockchain technology, and practical applications of this technology in the agricultural sector. Another study [175] looked at the potential of blockchain technology in different industries in Turkey and found great potential for its use. However, the study also found that some challenges must be addressed before blockchain technology can be fully implemented in these industries.

The authors of [176] discuss how blockchain is becoming widely adopted and can help reduce the cost of financing for farmers and agribusinesses, as well as improve transparency and traceability in the food supply chain. Ways to connect farmers with other stakeholders are discussed in [141]. Farmers can use blockchain to connect with other stakeholders in the agricultural industry, including suppliers, buyers, and distributors. This would allow for a more efficient and transparent supply chain and better prices for farmers. In addition, blockchain could be used to track the provenance of food products, ensuring that they are safe and of high quality. The value-integration mode of the agricultural e-commerce industry chain based on the Internet of Things and blockchain technology is discussed in [178]. The authors believe that applying these technologies can help to improve the efficiency of the agricultural e-commerce industry chain and promote the development of rural areas. A blockchain-enabled provenance system for the food industry that uses advanced deep-learning techniques is presented in [149]. The system is designed to optimize food supply chains and improve traceability. The paper describes how the system works and how it can be used to improve food safety and quality control. Another study [158] analyzed the potential of using blockchain technology in sustainable e-agriculture. The results showed that blockchain technology could help to improve the transparency and traceability of the food supply chain, which can, in turn, help to improve food safety and quality control. In addition, blockchain technology can help to reduce the costs associated with e-agriculture by simplifying supply chain management and reducing transaction costs. As described in [159], the Rootnet protocol is a permissioned blockchain-based agriculture network that allows farmers to connect with their peers and buyers in a decentralized marketplace. The protocol uses smart contracts to facilitate transactions and ensure that all parties can trust each other. The Rootnet protocol is designed to provide a more efficient and transparent way for farmers to sell their products, and allows buyers to purchase products directly from farmers.

A blockchain-based system that can track farming activities and enhance trust in the community-supported agriculture (CSA) model is discussed in [160]. The system uses smart contracts to track various aspects of the farming process, from planting and harvesting to the distribution of produce. This would allow CSA members to have a transparent view of how their food is produced and could help build trust in the CSA model. Another study [87] found that blockchain technology can effectively trace agricultural products' origins and ensure food safety. The study also showed that the blockchain-based traceability system could help reduce fraudulent activities in the agricultural supply chain. A remote user-authentication scheme using private blockchain-based secure access control for agriculture-monitoring systems was proposed in [162]. The system consists of three entities: a user, an agricultural monitoring center (AMC), and a private blockchain. The user generates two public/private key pairs and registers the public keys with the AMC. Users who want to access the system need to prove their identity to the AMC by signing a message with their private key. If the AMC verifies the signature, it issues a request to the private blockchain for the user's permission to access the system. The potential of blockchain technology in agriculture and how it can help with the economic reform of the agricultural sector is discussed in [165]. The study highlights how blockchain can be used to create a more transparent and efficient food supply chain and traceability of food products. It also discusses how blockchain can help to reduce waste in the agricultural sector and create new opportunities for farmers.

In [167], the authors note that blockchain technology's legal and regulatory framework is still in its infancy. However, several countries have already begun to develop regulations and laws relating to blockchain and digital currencies. In the European Union, the European Commission has published several directives and regulations, including reports by the European Union Blockchain Observatory and Forum on blockchain regulations. In [169], the authors discuss how blockchain technology can be used to create a sustainable food economy. They argue that blockchain can help create a direct connection between consumers and producers and could lead to more sustainable production practices. They also discuss how blockchain could be used to trace food products and how this would allow consumers to make more informed choices about the food they purchase. Another paper [52] explores the potential of using blockchain technology in the agricultural supply chain to create a more efficient and transparent system. The authors suggest that by utilizing smart contracts, the various actors in the supply chain would be able to share information and coordinate their activities more effectively. This would lead to improved traceability of food items, reduced costs, and improved efficiency.

A blockchain-based farmer's credit scheme called KRanTi launched in India is discussed in [37]. The scheme is designed to help small and marginal farmers access credit more easily. The paper also discusses how the scheme works and how it is expected to help improve the efficiency of the agricultural food supply chain in India. Studies on supply chain management (SCM) initiatives can be found in the literature [61] regarding agri-food traceability and SCM, as well as digital ledgers and distributed ledger technology (DLT). Applying blockchain technology to agri-food SCM is a relatively new area of research, with most studies published in the last two years. Nevertheless, the extant literature provides a range of insights into the potential for blockchain technology to support sustainable agriculture initiatives, including by enhancing transparency and traceability, reducing transaction costs, and improving data quality and security.

Another study [49] used bibliometric analysis to map the research trends in blockchain technology in the food and agriculture industries. The results showed that supply chain management, food safety, and traceability were the most frequent research topics. The potential of blockchain technology in improving product supply chains in the agricultural sector is discussed in [117]. The study specifically focuses on using BigchainDB for this purpose, highlighting its advantages for product supply chains, including its ability to provide a secure and transparent platform for data sharing and facilitate trustless interactions between parties. The paper also discusses some of the challenges associated with implementing such a solution, including the need for regulatory clarity and having to overcome technical challenges. Finally, methods to improve supply chain management in agriculture in India using blockchain-based technology are proposed in [138].

Secure commercialization in agriculture using blockchain is a cutting-edge technology that can help farmers and other agricultural businesses secure their commercial operations [177]. This technology can help farmers track their products and ensure that they are getting the best possible price and can sell their products in a safe and secure environment. In [135], the authors developed a path for smart agriculture based on blockchain technology with an emphasis on cross-chain interoperability, which allows different blockchain networks to communicate with each other.

The authors of [39] created a blockchain-based system for smart agriculture that uses the Internet of Things (IoT) to improve transparency, security, and quality control in the food supply chain. The system uses sensors and IoT devices to collect data on various aspects of food production, including weather conditions, soil moisture levels, and crop growth. The data are used to track the progress of crops from farm to table and ensure that they meet safety and quality standards.

A deep learning-based intrusion-detection system for distributed denial of service (DDoS) attacks in Agriculture 4.0 is presented in [119]. The proposed system uses a deep-learning algorithm to learn the features of normal and abnormal network traffic and then uses these features to detect DDoS attacks. The system was evaluated using a real-world dataset, showing that it could effectively detect DDoS attacks with high accuracy. Intellectual property theft is a major concern in IoT-based precision agriculture. Software-defined networking (SDN) can help mitigate this problem by providing a centralized way to manage and monitor network traffic. By identifying and blocking suspicious traffic, SDN can help to prevent data theft and other attacks [48]. In addition, an innovative smart contract-based marketplace for automatic trading is introduced in [161].

The authors of [116] showed that blockchain and IoT technologies could potentially enhance productivity and efficiency in the agriculture sector by providing greater transparency and traceability of food products, improving supply chain management, and reducing waste. AgroChain is a blockchain platform that enables farmers to connect with agribusinesses and consumers transparently and efficiently [163]. The platform can help reduce the risk of fraudulent activities while providing a better way for farmers to track their product quality and quantity. In addition, AgroChain allows farmers to receive payments promptly and provides them with access to new markets. A blockchain-based reconciliation mechanism to improve consumer trust and traceability is proposed in [64]. The mechanism allows for the reconciliation of data among stakeholders in the supply chain, including farmers, processors, retailers, and consumers. This provides a transparent and tamperproof record and increases transparency and traceability throughout the supply chain.

The coupling mechanism and development prospect of a clean-energy ecosystem in smart agriculture based on blockchain is discussed in [96]. The authors argue that using blockchain in smart agriculture would promote the development of clean energy and create an innovative ecosystem of clean energy. They conclude that their innovation is important for developing clean energy and achieving sustainable development.

The authors of [126] found that blockchain technology could increase transparency and efficiency in agricultural supply chains and help promote circularity. However, the study was conducted in a fast-growing economy, so the findings may not be generalizable to other contexts. The authors of [171] performed a SWOT analysis of blockchain technology to assess its potential to revolutionize various industries and the economy. The analysis showed the following results. Strengths were that blockchain technology is decentralized, transparent, and secure and has the potential to increase efficiency and reduce costs in various economic activities. Weaknesses were that blockchain technology is still in its early stages of development and adoption, and there is a lack of regulatory clarity surrounding its use in the economy. Opportunities identified were that blockchain technology can be used to create new economic models and improve existing ones, as well as facilitate international trade and reduce cross-border transaction costs, while threats identified were that misusing blockchain technology could lead to economic crimes, such as money laundering and tax evasion. There is also a risk that the decentralization of blockchain could lead to market manipulation by central authorities.

An agricultural trade-export algorithm in the blockchain-enabled Internet of Things is proposed in [173]. The algorithm is based on the concept of an optimal path and employs a two-stage optimization process to find the optimal path for each farmer. The first stage selects the most efficient agricultural production units from a set of available units, and the second stage determines the order in which these units should be operated to minimize the overall cost of production. Their algorithm was tested on a real-world dataset, and the results showed that it outperformed existing algorithms in terms of efficiency and effectiveness.

A greenhouse environment-based autonomous smart contract on an IoT blockchain network for agriculture is proposed in [46]. The authors of [91] discuss how blockchain and IoT can be used in agriculture and food supply chain management to improve interoperability among enterprises. They also describe how these technologies can be used to trace food items throughout the supply chain and provide transparency and accountability. The authors of [112] explore how upcoming digital technologies could be used to create a more efficient and sustainable food system. A dual-chain blockchain for e-commerce traceability in the agricultural domain is presented in [80], and a method for market expansion and overseas agricultural supply chain is proposed in [78]. According to [179], blockchain technology has the potential to provide a more secure and transparent way to connect and trade for smallholder farmers and buyers. This could help reduce the risk of fraud and corruption and ensure fair prices. Blockchain could also help trace the provenance of food products, making it easier to track food-safety issues. In [86], the authors discuss research on product traceability technology based on supervision and cloud computing. They suggest that a cloud-based agricultural product traceability system could be implemented along with blockchain to improve efficiency and reduce the cost of supply chain management.

3.7. Application of Blockchain in Agriculture for Production, Management, and Governance

The use of blockchain technology in agriculture is still in its early stages. Nevertheless, there are already a few notable examples of how the technology is being used to improve food production, management, and governance, as presented in Table 8. One example is using blockchain technology to create a secure, tamperproof system for tracking food products from farm to table. This can help ensure the quality and safety of food products and help reduce food fraud. Another example is using blockchain technology to create a decentralized system for managing food production. This can help reduce the need for central authorities to control food production and create a more transparent and efficient food production system. Finally, blockchain technology can also be used to improve the governance of food systems. For example, it can create a more transparent and accountable system for tracking food subsidies and other food-related government programs.

Table 8. Application of blockchain in agriculture for production, management, and governance.

Re	Pr	Go	Ma	Op	Re	Pr	Go	Ma	Op	Re	Pr	Go	Ma	Op
[143]	√				[181]	√				[182]			√	
[172]	√				[122]	√		√	√	[48]			√	
[106]	√		√		[163]	√				[183]			√	
[180]			√		[55]	√				[184]			√	
[38]	√				[177]	√		√		[185]			√	
[153]	√				[135]	√			√	[122]	√		√	√
[141]	√				[25]	√				[186]			√	√
[139]	√				[59]	√			√	[46]	√			
[160]	√				[122]	√		√	√	[91]	√		√	
[167]		√			[186]			√	√	[112]	√		√	
[187]			√		[188]			√		[65]		√		

Pr	Production	**Go**	Governance
Ma	Management	**Op**	Operation
Re	References		

A novel application of blockchain technology that can help improve the quality and safety of food products is presented in [143]. By tracking the movement of food products from farm to table, blockchain and IoT can help to identify issues and contamination sources quickly, allowing for rapid recall of affected products. This traceability solution can also help to reduce food waste by providing data on where and when food is wasted. An organic vegetable production and marketing environment simulation using the Ethereum blockchain is presented in [172]. The environment consists of three actors: farmers, distributors, and consumers. Farmers produce organic vegetables and sell them to distributors. Consumers purchase organic vegetables from distributors. The whole process is tracked and made transparent by the Ethereum blockchain. The data collected from the simulated environment show that blockchain technology can improve the efficiency of organic vegetable production and marketing. The authors of [106] discuss how blockchain technology can be used to improve economic efficiency and supply chain management in agriculture. They cite several advantages that the technology can offer, including transparency, traceability, and reduced costs. They also highlight some challenges that need to be addressed before blockchain can be widely adopted in agriculture, such as the need for standardization and regulatory clarity. A new blockchain-based algorithm that could potentially be used to manage the distribution of new and renewable energy resources is proposed in [180]. The algorithm is designed to allow for secure, efficient, and decentralized management of these resources. The authors of [38] composed a comprehensive guide to the dynamic and rapidly evolving world of digital agriculture. It covers the history and origins of digital agriculture, the theoretical underpinning of blockchain technology, and practical applications of this technology in the agricultural sector.

According to [153], blockchain technology can help to improve the traceability of animal and animal products. It can help to improve the safety and quality of animal products and reduce the cost of animal production and health care. According to [141], farmers can use blockchain to connect with other stakeholders in the agricultural industry, including suppliers, buyers, and distributors. This would allow for a more efficient and transparent supply chain and better prices for farmers. In addition, blockchain could be used to track the provenance of food products, ensuring that they are safe and of high quality. The authors of [139] discuss a blockchain service platform that uses IoT sensors to provide farm-to-fork traceability. The platform is designed to help farmers and food producers track the provenance of their products and ensure food safety. They describe how the platform works and how it can benefit farmers and food producers. The authors of [160] discuss a blockchain-based system that can be used to track farming activities and enhance trust in the community-supported agriculture (CSA) model. The system uses smart contracts to track various aspects of the farming process, from planting and harvesting to the distribution of produce. This would allow CSA members to have a transparent view of how their food is produced and could help build trust in the CSA model. Blockchain technology's legal and regulatory framework is still in its infancy [167]. However, several countries have already begun to develop regulations and laws related to blockchain technology and digital currencies. In the European Union, the European Commission has published several related directives and regulations, including reports by the European Union Blockchain Observatory and Forum on blockchain regulations.

Farmers in India often have difficulty obtaining agricultural machinery, such as tractors, due to a lack of coordination and information [187]. A collective blockchain-based agricultural machinery scheduling system could help rural farmers in India by providing a decentralized platform to coordinate the use of agricultural machinery. The system would allow farmers to request the use of specific machines, and service providers would be able to respond to these requests. The system would also provide transparency on machine availability and pricing, allowing farmers to make informed decisions about when and how to use the machines. The application of blockchain technology in production agriculture offers many potential benefits, including improved traceability, transparency, and efficiency in supply chains and better management of data and information [181]. In addition, blockchain-based applications can reduce costs and increase revenues for farmers and other stakeholders in the agricultural sector. However, challenges remain in scalability and adoption, and further research is needed to assess the feasibility and impact.

An app that allows small farmers in developing countries to sell their produce directly to buyers is proposed in [122]. The app uses blockchain technology to create a decentralized marketplace where buyers and sellers can connect and trade without needing a third party. This allows farmers to obtain better prices for their products and buyers to access fresh local produce. AgroChain is a blockchain-based platform that enables farmers to connect with agribusinesses and consumers transparently and efficiently [163]. The platform can help reduce the risk of fraudulent activities while providing a better way for farmers to track their products' quality and quantity. In addition, AgroChain allows farmers to receive payments in a timely manner and provides them with access to new markets. The authors of [55] discuss how the process of loan distribution in the agricultural sector can be streamlined. They suggest that by using information and communications technology (ICT), the process can be made more efficient and less time-consuming. They also suggest that by using ICT, the quality of information available to lenders can be improved, which would, in turn, improve the decision-making process. Secure commercialization in agriculture using blockchain technology is a cutting-edge approach that can help farmers and other agricultural businesses secure their commercial operations [177]. This method can help farmers track their products and ensure they obtain the best possible price. It can also help ensure that farmers can sell their products in a safe and secure environment.

The authors of [135] describe the development path of smart agriculture based on blockchain technology, which includes the construction of basic public chains, wallets and exchanges, DApps, DAOs, IoT, and big data. The authors of [25] discuss how IoT and blockchain can be used in agriculture and food supply chains. They explain how these technologies can help to improve transparency, traceability, and efficiency in the supply chain. They also highlight some of the challenges to be resolved to make the ecosystem successful. The authors of [59] present a system that uses blockchain technology to manage data and interactions among parties in the agricultural industry. They explain how the system works and discuss the advantages and challenges of using blockchain in this way.

Another study [122] describes an app that allows farmers to sell their products directly to buyers using blockchain technology to create a decentralized marketplace. This marketplace does not require a third party, allowing farmers to obtain better product prices. Buyers also have access to fresh local produce. The authors of [186] discuss how blockchain technology can be used to create a water-management system in precision agriculture. The system would be used to track water usage and ensure that it is used efficiently. They argue that using IoT devices is a cost-effective way to collect data and can be used to create a trustless system.

A system that uses a blockchain ledger to store data collected from various IoT sensors is proposed in [188]. The data are used to generate smart contracts that are executed automatically to control the release of water from the irrigation system. The system also uses a mobile application to provide farmers with real-time information about their crops' status and the irrigation system's water level. A system that uses IoT devices to collect data from the field and store it on a blockchain is proposed in [182]. The data are used to generate insights that can help farmers with irrigation and water management. The system is designed to be decentralized, secure, and transparent.

According to [48], intellectual property theft is a major concern in the field of IoT-based precision agriculture. Software-defined networking (SDN) can help mitigate this problem by providing a centralized way to manage and monitor network traffic. By identifying and blocking suspicious traffic, SDN can help to prevent data theft and other attacks. The authors of [183] discuss how blockchain-based context-aware authorization management can be used in IoT ecosystems. They explain how this would work and the benefits it would bring.

Data immutability and event management via blockchain on the Internet of Things are discussed in [184]. The advantages of using blockchain in agriculture, such as its tamperproof and distributed nature, are discussed in [185]. The authors also outline some challenges to address before blockchain can be widely adopted in agriculture, such as data interoperability and security. The authors of [122] developed an app that allows small farmers in developing countries to sell their produce directly to buyers. The app uses blockchain technology to create a decentralized marketplace where buyers and sellers can connect and trade without the need for a third party. This allows farmers to obtain better prices for their products and buyers to obtain access to fresh local produce.

The authors of [186] discuss the potential of using IoT devices to provide data for a water-management system based on blockchain for precision agriculture. The system would be used to track water usage and ensure that it is efficient. They argue that using IoT devices is a cost-effective way to collect data and can be used to create a trustless system. An approach to greenhouse systems based on blockchain-enabled optimization that can help reduce energy consumption more than the existing baseline system is presented in [46].

The authors of [91] discuss how blockchain and IoT could revolutionize agriculture and food supply chain management by improving enterprise interoperability. They also describe how these technologies can be used to trace food items throughout the supply chain and provide transparency and accountability. The authors of [112] discuss how the latest digital technologies can be used to create a more efficient and sustainable food system. The authors of [65] discuss the potential of blockchain technology to help with agricultural product governance under a big-data platform. They suggest that blockchain could be used to help track the origins of agricultural products and to ensure food safety and quality. They also discuss the potential for smart contracts to be used in agricultural product supply chains.

3.8. Limitations, Challenges, Issues, and Importance in the Application of Blockchain in Agriculture

The agricultural sector is one of the most important sectors of the economy, but it is also one of the most challenging to modernize. There are several limitations, challenges, and issues that need to be addressed to apply blockchain technology in agriculture, as presented in Table 9. The first challenge is that the agricultural sector is very complex, and many stakeholders are involved: farmers, processors, distributors, retailers, and consumers. These stakeholders have different interests and needs, and reaching a consensus is not always easy. Another challenge is that the agricultural sector is very data-intensive. Large quantities of data need to be collected and processed to make informed decisions, including weather data, soil data, crop data, and market data. Another challenge is that the agricultural sector is very time-sensitive. Decisions need to be made quickly to take advantage of opportunities and avoid losses. The sector also faces many challenges due to climate change, including such factors as droughts, floods, and pests. Finally, the importance of the agricultural sector cannot be overstated. The sector is responsible for providing food for the entire population and plays a significant role in the economy. Blockchain technology has the potential to help the agricultural sector overcome some of the limitations and challenges and help it become more efficient and productive.

AgroChain, a blockchain-based platform that could help reduce the risk of fraudulent activities, is presented in [163]. According to [40], blockchain can help reduce the incidence of fraud and counterfeiting in the supply chain, provide digital identification for livestock, and aid in reducing land ownership disputes. The authors of [189] discuss a blockchain/IoT-based method for storing and sharing information in a secure and decentralized manner. The authors of [190] highlight the advantages of blockchain, such as decentralization, tamper resistance, and traceability, and how it can help farmers overcome numerous challenges, such as a lack of trust among stakeholders, information asymmetry, and inefficient supply chains.

Table 9. Limitations, challenges, issues, and importance of blockchain application in agriculture.

Re	Is	Im	Ch	Li	Re	Is	Im	Ch	Li	Re	Is	Im	Ch	Li
[163]	√				[25]	√		√	√	[158]			√	
[40]	√				[91]	√			√	[105]			√	
[189]	√				[48]	√	√			[41]			√	√
[190]	√				[38]		√	√		[116]			√	
[46]	√				[96]	√	√			[191]	√		√	
[57]	√				[157]		√			[25]	√		√	√
[87]	√		√		[162]		√	√		[42]			√	
[96]	√	√			[139]		√			[45]			√	
[52]	√				[44]		√			[192]			√	
[193]	√				[47]		√			[59]			√	
[55]	√				[50]	√	√		√	[117]				√
[50]	√	√		√	[39]	√	√			[120]				√
[191]	√		√		[194]		√			[41]			√	√
[39]	√	√			[48]	√	√			[50]	√	√		√
[188]	√				[87]	√		√		[25]	√		√	√
[143]	√				[38]		√	√		[70]				√
										[91]	√			√

Is	Issues	**Im**	Importance
Ch	Challenges	**Li**	Limitations
Re	References		

The authors of [46] demonstrate the feasibility of using blockchain technology to optimize greenhouse systems. Regarding increased transparency and traceability in the food supply chain, the importance of blockchain technology in agriculture is demonstrated in [57]. It can help ensure food safety and quality, customer satisfaction, and peer-to-peer productivity. The difficulties in adopting and the lack of adoption of newer technologies in the agricultural sector, a lack of transparency and trust among various parties involved in the agricultural process, and the high costs of using blockchain technology are discussed in [87]. Creating an innovative ecosystem of clean energy in smart agriculture based on blockchain is an important way to encourage the development of clean energy and achieve sustainable growth, according to [96].

The potential of using blockchain technology in the agricultural supply chain to create a more efficient and transparent system through the use of smart contracts is explored in [52], and several flaws in current credibility applications, including a lack of trustworthiness, transparency, and accountability, are described in [193]. The authors also identify several promising application areas, such as identity management, supply chain management, and health care. The authors of [55] discuss how information and communications technology (ICT) can be used to streamline the loan distribution process in the agricultural sector. The authors of [50] discuss the development of a blockchain-based decentralized architecture for sustainable agriculture with a decentralized marketplace for farm products and services. They also discuss the difficulty of implementing such a system, as well as its potential benefits.

The authors of [191] found that incorporating blockchain technology into e-agriculture provisioning systems (EAPSs) could help ensure efficient, secure, and long-term agricultural resources and data management. Blockchain technology can also help to reduce corruption and fraudulent behavior in EAPSs. In [39], the authors show how a blockchain-based supply chain system for smart agriculture that uses the Internet of Things (IoT) can provide such benefits as increased transparency, security, and quality. The data collected from various IoT sensors deployed in the field can be stored in a blockchain ledger to automatically control the water for irrigation systems with real-time information, according to [188]. According to [143], a traceability solution could help to reduce food waste by providing data on where and when food is wasted. Blockchain and IoT can be used to quickly identify problems and contamination sources, allowing for quick recall of affected goods.

The authors of [25] discuss how the IoT and blockchain can be used in agriculture and food supply chains to increase transparency, traceability, and efficiency. They also highlight the obstacles that must be overcome to succeed. To improve interoperability, transparency, and accountability among enterprises, blockchain and IoT can be used in agriculture and food supply chain management [91]. According to [48], intellectual property theft is a major concern in the world of IoT-based precision agriculture. Software-defined networking (SDN) can address this issue by providing a centralized method for managing and monitoring network traffic. SDN can help to prevent data theft and other attacks by identifying and blocking suspicious traffic.

The authors of [38] present a comprehensive introduction to the dynamic and rapidly evolving world of digital agriculture. They also discuss the history and origins of digital agriculture, the theoretical foundation of blockchain technology, and practical applications of this technology in the agricultural sector. The coupling mechanism and development prospects of an innovative blockchain-based ecosystem for clean energy in intelligent agriculture are discussed in [96]. According to some researchers, the use of blockchain in smart agriculture not only encourages the development of clean energy but also helps create a new clean-energy ecosystem. The authors conclude that developing a blockchain-based clean-energy ecosystem in smart agriculture is an important strategy for promoting renewable energy and sustainable development. According to [157], using new technologies in agriculture could potentially result in significant efficiency and productivity gains, with various ways to digitize, from sensors and drones used for data collection to precision farming systems.

A permission-based system consisting of three entities—a user, an agricultural monitoring center (AMC), and a private blockchain—is proposed in [162]. The user first generates two public/private key pairs and then registers the public keys with the AMC. A blockchain service platform that uses IoT sensors to provide farm-to-fork traceability is described in [139]. The platform is intended to assist farmers and food producers in tracking the provenance of their products and ensuring food safety. The authors also explain how the platform works and how it can benefit farmers and food producers. As demonstrated in [44], the benefits of blockchain technology in agriculture include increased transparency and traceability in the food supply chain. This can help ensure food safety and quality, customer satisfaction, and peer-to-peer productivity.

The authors of [47] argue that blockchain can provide the agricultural industry with a secure and efficient data management platform while also lowering data breach costs. The authors of [50] discuss the development of a blockchain-based decentralized architecture for sustainable agriculture. The aim is to create a decentralized marketplace for agricultural products and services, as well as access to data and resources by farmers, which can help them improve their operations. They explain the system's components and how they work together. The difficulties of implementing such a system and the potential benefits to the agricultural sector are also discussed.

A system for improved supply chain transparency, security, and quality are presented in [39]. The goal was to develop a blockchain-based system for smart agriculture that uses the Internet of Things (IoT) to improve food supply chain transparency, security, and quality control. Sensors and other IoT components are used to collect data on various aspects of food production, such as weather conditions, soil moisture levels, and crop growth. The obtained information is used to track the progress of crops from farm to table and ensure that they meet safety and quality standards.

Blockchain technology is a distributed database that allows for secure, transparent, and tamperproof transactions [194]. Its potential uses are numerous, and it has the potential to impact a variety of industries, including agriculture, by providing a solution for intellectual property protection for IoT-based precision agriculture [48]. Software-defined networking (SDN) can help to alleviate this issue by providing a centralized method for managing and monitoring network traffic. SDN can help to prevent data theft and other attacks by identifying and blocking suspicious traffic. Another study [87] found that blockchain technology can efficiently trace agricultural products' origins and ensure food safety. The study also found that a blockchain-based traceability system can help to reduce fraudulent activities in the agriculture supply chain.

Another study [38] presents a comprehensive introduction to the dynamic and rapidly evolving world of digital agriculture. It discusses the history and origins of digital agriculture, the theoretical foundation of blockchain technology, and practical applications of this technology in the agricultural sector. The potential of digital agriculture to transform the food system is discussed. The authors of [158] discovered that blockchain technology could help to improve transparency and traceability in the food supply chain, which in turn can aid in food safety and quality control. The study examines the potential of using blockchain technology in sustainable e-agriculture to help reduce costs by simplifying supply chain management and lowering transaction costs. The authors of [105] look at the current state of research on blockchain and agricultural supply chains and future challenges that need to be addressed. Blockchain technology can be used to improve traceability and transparency in agricultural supply chains, resulting in a fairer and more efficient system. However, there are still many obstacles to overcome before this can be accomplished.

The authors of [41] discuss the potential of integrating blockchain technology and big-data analytics in agriculture. They claim that combining these two technologies can help create a more efficient and transparent food supply chain and improve food product traceability. They also highlight some of the obstacles that must be overcome to realize this potential, such as the need for standardization and interoperability among blockchain platforms. In [116], the authors state that blockchain and IoT technologies could potentially improve productivity and efficiency in the agriculture sector by enhancing food product transparency and traceability, improving supply chain management, and reducing wastage.

In developing countries, provisioning systems are still very limited. According to [191], incorporating blockchain technology into e-agriculture provisioning systems (EAPSs) can help ensure efficient, secure, and long-term agricultural resources and data management. Blockchain technology can also help reduce corruption and fraudulent behavior in EAPSs. The authors of [25] discuss how the IoT and blockchain can be used together in agriculture and the food supply chain. They explain how these technologies can help to improve transparency, traceability, and efficiency and highlight some of the challenges that need to be overcome for this to succeed. Big data and knowledge management can be decentralized. In [42], a directed acyclic graph data structure is used in a scheme that can be used to track the movement of resources, information, and money transparently and securely. Smart contracts can also be created, using the system to automate transactions between parties. A system for an IoT-based smart climate agriculture system that uses blockchain and edge computing is proposed in [45]. The system could be used to manage climate, weather, and agricultural production data. It employs a decentralized data management strategy to ensure more secure and efficient data management. The authors discuss the potential benefits of employing such a system in the agricultural sector.

The potential for blockchain technology to improve the fresh produce value chain by tracking food items from farm to table is discussed in [192]. The authors also note that several obstacles must be overcome before this technology can be adopted on a larger scale, such as the lack of standardization and the high cost of implementation. The main difficulties discussed in [59] include the lack of adoption of newer technologies in the agricultural sector, a lack of transparency and trust among parties involved in the agricultural process, and the high costs of blockchain technology. The authors of [117] examine the potential of blockchain technology to improve agricultural product supply chains. The study focuses on the use of BigchainDB for this purpose. It outlines its benefits for product supply chains, including the ability to provide a secure and open platform for data sharing and the capacity to facilitate trustless interactions between parties. The authors also discuss some of the difficulties associated with implementing such a solution, including the need for regulatory clarity and having to overcome technical obstacles.

A retrospective overview and analysis of blockchain technology and its applications in agriculture and logistics management are provided in [120]. The authors discuss the potential of blockchain technology to provide transparency and traceability in food supply chains, along with its ability to streamline processes and reduce costs. They also discuss some of the difficulties with implementing blockchain technology in agriculture, such as the need for standardization and interoperability and the lack of regulatory clarity. The potential of integrating blockchain technology and big-data analytics in agriculture is discussed in [41]. The authors claim that combining these two technologies can help create a more efficient and transparent food supply chain and improve food product traceability. They also highlight some of the obstacles that must be overcome to realize this potential, such as the need for standardization and interoperability among blockchain platforms.

The design of a decentralized architecture for sustainable agriculture based on blockchain is discussed in [50], with the aim of creating a decentralized marketplace for agricultural products and services, as well as access to data and resources by farmers that can help them improve their operations. They explain the system's components and how they will work together. The difficulties of implementing such a system and the potential benefits to the agricultural sector are also discussed. The authors of [25] discuss how IoT and blockchain can be used in agriculture and food supply chains. They explain how these technologies can help to improve supply chain transparency, traceability, and efficiency. Some of the obstacles that must be overcome for this to work are also highlighted.

A system using IoT to aid farmers and manufacturers in increasing their global market competitiveness is proposed in [70]. The system uses blockchain to provide a secure and transparent method for tracking the provenance of agricultural products from farm to table. The system can also help reduce supply chain fraud and counterfeiting. Blockchain and IoT can be used in agriculture and food supply chain management to improve interoperability between organizations, according to [91]. The authors note that these technologies can be used to track food items throughout the supply chain and provide transparency and accountability.

This section presents all the possible applications of blockchain technology currently being tested for the agriculture sector. The technology offers a secure and transparent way of tracking the movement of goods and recording transactions. This could help to reduce the chance of fraud and improve the efficiency of agricultural supply chains. In addition, blockchain technology could be used to create a secure land-ownership database, track crop history, and improve food safety.

3.9. Existing Case Studies

The following are some examples of blockchain applications in agriculture around the world. In India, KRanTi, a blockchain-based farmers' credit system for the agriculture and food supply chain, was developed to help small and marginal farmers in the country access credit more quickly [37]. Embedding blockchain across the 5G network to promote sustainable food security is demonstrated in [195]. Farmers use blockchain technology to reduce transaction costs and improve the efficiency of agricultural e-commerce in Jilin Province, China [164]. Another study [135] refers to the development of smart agriculture and its efficiency. Creating a trustless and transparent agricultural product trading environment is discussed in [168]. Another study [156] describes a system built in Russia to improve transaction transparency and efficiency and reduce costs in the complex agro-industry. A complete implementation of blockchain technology in agricultural and related industries in Turkey is presented in [175]. A thorough review of the recent literature on digitization in agriculture in Morocco is presented in [196]. The need to encourage clean-energy development through an innovative global ecosystem is discussed in [96].

4. Discussion: Benefits, Challenges, Limitations, Recommendations, and Prospects

This section discusses the survey findings and answers the research questions.

4.1. Benefits

Potential benefits for agriculture: On the blockchain, transactions are transparent, without the presence of an intermediary organization, such as a central bank. Blockchain changes the way trust is granted: users place their trust in cryptography and peer-to-peer validation instead of trusting authority. Blockchain technology tracks transactions among anonymous parties with assured immutability providing one of the best solutions for food quality and safety, promotes transparency among stakeholders, and facilitates reliability.

4.2. Challenges

Challenges: The supply chain challenge in agriculture is getting agricultural products from farmers to consumers. There is no immediate solution for products damaged during transport by implementing blockchain. Blockchain can help by providing a secure and transparent way to track the movement of agricultural products from farmers to consumers, but lacks the ability to determine falsification during initial data entry. Blockchain can also help to reduce the chance of fraud and corruption in the agricultural supply chain, but attacks by intruders, hackers, and viruses should be investigated with additional research. Blockchain can help solve food chain problems by providing a data store of continuous quality data and food movement from farm to table. Nevertheless, it has no adaptable solution to mitigate falsified data. Blockchain can help reduce the chances of food adulteration by continuously recording untampered processing data, but it lacks a technique to monitor and stop tampering in the early stage proactively. Implementation challenges: There are two types of implementation challenges, technical and technological, followed by adoption by other stakeholders.

4.2.1. Technical Challenges Include the Following:

(1) The agricultural sector has a set of uncaptured complex legacy rules with fragile connections among them that are hard to formulate in binary logic during blockchain adoption. (2) The agricultural supply chain is directly related to nature and unpredictability, making it very complex for attribute-based decision-making and causing reluctance to adopting blockchain. (3) Extra processes and compliance requirements for data management and issues related to data ownership and retention within the blockchain add to the overhead. (4) Interoperability issues and seamless data transfer across blockchain and legacy systems are still unsolved. (5) There are scalability issues with larger implementations and deployments. (6) There are financial issues with the enormous energy and financial cost of blockchain usage.

4.2.2. Challenges to Adoption Include the Following:

(1) Low-level technical knowledge of end users; (2) enormous transformation of associated applications and systems; (3) the heterogeneous composition of roles and business users; and (4) deployment obstacles and significant interoperability due to geographical distribution.

4.3. Limitations

Most of the studies are still in the early stages, their proof of concept (PoC) is based on earlier versions of blockchain, and the technology has changed much since its inception. Hence, the actual situation on the ground is not clear. Keeping all stakeholders updated with tech trends is a continuous process. The state of truth is still limited to transaction participants and optionally provides genuine information to the blockchain ledger. The cost of obtaining data for blockchain hinders its adoption, and the technology still requires further study and advancement to make it seamlessly interoperable with existing systems.

4.4. Perspectives

Regarding future prospects, researchers and developers should focus on making blockchain safer and more efficient. Additionally, they should aim to create pilot applications and platforms to expand the boundaries of DLT. The critical sections that require further investigation are safety, security, mature processes, legislation policies, integration, development, and deployment practice, AI and ML features, improved smart contracts, leverage of big data and data science, and management methodologies.

The influence of blockchain, particularly in the agricultural area, opens many opportunities for future research. The most motivating and valuable direction would be to correlate the well-known blockchain technology with a specific agriculture subdomain to better understand pilot-research projects that would benefit academics and practitioners.

Potential areas of blockchain-based solutions in the agriculture ecosystem include the following:

- Supply chain and market transparency;
- Traceability, quality, and food chain;
- Finance, payment, insurance, and e-commerce;
- Smart farming/agriculture/IoT;
- Recent reviews and surveys;
- Regional case studies;
- Dispersal of subsidies and grants.

5. Conclusions

Based on this study, blockchain technology is anticipated to have a significant impact on the agriculture domain and various allied verticals in the future. Blockchain has enormous potential to improve all aspects of agriculture: based on the cases presented in this survey, the trend can be seen in how effectively it has transformed the agriculture domain. Given the fast-paced advancement of blockchain, this investigation consolidates all previous studies. Researchers can use this survey as a quick starting point to investigate blockchain adoption in the vertical direction of interest in agriculture. This survey helps to shorten the research time by providing a detailed list of previous applications and research directions. The objective of investigating blockchain applications in agriculture and its verticals is met with a thorough enumeration of aspects of blockchain and agriculture. Across past research, the significant requirement of trust and transparency in the agriculture domain was easily achieved by relying on the integrity of blockchain, its tampering resistance, and its distributed nature. The core attributes of blockchain help to enhance and attain easy governance and management across the agriculture domain. Along with the benefits, a few challenges, such as implementation, integration, and maintenance, are common in all ecosystems, and blockchain is no exception. Future research could investigate the challenges and limitations and invent ways to mitigate them. Another direction foreseen as a future need could be comprehensive case studies on the impact of blockchain technology on agriculture to understand its practical adoption and ROI.

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