agriculture

*Review*

# Blockchain-Based Traceability for Agricultural Products: A Systematic Literature Review

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**Abstract:** In recent years, with the frequent crises of trust in the food industry, food safety issues have become an issue of particular concern to consumers. The traditional agricultural food logistics and transportation model can no longer guarantee the traceability of food safety information, and it is particularly important to establish an effective traceability system. Therefore, a traceability system is applied as a tool to assist in the assurance of food safety and quality, as well as to achieve consumer confidence. Blockchain is a new decentralized infrastructure and distributed computing paradigm that has gradually emerged. Blockchain has the characteristics of decentralization, immutable information and trustworthiness. When blockchain is applied to the traceability system of agricultural products, the quality of agricultural products will be well guaranteed. This article aims to provide a comprehensive review of the recent research efforts on traceability in agricultural products based on blockchain technology. First, the method of content analysis used in this article to sort out the papers is introduced. Second, the background concepts of blockchain and the key technologies are presented. Thirdly, the traceability applications based on blockchain technology for agricultural products are described in detail. Finally, we expand on the current trends and provide new perspectives pertaining to this exciting application of this field.

**Keywords:** blockchain; traceability; agriculture products; smart agriculture

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## 1. Introduction

Food safety is a crucial issue in today's world. Contaminated food can have severe impacts on public health and can even lead to fatalities. Additionally, it can adversely affect the economy and hinder overall economic growth [1,2]. According to the World Health Organization, 600 million illnesses and 42,000 deaths each year are attributed to unsafe food [3]. Unsafe foods that contain harmful bacteria, viruses, parasites or chemicals can cause more than 200 illnesses, from diarrhea to cancer. Each year, 30% of food-borne illness cases occur in children under the age of 5, killing an estimated 7000 children.

With the continuous progress of agricultural technology, the output of agricultural products is no longer the bottleneck of agricultural development, and marketable agricultural products need more safe and reliable quality assurance [4]. However, the intentional or unintentional violations of regulations during the production, processing, transportation and sales of agricultural products have led to many food safety problems. Examples of unsafe food include undercooked food of animal origin, fruit and vegetables contaminated with feces and raw shellfish containing marine biotoxins. Diarrheal pathogens are the leading cause of food-borne illness; the most common pathogens are norovirus, nontyphoidal Salmonella and Campylobacter, accounting for nearly 45% of all food-borne illnesses. During the last couple of decades, the credibility of the food industry was heavily challenged after a number of food crises, such as mad cow disease, dioxin in chicken feed and issues such as the use of genetically modified (GM) crops in foods [5,6]. As a consequence of the food scandals and incidents, customers call for high quality food with integrity, safety guarantees and transparency [6–9].

Governments have adopted regulatory measures to correct market inefficiencies and failures in ensuring the validity of agricultural product labeling information [6]. The mandatory traceability introduced in European Union (EU) Regulation 178/2002 is one of the most important means of ensuring and safeguarding the flow of information across the FOOD value chain in the EU [10]. In addition to mandatory traceability, there are several types of traceability systems that vary depending on the amount of traceability information, the stages of the value chain involved, the precision associated with product traceability, and so on [11]. Technology solutions such as radio frequency identification (RFID) technology, electronic identification and bar codes, smart packaging and equipment, deoxyribonucleic acid (DNA) testing and biosensors enable the management of tracking products to be more transparent and efficient and better optimize business processes, which benefit from timely, accurate, accessible, available and high-quality information [12,13]. However, the existing traceability systems do not guarantee a consistent flow of information along the agricultural product chain [6,7].

Blockchain is a distributed ledger technology that is widely used in areas such as cryptocurrencies, such as Bitcoin. Blockchain is a decentralized system that stores data in a network of multiple computer nodes, enabling decentralization, security and transparency of information [14]. The basic structure of a blockchain consists of "blocks" linked together in a "chain", shown in Figure 1. Each block contains a set of transaction data and includes the hash value of the previous block, creating a chain-like structure. Whenever a new transaction occurs, it is verified and added to a new block, which is then connected to the existing blockchain. The security of a blockchain is ensured through its decentralization and cryptographic algorithms. Since the data are distributed across multiple nodes, and each node maintains a complete copy of the ledger, no single entity can control or tamper with the information. Additionally, cryptographic techniques are used to protect the privacy and security of transactions. In addition to the cryptocurrency field, blockchain technology is widely applied in supply chain management, financial services, smart contracts, the Internet of Things (IoT) and other areas. By utilizing blockchain, decentralized, secure, and transparent methods of information exchange and data management can be achieved [6].

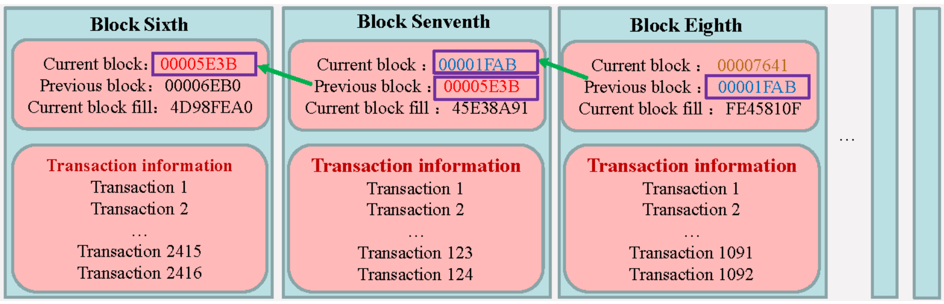


**Figure 1.** "Block" and "Chain" structure in blockchain.

The characteristics of the blockchain are as follows:

(1) **Decentralization:** In Blockchain, decentralization means that no single entity or organization has control over the network [15]. Instead, the network is maintained and governed by a community of participants. Therefore, the rights and obligations of any node are equal [16,17].

(2) **Transparency:** The data stored in the blockchain are transparent, and all network nodes on the blockchain can participate in the data maintenance of the blockchain [18]. This allows users of each node to query and proofread any data on the blockchain at any time, which increases convenience.

(3) **Anonymity:** The information of each block node does not need to be disclosed or verified, and the information transmission in the blockchain can be carried out anonymously. This helps to ensure that the privacy of each block node is not violated [19].

(4) **Tamper-Proof:** The information cannot be tampered with [20]. Since the data are added to the chain using cryptographic principles, and the next block contains the timestamp of the previous block, sorted in chronological order, the block chain can have the characteristics of being immutable or having a very high cost of tampering. Therefore, once the data are written to the blockchain, no one can easily change the data information without authorization. This is conducive to the guarantee of the authenticity of the data and improves the credibility of the system [21].

Based on the above characteristics, Blockchain technology is widely used in food safety, digital currency, financial transactions, data storage, etc. Among them, the food safety traceability, especially for agricultural products, is one of the important applications of blockchain [22,23]. Traceability refers to the ability to ensure the origin of a product or trace its history. The traceability system is a system that can ensure that the movement of products in the supply chain can be tracked and traced [24]. Blockchain technology can be applied to the agricultural supply chain to achieve end-to-end traceability [25]. Blockchain provides a permanent record for each transaction segment, which is grouped into separate blocks and cannot be tampered with [26]. Through the blockchain, all agricultural product information can be stored in a system that is shared and transparent to all members of the supply chain [27], instead of being stored in an opaque network system [28,29], which helps prevent the excessive use of chemicals and the use of uncertified chemicals in the production process [30]. Therefore, rapid response and efficient control of agricultural product quality problems are realized, and food safety and consumer health are ensured [31–33].

This paper aims to provide a comprehensive overview of the application research work of agricultural product traceability based on blockchain technology in recent years. This paper provides a panorama for readers to quickly understand and step into the field of blockchain technology and the application of blockchain-based technology in agricultural product safety. This survey has laid a foundation for promoting innovation in the field of agricultural product traceability blockchain technology and tapping the richness of this research field. This survey serves the researchers, practitioners and educators who are interested in blockchain technology for the traceability of agricultural products, with the hope that they will have a rough guideline when it comes to choosing the blockchain technology to solve the problem of the agricultural product safety overload at hand. To summarize, the key contributions of this survey are three-fold:

(1) A method of content analysis is proposed to sort out the literature and give the research process.

(2) An overview and summary for the state-of-the-art technology are proposed.

(3) We discuss the challenges and open issues and identify the new trends and future directions in this research field to share the vision and expand the horizons of blockchain technology research in the field of agricultural product safety.

## 2. Content Analysis Method and Research Process Design

Based on the above analysis of the applications of blockchain technology in the traceability of agricultural products, the content analysis method is employed to sort out the research and application of blockchain in agricultural product traceability.

### *2.1. Sample Extraction*

Generally speaking, compared with monographs, research reports and dissertations, journal articles can more acutely and directly reflect the research hotspots and frontiers.

**Paper collection:** Google Scholar is the most famous English search engine, and Baidu Scholar is the most famous Chinese search engine. Therefore, Google Scholar and Baidu Scholar are used as search engines for the initial paper screening. On the other hand, the Chinese database, CNKI (https://www.cnki.net/) (accessed on 24 August 2023), and English databases, such as Web of Science and IEEE Xplore, are adopted for further paper screening to discover more related papers. Through the search results, we find that the volume of the research papers is large. Due to the limited ability of manual analysis, according to Bradford's paper dispersion rule, most of the key papers are usually published in a few core journals. Therefore, Chinese papers are mainly limited to the papers in the Chinese Social Sciences Citation Index (CSSCI) journals and Chinese core journals. There are a large number of English papers in this field, and the representative important journals and conferences in the field of blockchain technology mainly include: IEEE International Conference on Blockchain (Blockchain); International Conference on Mainstreaming Blockchain Implementation (ICOMBI); International Conference on Big Data and Blockchain; International Conference on Computer Science and Its Application in Agriculture (ICOSICA); International Conference on Computer Engineering, Information Science and Application Technology; IEEE International Conference on Blockchain and Cryptocurrency (ICBC); International Conference on Global Security, Safety and Sustainability (ICGS3); Crypto; IACR Eurocrypto; USENIX Security; IEEE Access; Journal of the Science of Food and Agriculture; The Journal of the British Blockchain Association; Sustainability; Food Control; Future Generation Computer Systems; Artificial Intelligence in Agriculture; Future Generation Computer Systems; International Journal of Information Management and so on.

**Time interval:** From 2013 to 2023.

**Major search keywords:** The major search keywords are "blockchain", "agricultural product traceability", "agri-food traceability", "food safety", "blockchain food supply chain", "blockchain food", "blockchain food trust", "Hyperledger", "Bitcoin", "Ethereum", "smart contracts", " blockchain and fish", "blockchain and fruits", "blockchain and vegetables", " blockchain and egg", "blockchain and pork", "blockchain and tea", "blockchain and crop", etc. The above keywords basically cover all application scenarios of blockchain technology in the traceability of agricultural products.

**Determine the final research sample:** Is it related to blockchain technology and the traceability application of these technologies in agriculture? If relevant, include it in the research sample; otherwise, discard.

### *2.2. Content Analysis Coding*

This paper mainly uses the content analysis method to analyze the application of blockchain technology in agricultural traceability, which is on the basis of constructing content analysis coding. The content analysis is a research method that objectively and systematically describes the content to be studied. Furthermore, it is a scientific method that sees the essence through phenomena [34]. The paper mainly studies the technology and characteristics of blockchain, which then leads to its application in agricultural traceability. Therefore, it can be summarized into two target directions: one is the characteristics of blockchain technology and the other is how blockchain is applied in agricultural traceability. According to the research objectives of this paper, seven researchers discuss and set the analysis coding rule together.

**Basic information from the papers:** Title, author, year of publication, the journal name, technique used, applied model and the specific content of the model study.

**Research content analysis:** The analysis of blockchain solutions for traceability problems, comparison of different blockchain models, contrast traditional traceability systems with blockchain traceability systems, analysis of advantages and disadvantages of blockchain technology, and analysis of blockchain technology traceability application for agricultural products.

### *2.3. Research Steps*

**Step one:** According to the principle of sample extraction, the papers were extracted and screened, and then, 731 initial samples were obtained.

**Step two:** Is the paper related to the traceability of blockchain technology for agricultural products? If yes, it is classified into the statistical sample. Otherwise, it is discarded.

**Step three:** Identify the technologies used in the papers and their traceability scenarios in agricultural products. This step was performed independently by four researchers.

**Step four:** The preliminary identification results of the four researchers were combined, and the identification results, which were controversial, were discussed and determined by seven researchers.

**Step five:** The preliminary classification was performed by five researchers.

**Step six:** The controversial classifications were discussed and determined by seven researchers, and finally, the final research samples were obtained.

Based on the above content analysis method and research steps, the final sample papers are determined to be 161.

According to the design analysis above, the paper selection process is shown in Figure 2 [35,36].

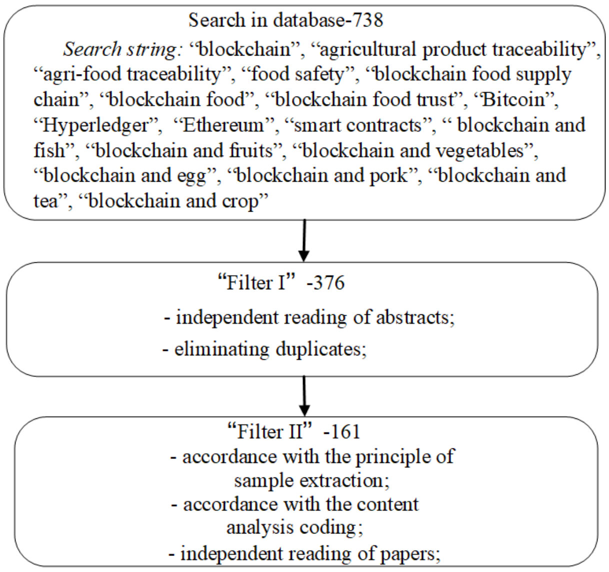


**Figure 2.** Paper selection process.

## 3. Key Issues in the Traceability of Agricultural Products

Traceability refers to tracing all processes from raw material procurement to production, consumption and disposal to identify "where, when and by whom the product was made". Once a problem occurs, the traceability system can respond quickly, obtain the whole process information, such as the production and distribution of the problem product; conduct investigation and location; determine the root cause of the problem; and then, solve the problem in a targeted manner. Aung and Chang [5] and Golan set three main goals for traceability, namely: (1) better supply chain management, (2) product differentiation and quality assurance and (3) better good for identifying non-compliant product offerings. Figure 3 shows the traceability process in food supply chains

The growing demand for commodity traceability has rapidly promoted the development of the traceability industry. However, the existing systems lack transparency and consumers' trust due to the unavailability of a fast and trustworthy way to retrieve information on the product's provenance [37]. Moreover,the existing traceability systems do not guarantee a consistent flow of information along the agricultural product chain [6,7]. Blockchain, as an emerging technology, provides a new way for traceability. Blockchain technology emerged in 2008 as a core component of the bitcoin cryptocurrency [38]. Blockchains provide transactional, distributed ledger functionality that can operate without the need for a centralized, trusted authority. Ledger recorded updates are immutable and cryptographic time stamping affords serial recording [39].

The development of traceability technology and blockchain technology has greatly improved the agricultural product traceability, but with the development of technology and the interaction with different social environments, many problems have arisen at the historic moment. For example, there are many doubts about the establishment of a decentralized system, and people are also very concerned about whether information has been tampered with, especially after the outbreak of the new coronavirus in 2020, and food safety is questioned. The application of blockchain technology in agriculture is also closely related to the current society and natural environment, and it also proposes solutions to current problems. When the credit of the central institution is questioned, the decentralized system established can solve the problem well [40]. In the blockchain system, each block is arranged linearly in chronological order, and the data in each block are open and transparent, which ensures that the information in it is not likely to be tampered with, and there is no mutual mistrust. It will not show up [41]. Through the blockchain technology, all food information can be stored in a shared and transparent system for all members of the supply chain, which helps prevent the illegal use of chemicals in the production process and ensures food safety [42,43]. Let us illustrate how blockchain can effectively prevent the excessive use of chemicals in the production process. (1) Transparency and traceability: Blockchain provides a decentralized, immutable ledger that can record and store information about the entire supply chain. By integrating this technology into the production process, it becomes possible to track the origin, movement and usage of chemicals from the raw materials stage to the final product. This transparency enhances accountability and allows stakeholders to verify the authenticity and compliance of the chemicals used. (2) Smart contracts and automation: Smart contracts can be implemented on the blockchain to establish predefined rules and conditions for the use of chemicals. These contracts can automate compliance checks, triggering alerts or even halting the production process if uncertified or excessive amounts of chemicals are detected. This reduces the reliance on manual checks and streamlines the monitoring and control of chemical usage. (3) Certification and verification: Blockchain can be utilized to create a trusted system for certifying and verifying the authenticity of chemicals. Certificates and audit reports can be stored on the blockchain, making them easily accessible and tamper-proof. This ensures that only certified chemicals meeting the required standards are used in the production process. (4) Data sharing and collaboration: Blockchain enables secure and efficient sharing of data between relevant parties in the supply chain, including manufacturers, suppliers, regulators and consumers. This sharing of information facilitates collaboration, enabling real-time monitoring, quick identification of potential issues and prompt action to prevent the excessive or unauthorized use of chemicals.

The application of blockchain technology for food safety is consistent with the purpose of "promoting the application of blockchain technology in food safety supervision" launched by the Chinese central government. The global outbreak of the new coronavirus that began in early 2020 has greatly affected global agriculture. On the one hand, the new crown epidemic has slowed the transportation of agricultural products, and agricultural products with too long transportation intervals may lose their transportation records [44]. On the other hand, the public may be worried about the safety of food transported from high-risk areas, because the detection results of harmful substances such as bacteria and viruses attached to the food are difficult to make public [45,46]. The agricultural traceability system based on blockchain technology can solve the above problems well. The traceability system can accurately trace the steps of agricultural products from the beginning of production, and the transportation data will not be lost when stored in the cloud database [47]. Under the influence of the epidemic, if products are to be safely disinfected during transportation, the blockchain-based traceability system can also accurately find the location of disinfection to ensure the quality and safety of agricultural products [48]. Table 1 summarizes existing blockchain-based solutions to traceability problems.

In the supply chain, for example, the use of blockchain technology, through its unique, non-tamperable distributed ledger recording characteristics combined with technologies such as the Internet of Things (IoT), realizes the entire record of the product from the source to the final consumer, including the source of raw materials and production process, processing links, warehousing information, inspection batches and logistics turnover, to third-party quality inspection, customs entry and exit, anti-counterfeiting verification and the entire process can be traced to consumers. On the other hand, on the issue of trust, the blockchain uses technical means such as time stamps and consensus mechanisms to realize the functions of non-tampering and the traceability of data and provide technical support for the establishment of a cross-institution traceability system. At the same time, third-party supervision agencies and consumers are included in the supervision system, breaking the information island, providing information support, and achieving transparency in the production process to a certain extent.

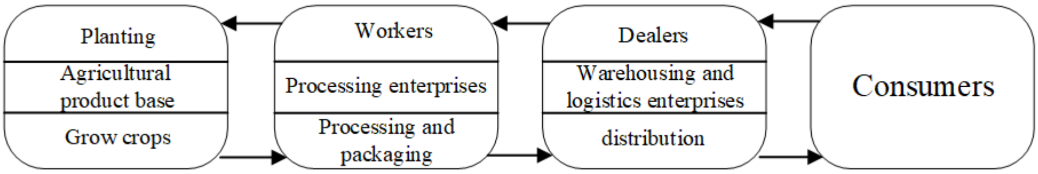


**Figure 3.** Traceability process in food supply chains.

**Table 1.** Blockchain solutions to traceability problems.

| Problem | Solution | Reference |
|---|---|---|
| How can we set up a system of honesty without a central authority? | Chronological distributed databases are used by blockchain where blocks are linked to each other in a proper linear manner, and it is impossible to be deleted. | [49] [50] [51] |
| How to prevent agricultural data from being tampered with in this information age? | A newly added block can not be deleted, and it will become a permanent record that can be accessed and verified by everyone on the network. | [49] [52] [53] |
| How can we coordinate our system with policies? | In order to adapt more widely, our distributed system is based on important international traceability system standards, Regulation (EC) No 178/2002. In a specific country or region, our system rules can be adjusted to suit local policies. | [49] [54] |
| Why it is important to build the system under the decline of agri-economy circumstances because of COVID-19? | During critical emergency periods, it can make unseen products traceable and produce products of high quality. It is an approach in disease warning. | [55] [39] |

## 4. Key Technology of Blockchain in the Traceability of Agricultural Products

### *4.1. Three Mainstream Platforms of Blockchain*

The blockchain system includes three mainstream platforms: Bitcoin [38], Ethereum [56] and Hyperledger [57]. Table 2 give the comparison of the mainstream platforms. Note: POA: proof of authority, POET: proof of elapsed time.

**Table 2.** Comparison of mainstream platform.

| Platform | Access Mechanism | Consensus Algorithm | Advantage | Disadvantage | Application | Reference |
|---|---|---|---|---|---|---|
| Bitcoin | Public | • POW | • Decentralization<br>• Dynamic<br>• High scalability, supporting more than 100,000 nodes consensus. | • Consume a lot of computing power and electricity.<br>• 51% attack.<br>• Low scalability.<br>• Low throughput.<br>• High latency. | • Tracking of carbon footprint on food production.<br>• Food Safety Systems.<br>• Food Supply Chain | [58]<br>[59]<br>[60] |
| Ethereum | Public | • Hybrid mode of PoA and PoS.<br>• PoW's improved algorithm Ethash.<br>• PoS's improved algorithm Casper. | • The Ethash algorithm largely resists the PoW computing power concentration problem.<br>• Turing-complete smart contracts | • Underscalability<br>• Fewer nodes than Bitcoin | • Organic food supply chain.<br>• Agri-food supply chain.<br>• Supply chain product origin tracking.<br>• Food traceability | [30]<br>[61]<br>[62]<br>[63] |
| Hyperledger | • Consortium | • POET<br>• PBFT | • Tamper proof<br>• Efficient risk management<br>• Energy saving<br>• High scalability<br>• Confidential transaction<br>• Access control<br>• Programmable<br>• Pluggable<br>• Data sharing and privacy protection | | • Food distribution<br>• Smart Agriculture<br>• Supply chain management | [49]<br>[64]<br>[65] |

**Bitcoin:** Bitcoin technology is a distributed ledger that records Bitcoin transactions, and Bitcoin is the most successful blockchain application.

**Ethereum:** Ethereum is an open source public chain platform with smart contract function, and Ethereum is the most widely used platform in public blockchains, which everyone can participate in, and everyone can develop smart contracts. Compared with Bitcoin, the biggest feature of Ethereum is the introduction of the smart contract and programmable underlying layer, which enables people to develop blockchain applications for various purposes based on its architecture.

**Hyperledger:** Hyperledger, including Hyperledger Fabric and Hyperledger Sawtooth, is an open source project initiated by the Linux Foundation. Hyperledger Fabric is the most widely used platform in consortium blockchains and and Hyperledger Sawtooth is a modular platform for building, deploying and running distributed ledgers. Hyperledger provides an open source business alliance chain framework, which aims to provide the foundation for the development of blockchain applications and help enterprises to build enterprise-class blockchain solutions more easily [66,67].

Both Ethereum and Hyperledger hold two types of data: permanent and transient. Perpetual data are a transaction. Once a transaction is confirmed, it is recorded on the blockchain and can never be changed again.Temporary data are the state of the world. The world's state is the current state of all accounts. When an account initiates a transaction, the account balance changes. The world's state is stored in a key-value database. Ethereum has high reliability but no privacy. If one wants to have privacy, one needs to work out how to encrypt it oneself, and a Hyperledger can support privacy by sacrificing reliability.

### *4.2. Other Platforms of Blockchain*

**Ripple:** Ripple is the world's first open payment network [68] and focuses on a currency exchange system for global payment solutions.

**XuperChain:** Baidu Super Chain (XuperChain) [69,70] technology is a blockchain technology for which Baidu holds completely independent intellectual property rights. XuperChain is a blockchain 3.0 solution that Baidu plans to open source with powerful network throughput and high-concurrency general smart contract processing capabilities. Based on the pluggable consensus mechanism, directed acyclic graph (DAG) parallel computing network and three-dimensional network, XuperChain truly breaks through the technical bottleneck of the current blockchain and paves the way for the wide application of the blockchain. In addition, XuperChain is most likely to be compatible with the Bitcoin and Ethereum ecology, is friendly to blockchain developers and has a low migration threshold. The global deployment of XuperChain is the foundation of XuperChain's credibility. Super nodes with strong performance participate in the competition for bookkeeping rights to ensure the efficiency of the entire network operation. However, other lightweight nodes act as supervisory nodes to monitor the performance of the super nodes, therefore, forming a more credible and autonomous blockchain operation system.

**Corda:** Corda [71,72] is a blockchain project designed for commercial purposes that allows users to perform blockchain operations in a relatively private environment, and its smart contracts can help commercial organizations directly exchange value.

**TrustSQL:** TrustSQL [73] is a Tencent Trusted Blockchain, dedicated to providing enterprise-level blockchain infrastructure, industry solutions and providing safe, reliable and flexible blockchain cloud services. On the other hand, TrustSQL provides a one-stop overall solution for the construction of blockchain industry applications for cooperative enterprises and helps cooperative enterprises to go faster and farther in the new blockchain field.

**Antchain:** Antchain [73,74] is a blockchain technology platform with high performance and strong privacy protection independently developed by Ant Group. Antchain is committed to creating a one-stop application development platform and services, helping customers and partners quickly and easily build blockchain applications in various business scenarios and promoting the development of the real economy.

### *4.3. Node Access Chain Mechanism: Permissionless Blockchain and Permissioned Blockchain*

According to the node access chain mechanism, a blockchain system can be categorized as either permissionless blockchain or permissioned blockchain [75,76]. Table 3 shows the comparison between permissionless and permissioned blockchain.

**Permissionless blockchain:** In the permissionless blockchain system, there is no license authority to check the identity of nodes, and nodes can arbitrarily join or exit the system in an anonymous form. Therefore, the permissionless blockchain is also called public blockchain. Based on this open nature, the scale of the public blockchain system is usually large, and the consensus nodes can even reach tens of thousands. The public chain is completely decentralized [77,78], and security is maintained by means of proof-of-work (PoW) or proof-of-stake (POS) mechanisms. They exist in the form of a combination of financial rewards and cryptographic digital verification and follow the principle that the financial reward for each individual is proportional to his contribution to the consensus process. The barriers to entry are low; any node can join and leave the system. The users are protected from developers, and all of the data are open, transparent and almost impossible to tamper with. Bitcoin and Ethereum are public chains.

**Permissioned blockchain:** The nodes in the permissioned blockchain system need to go through the admission review of the central organization, and then they can join the system after being authorized. Therefore, the scale of the permissioned blockchain system is often small, and the number of nodes is usually tens to hundreds [79]. According to different application scenarios, the permissioned blockchain is divided into consortium blockchain and private blockchain [75,80]. The consortium chain is usually composed of several different institutions with the same industry background. The consensus nodes come from various institutions within the alliance, and the blockchain data are shared within the alliance [81,82]. Nodes can only join the alliance network after authorization and only open all or part of the functions to the members of the alliance. Some nodes are designated as bookkeepers in advance. The generation of each block is decided jointly by all bookkeepers. Other nodes can trade but have no bookkeeping rights. It improves the efficiency of settlement and clearing, almost does not need manual participation and can also reduce the cost of settlement and clearing. Hyperledger is an alliance chain (consortium). Private chains are typically deployed within a single organization, and consensus nodes come from within the organization, similar to traditional distributed data clusters.

**Table 3.** Comparison between permissionless and permissioned blockchain.

| Context | Permissionless Blockchain | Permissioned Blockchain |
|---|---|---|
| Application scenarios | Public blockchain | Consortium chain, private blockchain |
| Access mechanism | Free access | Review access |
| Network size | Large | Small |
| Throughput | Low | High |
| Consistency | Probabilistic (weak) consistency | Determine (strong) consistency |

### 4.4. Consensus Algorithm

The consensus algorithms in blockchain are the mechanisms used to achieve agreement or consensus among multiple nodes in a decentralized network [83,84]. They ensure that all participants in the network agree on the validity and order of transactions recorded on the blockchain. Here are a few commonly used consensus algorithms:

**Proof-of-Work (PoW):** POW is a countermeasure against service and resource abuse or denial of service attacks [85,86]. Generally, users are required to perform some time-consuming and appropriate complex calculations, and the answers can be quickly verified by other users. POW uses time, equipment and energy as a guaranteed cost to ensure that services and resources are used by real needs.

Pros: PoW is characterized by high security, and damage to the system requires a huge cost [87].

Cons: (1) Waste of resources: A large number of hash operations will cause a great waste of power and computing resources. (2) Low network performance: It is not suitable for commercial application because of the speed of 7 transactions per second [88].

**Proof of Stake (PoS):** POS is similar to the shareholder mechanism in real life. In a PoS consensus algorithm, validators are chosen to create new blocks based on the amount of cryptocurrency they hold and their "stake" in the network [89,90].

Pros: (1) Resource saving [91]: PoS eliminates the need for high computational power and energy consumption, making it more environmentally friendly. PoS was first proposed in 2013 and was first implemented in the Peercoin system. (2) Avoid inflation [92]: PoS revenue rewards mainly come from user transactions.

Cons: Low credit: The credit base of PoS cryptocurrency is not solid enough.

**Delegated Proof of Stake (DPoS):** DPoS [93] is similar to PoS but introduces a delegated mechanism. The token holders vote for delegates who represent them in block production. These delegates take turns in generating blocks, and stakeholders can replace them through voting if they fail to perform their duties.

Pros: (1) DPoS coins are much more scalable than POW cryptocurrencies as they never start requiring high computing power and are generally approachable for users with poor equipment. (2) DPoS blockchains showed themselves to be faster than PoW and PoS-based blockchains. (3) DPoS coins are more democratic and inclusive than their alternatives. DPoS vs. PoS offers more governance power to users with small stakes, DPoS vs. PoW does not require as much computing power and, therefore, is not so financially demanding on the user. (4) As the threshold to enter is very low, DPoS is largely considered to be the most decentralized approach to the consensus mechanism. (5) DPoS is energy efficient and environmentally friendly [94]. (6) DPoS networks have strong protection from double spend attacks.

Cons: (1) The successful existence of the network requires the participation and coordination of a genuinely interested community for the effective governance of the panel of witnesses by voting them in and out. (2) DPoS systems are vulnerable to centralization as the number of witnesses is strictly limited. (3) DPoS blockchain is exposed to the flaws of classic real-life voting. For example, DPoS users with small stakes can decide that their vote does not matter in comparison with the votes of bigger stakeholders.

**Practical Byzantine FaultTolerance (PBFT):** PBFT [95,96] is a consensus algorithm designed for permissioned blockchains. It requires a predetermined set of nodes known as validators who take turns being the leader to propose blocks. Validators reach consensus through a multi-round voting process. PBFT is known for its fast finality and is used in platforms such as Hyperledger Fabric.

Pros: (1) The state machine copy replication protocol is proposed for the first time in an asynchronous network environment. The algorithm can work in an asynchronous environment and improve the response performance by more than one order of magnitude on the basis of the earlier algorithm through optimization. (2) Encryption is used to prevent spoofing and replay attacks, as well as detect corrupted messages.

Cons: (1) PBFT only applies to permissioned systems. (2) The communication complexity is too high and scalability is relatively low. (3) The delay is high when the network is unstable.

Table 4 shows the consensus algorithm in an agricultural products traceability scenario.

**Table 4.** The consensus algorithm in agricultural products traceability scenario.

| Consensus Algorithm | Goal | Method | Reference |
|---|---|---|---|
| PoW | • Solve the problem of food safety traceability in college canteens to ensure the safety of students and teachers. | Through the process of collecting information, generating transactions, PoW consensus mechanism processing and query feedback, the source of food can be traced through the blockchain, hidden food safety hazards can be found in time, and the traceability efficiency is improved. | [97] |
| PoS | • To meet the needs of food traceability and blockchain lightweight deployment, taking into account both efficiency and accuracy. | Integrating a novel deployment of blockchain, IoT technology and fuzzy logic into a comprehensive traceability shelf life management system for managing perishable food. The traceability system uses PoS for consensus and evaluates the share of supply chain stakeholders by considering responsible shipping time, stakeholder analysis, and active shipments. | [98] |
| DPoS | • Improving traceability and transparency in the food supply chain. | A novel BIOT [1]-based hierarchical framework using EOSIO [2] is proposed for efficient food traceability. The EOSIO blockchain adopts the DPoS consensus mechanism to improve system efficiency. | [99] |
| PBFT | • Solve the issues of centralization, data tampering and high communication cost in traditional supply chain traceability. | A permissioned blockchain-based food traceability framework is proposed. The proposed framework is decentralized, and the supply chain data of the framework cannot be tampered with. The adopted PBFT consensus algorithm improves the performance of processing transactions. | [100] |
| RBFT [3] | • Realize accurate identification and improve the robustness of the system. | Combining blockchain technology and wireless network technology to build a blockchain platform, using the RBFT consensus mechanism to achieve "accurate identification" of the poor. | [101] |
| PoA [4] | • The immutability and security of data, the low cost in making the transactions, and so on. | A method of building a supply chain management system for tracking the origin of agricultural products based on blockchain technology is proposed. The supply chain model uses PoA to implement the consensus algorithm. | [62] |
| PoTx [5] | • Achieve scalability with reduced communication overhead and computation power. | A blockchain system with user identification and an access control mechanism is proposed to fill the gap of each supply chain participant. Furthermore, a novel PoTx consensus algorithm is proposed, which selects a random validator from the consensus group based on the transaction count to enhance the fault tolerance of the system. | [102] |

1. BIOT: Blockchain and the Internet of Things. 2. EOSIO [103]. 3. RBFT: combination of the Raft algorithm and the PBFT algorithm. 4. PoA: Proof of Authority. 5. PoTx: Proof of Transaction.

### 4.5. Smart Contract

A smart contract is a digital protocol that uses algorithms and programs to write contract terms, deploy them on a blockchain and execute them automatically according to rules [104]. Smart contracts allow trusted transactions without third parties, which are traceable and irreversible, with the aim of providing security guarantees superior to the traditional contract methods and reducing other transaction costs associated with contracts [105–107]. Blockchain enables decentralized storage, and smart contracts enable decentralized computing on top of that.

To sum up, smart contracts have the following advantages over traditional contracts:

• **Automation:** Smart contracts are self-executing and operate based on predefined conditions. They eliminate the need for intermediaries or third parties, such as lawyers or banks, to enforce the terms of the contract. This automation streamlines the execution process, reduces costs and eliminates the possibility of human error.

• **Transparency:** Smart contracts are built on blockchain technology, which ensures transparency and immutability. All contract terms and actions taken are recorded on the blockchain, providing a transparent and auditable trail of activities. This transparency helps to build trust and reduces the potential for fraud or manipulation.

• **Efficiency:** Smart contracts streamline the contract management process by automating tasks such as verification, execution and enforcement. This increases operational efficiency and reduces the time it takes to execute a contract. Additionally, smart contracts can handle complex calculations and updates in real-time, eliminating the need for manual intervention. On the other hand, smart contracts can be executed instantly as long as the predefined conditions are met. This eliminates the need for lengthy negotiation periods and manual processing. Additionally, smart contracts are not bound by geographical limitations, making them accessible to anyone with an internet connection [107].

• **Security:** Smart contracts use cryptographic techniques to provide a high level of security. Once a smart contract is deployed on a blockchain, it becomes nearly impossible to alter or tamper with its contents. This ensures the integrity and security of the contract, reducing the risk of fraud or unauthorized modifications.

• **Cost savings:** By eliminating intermediaries and automating contract processes, smart contracts significantly reduce the costs associated with traditional contract management. Users can save on legal fees, enforcement costs and operational inefficiencies, resulting in overall cost savings [106].

Overall, smart contracts offer increased efficiency, transparency, security and cost savings compared to conventional contracts. Their automation capabilities and integration with blockchain technology have the potential to revolutionize contract management in various industries [108]. Table 5 shows the smart contracts in an agricultural product traceability scenario.

**Table 5.** The smart contract in an agricultural product traceability scenario.

| Goal | Method | Advantage | Reference |
| --- | --- | --- | --- |
| • To achieve the traceability and sharing of the workflow of the food supply chain, break the information islands between enterprises, eliminate the need for central agencies and institutions and improve the reliability and security of integrity transaction records. | A framework for tracking and executing transactions utilizing Hyperledger smart contracts is proposed. Farmers record details of the environment and crop growth data in the interplanetary file system (IPFS), and store the file IPFS hash value in the smart contract. | Transparency<br>Security | [109] |

**Table 5.** *Cont.*

| Goal | Method | Advantage | Reference |
|---|---|---|---|
| • Eliminate the need for trusted centralized agencies and intermediaries in food supply chain traceability and provide transaction records to improve efficiency and security with a high degree of integrity, reliability and security. | The proposed solution utilizes smart contracts to manage and control all interactions and transactions between all participants in the supply chain ecosystem. All transactions are recorded and stored on the blockchain's immutable ledger, linked to a decentralized file system (IPFS). | Reliability<br>Efficient<br>Security | [110] |
| • The smart contracts that govern the system and the user interface to interact with them are automatically generated, resulting in a system that works semi-automatically. | A new approach is proposed to easily customize and write Ethereum-based general-purpose smart contracts designed for the agri-food industry sector, capable of reusing code and modules and automating processes to reduce development time while remaining secure and reliable. | Automation<br>Cost savings<br>Security<br>Efficiency | [111] |

### *4.6. Applications of Quick Response (QR) Code in Traceability of Agricultural Products*

As the saying goes, "Food is the most important thing for the people", and agricultural products are becoming more and more important in people's lives. With the improvement in quality of life and health awareness, consumers are paying more and more attention to the quality and safety of agricultural products. However, the process from production to sales of agricultural products is complex and involves many links. Making the public conveniently query the relevant information for agricultural products, and use the quick response (QR) code on a mobile phone to scan and query the identification label, is simple and easy. A two-dimensional code can store and express information in both horizontal and vertical dimensions at the same time. It has the advantages of low printing and trial reading cost, high information security and high recognition accuracy [112]. When scanning by QR code [113], the matching of traceable data and uplink data is realized, which ensures that the generated product is one code by one. When it is made into a label and pasted on the outer packaging of agricultural products, consumers can query the planting, production, processing, logistics, sales and other information concerning agricultural products anytime and anywhere by scanning the code from the wechat e-commerce platform [55,112]. Furthermore, timely feedback concerning false information or wrong information is possible [114]. For example, in the planting information, the QR code can contain information on product origin, sowing and seedling raising, fertilization, irrigation, drug control of diseases and pests, harvesting time and so on, as shown in Figure 4. It can informationize the production process of agricultural products, establish an "electronic file" for each agricultural product, record the whole process of their production and store the recorded information in the data of the traceability management system. The library [114] is convenient for future inquiry. At the same time, encryption technology can be used to encrypt the information through the private key to generate two-dimensional code labels for each batch of qualified agricultural products [49]. The products that have not been inspected or fail to pass the inspection can not generate a two-dimensional code, and the two-dimensional code label for agricultural product traceability can not be used. During the sales process, consumers can use the QR code identification system in their smartphones [50]. If consumers can understand the product code, producer, production date, traceability management system website and other information more clearly and in detail, they can use electronic files to verify that products are electronically documented. Agricultural products will be displayed to consumers at a glance, truly "buying with confidence, eating with confidence" [115]. The application of the QR code in the traceability system of agricultural products is of great significance for the construction of the traceability system of agricultural products and provides a low-cost and high-efficiency promotion scheme for local characteristic agricultural products. The traceability system of agricultural products [49,52], carries out "electronic" management for the whole process of production records for agricultural products and establishes transparent "identity files" for agricultural products. The purchasers and consumers can quickly query relevant production information by using mobile phone two-dimensional codes so as to realize "root tracing", meet consumers' right to know, and purchase and consume at ease. At the same time, through this move, it can improve the producers' sense of scientific production self-discipline, enhance the brand of agricultural products and better promote the circulation and sales of high-quality agricultural products, which has a good application prospect and high promotion value [55,116].

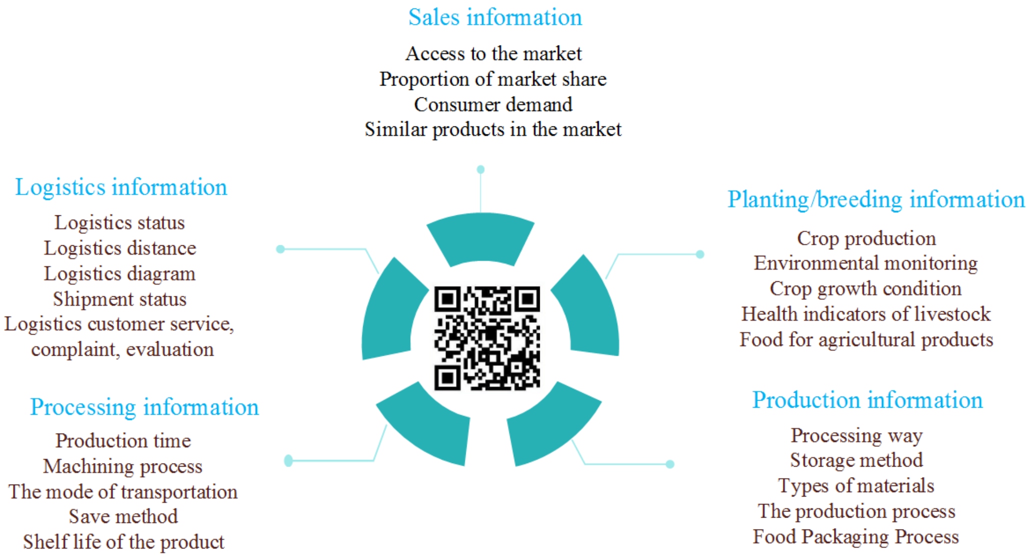


**Figure 4.** Function of the quick response code.

*4.7. Comparison of Traditional Traceability System and Blockchain Traceability System*

With the globalization of trade, the supply chain of agricultural products has become more and more complex, and it has become more and more difficult to track objects through its complex network. Traditional traceability systems do not guarantee a consistent flow of information along the agricultural product chain [6,7]. Table 6 shows the comparison of the traditional traceability system and blockchain traceability system.

**Table 6.** Contrast traditional traceability systems with blockchain traceability systems.

| Context | Traditional Traceability System | Traceability System Based On Blockchain |
|---|---|---|
| Database operations | Can create, read, update and delete. | Can not update and delete. |
| Data storage | Single server storage. | Distributed storage. |
| Tamper-proof data | Data is easily tampered with. | Data tampering is expensive. |
| Consensus mechanism | Unnecessary. | Required. |
| Trust | Based on the trust of the food industry and its brand. | People who do not know each other can be trusted. |
| Speed and efficiency | Depend on the performance of the database and server. | Subject to consensus algorithms. |
| Interoperability | Low | High |

Based on the analysis in Table 6, compared with traditional traceability technology, blockchain-based traceability technology is more suitable for storing food data [117]. The specific reasons are as follows:

**Database operations:** Traditional databases have operations such as create, read, update and delete, while blockchain databases do not have update and delete operations [7]. In blockchain, no update operation means that as long as the data are recorded in the database, they cannot be modified, and no delete operation means that the data uploaded to the library cannot be erased. Therefore, the blockchain database fundamentally determines the openness, transparency, irreversibility and tamper resistance of the traceable data information [118], which cannot be achieved by traditional relational databases.

**Data storage:** The blockchain is a distributed storage of data, and the data are stored on all nodes of the decentralized system at the same time. Even if some nodes fail, as long as there is still a normal operating node, the blockchain main chain data can be completely restored without affecting the recording and updating of subsequent block data. Therefore, the problem of data loss can be solved. The traditional traceability system is a centralized storage of data. When the server fails, the data are extremely easy to damage or lose. Therefore, the data are easily lost.

**Tamper-proof data:** Blockchain has the characteristic that data cannot be tampered with, which is derived from the data structure and consensus mechanism of blockchain [119]. Blocks between blockchains are linked together using cryptography algorithms such as Hash, Merkle Tree, SHA256, elliptic curve cryptography (ECC), etc. Therefore, when the main chain is long enough, if you want to add, delete and modify the data of one of the blocks, you need to prove all the blocks after the modified block from cryptography. If the tampered block is at the front of the main chain, the cost of tampering with the data is much higher than the profit after tampering. The single characteristic of traditional traceability data storage determines the nature of its data that are easy to tamper with.

**Consensus mechanism:** The distribution of bookkeeping rights is determined by the consensus mechanism. To ensure data synchronization between nodes and ledger consistency, only one person is allowed to keep records at a time. The traditional traceability system does not require a consensus mechanism, and a small number of official personnel are responsible for uploading data.

**Trust:** Blockchain solves complex trust issues through smart contracts and consensus mechanisms, enabling individuals or institutions that do not know each other to reach a consensus. In the traditional traceability system, people can only trust the food industry and its brands unilaterally [120,121].

**Efficiency:** Blockchain requires identity verification and a consensus algorithm, and the specific efficiency depends on the pros and cons of the algorithm. The efficiency of the traditional traceability system depends on the performance of the database and server.

**Interoperability:** Interoperability is for the exchange of information between various systems, and blockchain is a distributed system with good interoperability. The current interoperability of the traditional traceability systems is quite low.

All in all, the use of blockchain technology for traceability can well make up for the traditional traceability system's shirking of responsibilities, tampering with account books, accountability, private exploitation of loopholes and loss of information. Therefore, in the food supply, a blockchain-based traceability system has proven to be a better choice [122,123].

## 5. Applications of Blockchain in the Traceability of Agricultural Products

According to the report presented by the Deloitte [124], 51% of the consumers are willing to pay more for healthy and safe food, and this percentage continues to grow [124,125]. Consumers demand the traceability that can be verified as an essential aspect of safety and quality. In order to meet this demand, a system that can provide information on the source and life cycle of commodities is needed [5]. On the other hand, in recent years, with the commercialization of precision agriculture technology, people have become increasingly interested in agricultural data. As we all know, agricultural data are messy, especially data from joint yield monitors. Analysts are concerned about the validity of the data, especially considering that others may affect the data quality at various steps in the data path [126]. Moreover, managing huge data sets encounters several challenges, mainly related to incomplete, unstructured and inaccurate data. To that end, blockchain technology, a decentralized ledger that facilitates block-encrypted data transactions, has attracted more and more academic and commercial interest because it can verify, audit and transmit the confidentiality of data and information [127]. Table 7 shows the traceability application of blockchain technology in different agricultural products. Table 8 shows that some companies or regions have applied the blockchain technology to agricultural products and integrated them into real life.

### 5.1. Fish

Seafood is one of the most valuable food-based primary industries. However, the fishery has not been well regulated. More than 30% of the world's fish resources are overfished [128]. Meanwhile, since the key certificate of origin and temperature records are not completely visible to consumers, it is difficult to evaluate the quality of seafood in practice. Therefore, due to the lack of reliable food and quality tracking information, it is difficult to accurately evaluate the quality of fish in practice [129]. Blockchain technology is now being used to improve tuna traceability to help stop illegal and unsustainable fishing practices in the Pacific Island tuna industry, a major development for global fisheries [130]. Working with the Sydney Fish Market (SFM), the authors developed a blockchain-enabled fish provenance and quality tracking (BeFAQT) system [129]. A multi-layer blockchain architecture based on attribute-based encryption (ABE) is proposed to solve the privacy problems caused by the application of blockchain encryption in the fish supply chain and realize the sharing of trusted and confidential data among the parties of the supply chain. Field trials show that BeFAQT can provide trusted and comprehensive fish provenance and quality tracking information in real time. In [131], the authors were set to explore how blockchain technology could improve supply chain visibility. The exploratory research was conducted through semi-structured interviews with actors and blockchain experts in the fish farming industry. The main conclusion to be drawn from the results is that blockchain can increase the business value by leveraging the usefulness of information to enhance industry visibility and improve operational efficiency through better prediction and planning through data analysis. An assessment for blockchain technology in the supply chain setting is created and later is expanded to a more general environment. Therefore, the assessment of blockchain technology is useful for companies or individuals who plan to use blockchain in the future or want to better understand blockchain technology [132]. Digital technologies such as blockchain can help achieve certain Sustainable Development Goals related to livelihoods, food security and the environment by identifying problems in real time and implementing interventions [127]. The research takes the Thai fishery as the background and studies the design of a blockchain-centric food supply chain to promote Sustainable Development Goals. The main findings indicate that there is data asymmetry in the supply chain, which can achieve the Sustainable Development Goals. A blockchain-based fish farm platform to ensure the integrity of agricultural data is proposed [126]. The platform is designed to provide safe storage for fish farmers to preserve large amounts of agricultural data that cannot be tampered with. The various processes of the fish farm are automatically executed through smart contracts to reduce the risk of error or manipulation. To explore the effect of blockchain technology (BCT) adoption in the context of multi-tiered supply chains (SC), Tokkozhina et al. [133] examine the practical adoption of BCT in a multi-tiered supply chain for frozen fish products in Portugal. A mixed approach of qualitative and quantitative data collection was used. Three semi-structured interviews were conducted with participants from a single frozen fish SC, including suppliers, transporters and retailers. The results showed that consumers were more likely to buy fish with traceability information. In order to effectively trace and manage products in the fishery supply chain, a private Ethereum blockchain-based solution is proposed [134]. The solution effectively manages fishery supply chain operations in a decentralized, transparent, traceable, secure, private and trustworthy manner. Furthermore, the solution architecture and five smart contracts to automate the processes in fishery supply chain are presented. A security analysis is performed to show that the proposed solution is both secure and trustworthy.

### 5.2. Fruits

The fruit retail sector faces a massive problem with the reduction of contaminated food. Almost one out of ten people worldwide fall ill every year after consuming contaminated food, and this is increasing dramatically. Therefore, a blockchain-based retail fruit chain is needed to secure the food supply for society, both in-country and globally [135]. Based on this fact, agricultural product traceability requires a technology that bridges the flow of information across the supply chain and potentially ensures traceability for end consumers. Shevchuk et al. take the pineapple supply chain as an example for study in order to narrow down the scope [125]. The analysis results show that blockchain technology can be used as a perspective tool for pineapple supply chain traceability. In order to study and discuss blockchain technology and its application in the retail market, Sharif et al., employ a cross-sectional approach and the unified theory of acceptance and use of technology (UTAUT2) by adding trust as an independent variable [135]. The study provides insight into the Malaysian fruit retail environment from different perspectives, not only in terms of business processes and competition but also in terms of cooperation between retailers and customers. It concludes that the Malaysian retail industry urgently needs technological transformation, industrial innovation and new growth paths, such as adopting blockchain systems and systems, to maintain its future global market share. At present, the fresh fruit supply chain has the characteristics of many subjects, wide distribution and complex transactions, which bring about issues such as tamper-proof,information, the supply–demand relationship and regulatory traceability [136]. By using blockchain technology in the fresh fruit supply chain, the blockchain can upgrade the fresh fruit supply chain. The blockchain system collects and uploads reliable data through IoT-related technologies, from fruit picking to final consumption. However, the blockchain has some limitations, such as reliance on the IoT, immature fruit preservation technology, unclear legal supervision and so on. In order to limit storage growth and improve the query efficiency of the blockchain, The "double chain and double storage" blockchain model for the fruit and vegetable supply chain was developed [137]. The double chain double storage model based on Hyperledger takes into account the openness, security and information privacy of enterprises in all links of the transaction information and can significantly improve the efficiency of the blockchain storage query.

### 5.3. Vegetables

Vegetable agricultural products have the characteristics of green, healthy and having a high nutritional value [138] and are deeply loved by people. However, the storage time of fruits, vegetables and agricultural products is short, and the storage temperature requirements are low, and food safety accidents are extremely prone to occur [139]. To overcome the problem of heavy data load pressure and poor privacy security in the process of data growth in the blockchain traceability system, a method for on-chain and off-chain data storage based on "database + blockchain" is proposed [140]. The public information displayed to consumers is stored in the local database in the supply chain, and its hash value is uploaded to the blockchain system through the SHA256 algorithm. The private information encrypted by the CBC encryption algorithm is stored in the blockchain for sharing by related companies. To take advantage of the important properties of blockchain: transparency and privacy, Yang et al. [141] use hyperledger fabric to build a blockchain network that is compatible with the vegetable supplier problems. A 9-channel blockchain network was created using kafka. This performance indicates that a multiple channel blockchain network could help the vegetable supplier to improve their ledger capabilities to be less than one day. A scalable, modular, low-cost IOT/smart agriculture (SA)-oriented management platform called VegIoT Garden, which is based on commercial-off-the-shelf (COTS) devices, is designed to support farmers in improving the commodities they produce, identifying key issues, and addressing irrigation-related issues, identifying possible correlations between climate characteristics, and this paper presents field productivity and crop health [142]. To study the blockchain and technology that match vegetable production, Massaro et al. [143] described the entire scenario and the use of blockchain technology and concluded that the technology and methods used in the literature are suitable for quality traceability. It is also useful to apply other supplies.

### 5.4. Eggs

In order to track the products from farm to fork using blockchain and IoT-enabled technologies, the use cases for deploying blockchain in food delivery are introduced, especially related to egg supply chains in the Midwestern USA [49]. By establishing a traceable and transparent food supply chain, consumers can obtain the information they need and make informed choices about the food. For stakeholders in the food supply chain, having traceability and transparency can better establish relationships with their customers, increase efficiency, and reduce food recall costs, fraud and product losses. Through a review of the literature from 2008 to 2020 that primarily examined the use of blockchain technology in supply chain management and explored two blockchain projects: Nimble and Carrefour, a conclusion can be derived that countries and supply chains such as chicken, tomatoes, eggs, oranges, etc, to the same extent, are making bold moves toward using blockchain on a large scale [144].

### 5.5. Pork

In response to food contamination scandals on a global scale, retail giant Walmart is using blockchain technology to solve food safety issues in the supply chain [145]. In 2016, Walmart tested a blockchain-based solution to monitor pork products in China. In May 2017, Walmart successfully used blockchain to track and verify pork products from a farm owned by Chinese meat producer Jinluo [145]. With a farm-to-table approach, Walmart's blockchain solution reduced time for pork traceability. Moreover, the consumer loyalty is greatly improved. To study extensively the application of blockchain-enabled food supply chains in developing countries, a comprehensive assessment of blockchain traceability in food supply chains is conducted through a case study of the pork supply chains in Vietnam to gain a deeper understanding of the potential impact on the food supply chain sustainability [146].

### 5.6. Tea

Tea traceability requires all organizations to participate in the traceability link. However, with the increase in traceability links, the groups involved are complex and will produce a lot of problems, such as, every link to all the people involved will no doubt increase the complexity of the traceability system and the efficiency of management. Therefore, how to effectively and quickly identify the tea traceability information in each link is a very important problem [147]. A block-chain traceability system based on smart agriculture with the integration of wireless sensor networks and Ethereum, which aims to realize the reliable traceability of agricultural products [148]. The OR code is used to provide consumers with safe, reliable and real farm product traceability information. Moreover, a holographic database for the entire tea industry chain from farmland to table is created to realize the efficient control of food quality and safety. To accelerate resource deployment, reduce waste and improve the durability and sustainability of the circular tea supply chain, a radio frequency identification (RFID) technology driven by a blockchain technology (BCT) practice model is proposed, which can help to manage the complexities of circular tea supply chain management (CTSCM) [149]. The proposed model can provide a deeper understanding of inventory performance, resource usage and industry processes. To achieve system automation and credibility in the field of agricultural product traceability, a machine learning (ML)–blockchain–IoT-based tea credible traceability system (MBITTS) is designed and implemented [150]. IoT devices can automatically collect information related to key aspects of traceability. The data are collected and entered into a blockchain system for processing, storage and query. The distributed, decentralized and immutable nature of the blockchain guarantees the security of the data entering the system. Compared with the existing blockchain-based agricultural product (tea) traceability systems, the introduction of an ML data verification mechanism can guarantee the accuracy of the information on the chain (up to 99%). The tea production and supply chain (PSC) can realize the benefits of all participating enterprises by coordinating tea planting, product processing, transportation and product sales. In order to achieve full chain tea counterfeiting supervision and automatic environmental management, a blockchain–IoT-empowered decentralized framework is proposed [151]. In addition, an improved adaptive weighted data fusion algorithm is designed to achieve accurate IoT data and efficient resource allocation, and an optimal irrigation strategy for automatic planting environment adjustment is proposed. The experimental results show that the proposed framework can achieve the high throughput and the efficiency of resource-saving automation.

### *5.7. Crop*

In order to solve the complex and economically infeasible problems of the traditional crop insurance system, a blockchain-based crop insurance solution is suggested [152]. Currently, the cost of managing insurance is a basic obstacle to the use of this facility. By using the Ethereum-based blockchain correctly, this fee can be greatly reduced. By using the improved blockchain technology in a breeding information management system, the Golden Seed Breeding Cloud Platform (GSBCP) is proven, which is an architecture to store high-throughput crop breeding data efficiently and safely [153]. In the case of a large amount of data, especially when breeders query breeding data, this storage architecture can significantly improve the efficiency of GSBCP. Providing farmers with information and connecting them has always been a challenge. To tackle these challenges, a cost-effective, blockchain-based security framework was proposed to build a farmer community and crowdsource the data they generate to help the farmer community [154]. Moreover, a revenue model is also incorporated to provide incentives to farmers. The integration of a deep neural network-based model to the proposed framework, which can predict any abnormalities present within the crops and give the possible solutions, would be much more coherent. A crop monitoring and classification system based on the IoT is proposed for automatic sensing, storage and monitoring of real-time parameters, which have an important impact on the quality and yield of crops [155]. In order to increase crop yields and secure all the valuable data related to seed type, fertilizer and crop costs, a smart agriculture technique is proposed [156]. IoT sensor devices are used to collect data from farms, crop yield predictions are realized based on machine learning algorithms, and all valuable data related to seed types, fertilizers and crop costs are stored in blocks to secure the security of the data and communication. Compared with the traditional methods, the proposed technique offers higher accuracy and profit from seed selection to transaction. Blockchain and edge computing-based transactions increase security and reduce transaction latency. The proposed system ensures the sustainability and traceability of agriculture.

**Table 7.** Applications of blockchain in the traceability for agricultural products.

| Food | Goal | Method | Advantage | References |
|---|---|---|---|---|
| Fish | • Ensure agriculture data integrity.<br>• Promote sustainable development goals within the context of the fish industry.<br>• Create an assessment for blockchain technology in a specific industrial (supply chain) setting.<br>• Explore how blockchain technology could improve supply chain visibility.<br>• Accurate assessment of fish quality to ensure food safety.<br>• Explore the consequences of information availability inherent for BCT adoption pilots in the SC context.<br>• Trace the fisheries supply chain to assist stakeholders in identifying the origin and causes of product fraud and malpractice. | (1) Diverse processes of the fish farm are executed automatically by using the smart contract to reduce the risk of error or manipulation.<br>(2) Data asymmetry exists in supply chains to achieve Sustainable Development Goals.<br>(3) Using Strandhagen's control model methodology to design an AS-IS model to explore the effects of blockchain technology in Norwegian fish supply chains.<br>(4) Exploratory research was conducted through semi-structured interviews with fish industry actors and blockchain experts.<br>(5) A multi-layer blockchain architecture based on ABE is proposed to solve the privacy problems caused by the application of blockchain encryption in the fish supply chain and realize the sharing of trusted and confidential data among the parties of the supply chain.<br>(6) follows a mixed-method approach, with qualitative and quantitative data collection techniques.<br>(7) A solution based on the private Ethereum blockchain has been proposed to effectively manage fisheries supply chain operations. | (1) Providing fish farmers with secure storage for preserving the large amounts of agriculture data that cannot be tampered with.<br>(2) Contributing to the supply chain management field and ultimately impacting the resilience of fishery ecosystems and the achievement of sustainable development goals.<br>(3) Finding indicators for which types of supply chains blockchain technology could bring positive strategic implications.<br>(4) It is concluded that blockchain can use the usefulness of information to enhance the visibility of the industry, better predict and plan through data analysis, improve operational efficiency and thereby increase business value.<br>(5) The BeFAQT is able to provide trusted and comprehensive fish provenance and quality tracking information in real-time.<br>(6) The results show that consumers are more likely to buy fish products with traceability information.<br>(7) The solution effectively manages fisheries supply chain operations in a decentralized, transparent, traceable, secure, private and trusted manner. | [126]<br>[127]<br>[132]<br>[131]<br>[129]<br>[133]<br>[134] |
| Fruits | • Research question: "Which . technology should be chosen and how should it be integrated into a company's pineapple supply chain to ensure traceability?"<br>• Identifying the critical factor of fruit blockchain in the retail market and the relationship between the key factors blockchain in the retail industry.<br>• To solve the problems of anti-tampering, the supply and demand relationship and traceability of supervision in the fresh fruit supply chain.<br>• To limit storage growth and improve the query efficiency of the blockchain. | (1) Based on qualitative research, the study adopts data collection techniques such as desk research and semi-structured interview, and adopts content analysis and narrow analysis to analyze the data.<br>(2) A cross-sectional approach was used, and trust was added as an independent variable to the (UTAUT2).<br>(3) Collect and upload reliable data from fruit picking to final consumption through IoT related technologies.<br>(4) The "double chain and double storage" blockchain model for the fruit and vegetable supply chain was developed. | (1) The technology integration concept was defined. A conclusion is drawn that the hypothesis of traceability in the food industry still needs to be proven by market research.<br>(2) Providing different perspectives of Malaysian retail fruit blockchain environment, not only in terms of business processes and competition, but also cooperation between retailers and customers.<br>(3) Blockchain balances the tension between supply and demand, brings money to businesses and simplifies regulation and traceability. However, blockchain has some limitations, such as relying on the IoT, immature fruit preservation technology and so on.<br>(4) The dual-chain and dual-storage model based on Hyperledger takes into account the openness, . security and information privacy of enterprises in all links of transaction information, and can significantly improve the efficiency of blockchain storage query. | [125]<br>[135]<br>[136]<br>[137] |
| Vegetables | • In order to solve the problems of centralized management, opaque information, unreliable data and easy to generate information islands in traditional traceability systems.<br>• Discuss a case of a vegetables supplier's problems in terms of ledger.<br>• In order to meet the needs of agriculture 4.0 and smart agriculture for technology.<br>• Present some results of an industry research project by describing the entire vegetable scene, implementing the architecture of the blockchain, the principle of sequence diagrams, and embedding blocks and transactions in the prototype network. | (1) A dual storage structure of "database + blockchain" on-chain and off-chain traceability information is constructed, which reduces the load pressure of the chain and realizes information query.<br>(2) Use hyperledger fabric to build a blockchain network. A 9-channel blockchain network was created using kafka.<br>(3) VegIoT Garden: a modular IoT management platform for urban vegetable gardens is proposed, which is based on COTS devices, adopting short- and long-range communication protocols (IEEE 802.11 and LoRa).<br>(4) Present some results of an industry research project by describing the entire scenario, the realization of the blockchain architecture, the principle of sequence diagrams, and the prototype of network embedded blocks and transactions. | (1) The system improves the query efficiency and the security of personal information, ensures the authenticity and reliability of the data in the supply chain management, and meets the practical application requirements of agricultural product traceability.<br>(2) The results show that a multi-channel blockchain network can help vegetable suppliers increase their ledger capabilities to within a day.<br>(3) The platform can gather, monitor, and analyze sensor data collected from an urban vegetable garden, using blockchain as an enabler to satisfy security requirements.<br>(4) The preliminary results presented prove that the techniques and methods used in the literature are suitable for quality traceability. The method is useful for applying the proposed framework to other supply chains. | [140]<br>[141]<br>[142]<br>[143] |
| Eggs | • Track products (eg. eggs) from farm to fork using blockchain and IoT enabled technologies.<br>• To answer: will blockchain become the norm for supply chain management? | (1) Creating traceable and transparent supply chains for food.<br>(2) Review the literature about the use of blockchain technology in supply chain management, and explore two blockchain projects: Nimble and Carrefour. | (1) Consumers can obtain the information they need and make wise choices about the food. For stakeholders in the food supply chain, traceability and transparency can better establish relationships with customers, improve efficiency and reduce the risks and costs of food recalls, fraud and product losses.<br>(2) It is concluded, to the same extent, countries and supply chains are also boldly attempting to use blockchain on a large scale. | [49]<br>[144] |
| Pork | • Brand protection and security through transparency.<br>• To study extensively the application of blockchain-enabled food supply chains in developing countries. | (1) Using IBM's blockchain solution based on Hyperledger Fabric to realize "complete end-to -end traceability" for pork.<br>(2) A comprehensive assessment of blockchain traceability in food supply chains is conducted through a case study of pork supply chains in Vietnam. | (1) Enhancing consumer loyalty, and farm-to-table traceability time is greatly reduced.<br>(2) Gain a deeper understanding of the potential impact on food supply chain sustainability. | [145]<br>[146] |

**Table 7.** *Cont.*

| Food | Goal | Method | Advantage | References |
|---|---|---|---|---|
| Tea | • To know about the benefits and impact of BCT on the tea supply chain and its sustainable performance.<br>• To realize the reliable traceability technology of agricultural products.<br>• To accelerate resource deployment, reduce waste and improve the durability and sustainability of the circular tea supply chain.<br>• To achieve system automation and credibility in the field of agricultural product traceability.<br>• To achieve full chain tea counterfeiting supervision and automatic environmental management. | (1) Introduce the resource-based view (RBV) and network theory (NT) into the tea supply chain. A BCT-driven conceptual model of the tea supply chain was developed, the data using the structural equation modeling method of partial least squares regression are analyzed.<br>(2)Propose a block-chain traceability system based on smart agriculture with the integration of wireless sensor network and Ethereum. Adopt the food risk assessment and safety traceability technology based on the hazard factor to design the multi-role, multi-link and multi-factor intelligent management system.<br>(3) A RFID technology driven by BCT practice model is proposed.<br>(4) A MBITTS is designed and implemented, in which, IoT can automate the collection of information of traceability and blockchain guarantees the security of the data entering the system.<br>(5) A blockchain–IoT-empowered decentralized framework is proposed. An incentive scheme based on blockchain technology is designed to attract tea PSC participants and encourage good behaviors of participating companies. Automation of environmental monitoring and equipment control through IoT technology. | (1) The research results show that the use of BCT has a significant positive impact on the tea supply chain; in particular, transparency and reliability are shown as sustainable performance parameters. This study is the first report to integrate BCT into the supply chain and contributes to the lack of relevant literature.<br>(2) Traceability QR code provides consumers with safe, reliable and true traceable information for agricultural products. Create a holographic database for the entire tea industry chain from farmland to table.<br>(3) Help to manage the complexities of CTSCM and provide a deeper understanding of inventory performance, resource usage and industry process.<br>(4) The introduction of ML data verification mechanism can ensure the accuracy of information on the chain (up to 99%).<br>(5) The high throughput and the efficiency of resource-saving automation are, thus, achieved. | [157]<br>[148]<br>[149]<br>[150]<br>[151] |
| Crop | • An affordable, efficient, low cost crop insurance solution based on blockchain is proposed to solve the complexity and economic infeasibility of traditional crop insurance.<br>• By using improved blockchain technology in a breeding information management system, an architecture to store high-throughput crop breeding data efficiently and safely is proposed.<br>• Through crowdsourcing and community building to provide information to farmers and connecting them.<br>• The paper aims to directly connect the farmers and the distributors, eliminating the middlemen using blockchain technology.<br>• Increase crop yields and secure all valuable data related to seed type, fertilizer and crop costs. | (1)With the proper use of blockchain based on ethereum, a blockchain-based crop insurance is proposed.<br>(2) A light blockchain is used in the storage architecture, to save key breeding data. Different types of blockchains are used to store different types of breeding data. The proxy encryption technology is used to ensure data security.<br>(3) A cost-efficient and blockchain-based secure framework for building a community of farmers is proposed. The integration of a deep neural network-based model to framework, which predicts any abnormalities in crops and gives the solutions.<br>(4) IoT-based crop monitoring and classification system is proposed, which employs LoRa for communication and blockchain for data trust and security.<br>(5)IoT sensor devices are used to collect data from farms, crop yield predictions are realized based on machine learning algorithms, all valuable data related to seed types, fertilizers and crop costs are stored in blocks to secure the security of data and communication. | (1) The system can increase the transaction throughput and decrease the end-to-end latency.<br>(2) In the case of a large amount of data, especially when breeders query breeding data, the efficiency of GSBCP is significantly improved.<br>(3) The simulation results show that the prediction accuracy of this model is high.<br>(4) The system can automatically sense, store and monitor real-time parameters that play an important role in determining a crop's quality and yield.<br>(5) Compared with the traditional methods, the proposed technique offers higher accuracy and profit from seed selection to transaction. Blockchain and edge computing -based transactions increase security and reduce transaction latency. The proposed system ensures the sustainability and traceability of agriculture. | [152]<br>[153]<br>[154]<br>[155]<br>[156] |

**Table 8.** Applications of blockchain technology in agricultural traceability that have been implemented.

| Company or Region | URL | Introduce |
|---|---|---|
| VoneTracer | https://www.vonetracer.com/?bd_vid#/login | VoneTracer uses blockchain technology to achieve food traceability, helps customers increase product trust and helps companies enhance their brand image. |
| IBM Food Trust | https://www.ibm.com/cn-zh/blockchain | IBM Food Trust can trace products in seconds, and the consumer can view all information about these products to verify their safety. |
| HiMarking | https://www.himarking.com/ | Focusing on the research of products with a one thing one code digital application field, serving the world famous brand enterprises, is a technology company committed to the digital intelligence of things and brand digital marketing services. |
| Mite Smart | http://www.mtscitech.com/ | Founded in 2006, it is positioned in the IoT industry, specializing in creating a product IoT system with identity codes as the core for customers. Thoroughly solving the important problems of ethylene related to brand safety, such as quality traceability, anti-counterfeiting and anti-channeling, logistics management, channel control and product traceability that have plagued enterprises for many years. |
| TE-FOOD | https://www.te-food.com/ | TE-FOOD is a food traceability system that integrates supply chain companies, consumers and government authorities to improve food safety. |
| ANT GROUP | https://antchain.antgroup.com/ | The large-scale commercial traceability service platform uses blockchain and Internet of Things technology to solve the authenticity of traceability information and drive rapid business growth through marketing capabilities. It has traceability solutions for cross-border commodities, authentic products of origin, industrial traceability, food supervision, etc., which is suitable for traceability scenarios in all fields. |
| Tencent | https://cloud.tencent.com/ | Provide efficient, open, secure and flexible blockchain services to create a credible value channel between enterprises. |
| Life code | https://isite.baidu.com/ | Lifecode Technology Co., Ltd. is a high-tech enterprise integrating software development, system integration and big data marketing. It focuses on precision marketing, brand micro-business, new retail and ecological data application services based on the product one-code. |
| Fairfood | https://fairfood.nl/ | Fairfood is working on the transition to a sustainable food system. To this end, innovative solutions were developed,creating open and easy-to-use solutions. |

## 6. Future Directions

Blockchain technology can enhance the traceability of agricultural products by providing a transparent and immutable record of the product's journey from farm to fork. Here is how blockchain can be utilized for traceability in the agricultural industry: (1) Provenance Tracking: Blockchain allows for the creation of an auditable and tamper-proof record of every step in the supply chain. From the initial planting or breeding of a crop to its harvest, processing, packaging and distribution, each transaction can be recorded on the blockchain. This ensures that all relevant information about the product's origin, such as farm location, farming practices, use of fertilizers or pesticides and quality inspections, is securely documented. (2) Batch and Quality Control: By assigning a unique identifier or tag to each batch of agricultural products, blockchain enables the easy tracking and monitoring of products throughout their life cycle. Information regarding quality tests, certifications and any related data can be linked to the specific batch on the blockchain. This enables the quick identification and recall of faulty or contaminated products, improving food safety and reducing risks. (3) Supply Chain Transparency: Blockchain facilitates transparency by allowing all participants in the supply chain, including farmers, processors, distributors, retailers and consumers, to access and contribute to the shared ledger. Each party adds their respective data, such as shipping details, temperature logs during transportation and storage conditions. This information can be made visible to consumers, ensuring they have a clear understanding of the product's journey and authenticity. (4) Smart Contracts and Conditions: Blockchain can automate contract execution through smart contracts. These digital agreements can enforce predefined conditions, such as quality standards or fair trade practices. For example, if a farmer agrees to use organic farming methods, IoT sensors can collect data on pesticide usage, and the blockchain can verify compliance. Smart contracts can automatically trigger payments or penalties based on predefined criteria, promoting accountability and trust. (5) Consumer Engagement: With blockchain, consumers can scan a product's QR code or use an app to access detailed information about its origins, certifications and sustainability practices. This empowers consumers to make informed purchasing decisions, supports ethical brands and encourages companies to adopt more sustainable and responsible agricultural practices. By leveraging blockchain technology, the traceability of agricultural products can be significantly improved, promoting transparency, trust and sustainability throughout the supply chain. This section further analyzes the blockchain technology from a critical and exploratory perspective and then gives future research directions.

### *6.1. A Critical Perspective on Blockchain Technology*

From a critical perspective, blockchain technology has some potential problems and flaws. First, the decentralized nature of blockchain can reduce the involvement of middlemen and reduce the potential risk of fraud; however, it can also lead to some challenges. For example, in a centralized system, the intermediaries usually take on some responsibilities, such as customer service, maintenance and dispute resolution. In blockchain, these responsibilities are shifted to users, who are responsible for managing and protecting private keys, dealing with technical issues, etc. Therefore, these responsibilities may be a burden for users who are not familiar with blockchain technology.

Another issue is blockchain scalability. Since all transactions and data need to be replicated and verified by nodes in the network, the throughput and speed of the blockchain may be limited when used at scale. Most of the current public chains can only handle a limited number of transactions, which leads to long confirmation times and high fees. Although some new technologies and architectures are being developed to improve the scalability of blockchain, this is still a challenge that needs to be solved.

In addition, the energy consumption of blockchain technology is also worthy of attention. Some public chain consensus mechanisms, such as proof of work, require a lot of computing power to solve cryptography problems, which leads to huge energy consumption. This raises some controversy and concerns in the context of environmental sustainability.

### *6.2. An Exploratory Perspective on Blockchain Technology*

From an exploratory perspective, although blockchain technology faces some challenges, it still has great potential. People have conducted many explorations and experiments on how to better use blockchain technology to create value and solve practical problems. In the financial field, people are thinking about how to use blockchain to simplify cross-border payments and improve the efficiency of transaction settlement and clearing. In the field of supply chain management, people are studying how to use blockchain to provide traceability and transparency to reduce product counterfeiting and improve the credibility of the supply chain.

Overall, the critical and exploratory perspectives jointly reveal the advantages and limitations of blockchain technology. As an emerging technology, blockchain is still in the process of development and improvement. Understanding the strengths and weaknesses of blockchain helps us clarify its potential and limitations, and drive its wider adoption in practice.

The future research directions of blockchain technology are as follows.

### *6.3. The Access Threshold of Blockchain Technology Is High, and the Technology Needs to Be Further Optimized*

Although some people are aware of the content of agricultural traceability, they do not have a systematic understanding of the information and have no in-depth understanding of the traceability nature of the quality of agricultural products [14,30]. Most blockchains are relatively large and exist in various industries, which are interrelated with different industries. However, in the early development of blockchain, its underlying technology was subject to many restrictions, and its throughput, delay time, capacity and security needed to be improved [158]. The blockchain technology needs to be further optimized to ensure the quality of agricultural products, and the high technology access threshold is also one of the main restrictions on the traceability of agricultural products [57]. The technology in the traceability application of agricultural products supported by blockchain technology [159] involves cryptography, computer science, network knowledge and artificial intelligence [160,161]. However, at present, there is a lack of professional talents in the frontier areas of cross fields. For enterprises, blockchain technology makes the overall cost increase, which is not conducive to the wide application of blockchain technology in the market. For farmers, expensive blockchain equipment or technology further hinders the application of blockchain technology in the traceability of agricultural products. Therefore, the future application of blockchain technology in agriculture needs to be further optimized to meet the needs of all parties.

### *6.4. Leveraging Big Data and Machine Learning Algorithms to Establish the Smart Agriculture Paradigm*

In the future, the combination of agricultural blockchain technology and artificial intelligence will bring the establishment of a new paradigm to smart agriculture [37], in which all different services, components and stakeholders will be connected to each other. In addition to the enhancement of the traceability system, smart agriculture can also provide benefits for more scientific production by using big data and machine learning algorithms. Therefore, scientific research should move towards a more practical method of creating pilot applications and platforms in the next few years, and by combining big data [162–164], artificial intelligence and machine learning technologies [110,165]to create a smarter, safer and more well-protected smart agriculture.

### *6.5. Combination of 5G and the Internet of Things*

With the rapid development of agricultural technology, smart agriculture and vertical farm concepts, the process from production to delivery of crops may be transformed [166]. For growers, monitoring soil quality, irrigation, pests and disease, crop storage and production and harvesting activities in a precise and effective manner is a game-changing technology [167–169]. In addition, the popularization and utilization of 5G in industrial and agricultural scenarios makes the application of many technologies possible, which will definitely help the intelligent and modern development of agricultural production [170–172]. The IoT is stepping out of its infancy into full maturity and establishing itself as a part of the future Internet [173]. The IoT plays a central role in turning current agriculture into smart agriculture, electrical grids into smart grids and houses into smart homes, and this is only the beginning [174,175]. For tangible assets, by combining the IoT technology to design a unique identifier for the asset and deploy it on the blockchain, it can form a digital smart asset and realize the authorization and control of distributed assets based on the blockchain [173] so as to finally form the brand of agricultural products and produce brand utility.

### *6.6. The Blockchain Agricultural Traceability System Will Contribute to the Construction of a Blockchain Parallel Society*

In recent years, the rapid development of the Internet has made the real world and the virtual world closely coupled, and society will develop into a physical, artificial and networked man–machine–object ternary coupling system, called the Cyber–Physical–Social System (CPSS). The blockchain technology is one of the infrastructures to realize the CPSS parallel society. At present, the CPSS parallel society has begun to take shape, but there is still no mature paradigm to refer to for future development. The establishment of a distributed blockchain agricultural traceability system is conducive to promoting the decentralized development of society and making important contributions to the construction of a blockchain parallel society.

## **7. Conclusions**

Blockchain is a revolution with a wide range of applications, and blockchain technology is widely used in the traceability of agricultural products. Through blockchain technology, a reliable and non-tamperable traceability system can be established to realize the full traceability of agricultural product production, processing, circulation and other links.

Blockchain traceability can record important information such as planting, fertilization, pesticide use, picking and processing of agricultural products and link them sequentially in the form of blocks to form a chain structure. Each block contains a timestamp and the hash value of the previous block, ensuring data transparency and credibility. Through blockchain traceability, consumers can scan the QR code on the product or visit the website to view the product's production information, processing process, transportation route, etc., and understand the authenticity and quality and safety of the product. At the same time, blockchain technology can also improve the transparency of the supply chain, reduce information asymmetry and fraud and protect the rights and interests of consumers. At present, some blockchain traceability platforms are widely used in the field of agricultural products, such as "Ant chain" and "Mite Smart". These platforms provide credible agricultural product traceability services through blockchain technology, providing consumers with safer and more reliable product choices.

In this paper, an extensive review of the most notable works to date on blockchain technology for agricultural product traceability is provided. We proposed a study design method for organizing and clustering existing publications, listed some models and intuitively reflected the advantages of blockchain traceability by comparing with the traditional traceability systems. A bunch of important application scenarios and applications are highlighted. Finally, the paper analyzes the status quo of blockchain traceability technology and gives future directions.

In summary, for the implementation of a traceability system to be successful, the system should have the following properties: (1) reduced risk, (2) reduced cost, (3) saved time and (4) increased trust and transparency. Stakeholders will be willing to adopt new ways of working only if they are convinced that the proposed approach is user-friendly, increases productivity and brings added value.

This review is a qualitative study. In future works, we will combine quantitative and qualitative methods to further study the application of blockchain in traceability.

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