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Harnessing the Power of Blockchain in the Agri-Food Sector: A Meta-Analysis of Current Research and Best Practices

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Abstract

The Blockchain is a shared and “immutable data structure defined as a digital register whose entries are grouped into “blocks, concatenated in chronological order, and whose integrity is guaranteed through the use of cryptography. Blockchain technology in agriculture and agribusiness has gained significant attention as a potential solution to various challenges the agri-food industry faces. In this paper, we conduct a meta-analysis exploring the various applications of Blockchain in agriculture and agribusiness. We examine the types of technology used, the specific product branches involved, and the security protocols employed. Our findings show that several experiments and pilot projects have been conducted in the field and that Blockchain applications such as Hyperledger Fabric and Corda are ready for real-world implementation in the agri-food sector. We also identify potential benefits of using Blockchain in the agri-food sector, including enhanced product quality guarantees, improved traceability and transparency, assurance of provenance, and more equitable distribution of profits along the agri-food supply chain. Overall, our review suggests that the use of Blockchain in agriculture and agribusiness has the potential to address a range of challenges faced by these sectors and drive innovation, technical, and economic efficiencies.

Keywords: Blockchain, Agriculture, Agri-food, Network characteristics, Hyperledger Fabric, Corda

1 Introduction

Cryptography represents a branch of mathematics that finds application in many sectors, from finance and telecoms to defense and cybersecurity. In particular, this sector uses specific techniques to protect the information belonging to three macro areas: *Secret Key Cryptography* (SKC), *Public Key Cryptography* (PKC), and *Hash Functions* [59]. The hash functions used for digital signatures have grown exponentially thanks to Blockchain technology’s implementation. This function associates a fixed-length digest $h(m)$ to a string of any length m , verifying the properties of Preimage, 2nd-Preimage, and Collision Resistance. This way, finding two inputs that generate the same digest is impossible (and computationally too expensive) [13]. Some classic examples of hash functions are Message-Digest 5 (MD5), an algorithm that consists of five phases and 64 operations, which generate an output unique from other digests [48]; and Secure Hash Algorithm 256 (SHA256), which produces a 256-bit digest in output [47]. The latter, in particular, represents one of the critical

elements of Blockchain cryptography.

Blockchain is a digital transaction ledger that transcribes information in sequential blocks based on cryptography and is maintained by a network of multiple computing machines that are not relying on a trusted third party [26]. The main characteristic of this ledger is decentralization, which means it is not controlled by any specific entity or organization. Rather, it consists of a network of nodes that maintain its integrity. Several types of Blockchains have been developed, including public and private, with the emergence of the first Bitcoin Blockchain leading to their widespread use [36]. In fact, in the Bitcoin system, the digital signature mechanism is used to transfer money (Bitcoin, in fact) from one to another using the Blockchain structure as a register to record the transactions that have taken place [13]. This framework uses cryptography to solve the Proof-of-Work problem and verify transactions [2]. The *Proof-of-Work* (PoW) and *Proof-of-Stake* (PoS) consensus algorithms are mechanisms used by the network to reach consensus, which ensures that the protocol rules are followed and transactions are processed correctly. In the PoW algorithm, a node is selected as the next one based on a complex computational process that consumes resources. In contrast, in the PoS algorithm, nodes are organized in a stack and selected for the next block based on various factors such as age or status. For example, in the Bitcoin Blockchain, transactions are recorded in blocks and are verified approximately every 10 minutes based on a variety of factors, including:

- **Network congestion**, a larger number of transactions may result in longer processing times due to the limited number of transactions that the Bitcoin network can handle per second;
- **Transaction fees**, transactions that include higher fees are more likely to be processed more quickly, as they are given priority by miners;
- **Miner's preferences**, miners can choose which transactions to include in the blocks they mine, and they may prioritize transactions that offer higher fees;
- **Size of transaction**, larger transactions require more data to be processed, which can result in longer processing times;
- **Complexity of transaction**, transactions that involve more complex processes, such as multi-sig transactions or transactions that involve smart contracts, may take longer to process;
- **Security of the network**, if the bitcoin network is under attack or experiencing other security threats, it may take longer for transactions to be processed;

- **Stability of the network**, if the network is unstable due to technical issues or other problems, it may take longer for transactions to be processed;
- **Availability of miners**, if there are fewer miners available to process transactions, it may take longer for transactions to be included in a block;
- **Use of off-chain transactions**, some bitcoin transactions can be processed off the Blockchain using techniques such as the Lightning Network, which can potentially result in faster processing times.

The functioning of the block structure can be summarized in the following: every time there is an exchange of money between the wallets of two subjects, the data structure generally identified as a “transaction” records a series of information, such as the amount of money exchanged, the time and information of the subjects who carried out the exchange, authorized by the respective private keys of the wallets (encrypted and made available for use thanks to the transformation into public keys) [2]. The transaction, which has been authorized but not yet validated by the network, is disseminated to the Blockchain nodes and collected in a pool, forming the heart of the following block to be validated through the widespread consensus mechanism [18]. Each block, linked to the previous one, consists of a header and the collected transactions (so-called TX) [2]. In particular, the block’s header contains information about the previously-validated block (such as the hash) and a series of its information such as timestamp, height and size, Merkel root (which combines the hashes of the block’s transactions), difficulty bits and Nonce. The latter represents the variable element that the miners must look for to obtain the correspondence with the hash generated by all the information in the block in exchange for a reward and stands for Number (*No*) used only *once* [2]. Once the block has been validated via widespread consensus, it is added to the Blockchain thus becoming immutable if the Blockchain is secured against the 51% attack. In addition to cryptographic techniques, consensus algorithms are used to maintain a blockchain’s security and integrity. These algorithms ensure that all participating nodes in the network agree on the validity of transactions and the state of the ledger, preventing any single node from manipulating the data. It is important to note that cryptographic systems are not invulnerable and can potentially be vulnerable to attack. For this reason, it is essential to regularly update and improve cryptographic techniques to address these potential vulnerabilities and weaknesses. By staying current with the latest developments in cryptography, it’s possible to ensure that Blockchain systems remain secure and reliable. [2] This will sometimes require a fork, which can either be hard or soft. In a Blockchain, a hard fork is a change to the protocol that makes previously invalid blocks/transactions valid (or vice-versa), requiring all nodes or users to upgrade to the new version of the protocol software. This can be contrasted with a soft fork, a change to the protocol that is backward-

compatible and does not require all nodes to upgrade. A hard fork can be thought of as a change to the Blockchain that creates a permanent divergence in the Blockchain, commonly resulting in the creation of a new cryptocurrency. Soft forks, on the other hand, do not create a new cryptocurrency and only require a majority of miners to upgrade to be implemented. Both hard and soft forks can be used to add new features to a Blockchain or reverse transactions (in the case of a hard fork only). They can also address security vulnerabilities in a Blockchain or allow the ledger to scale more efficiently [2].

The functioning of the Ethereum Blockchain is similar but has further advantages related to the possibility of using *Decentralized Applications (DApps)*. These interfaces connect the *Smart Contracts* [57, 1] with the user interface. Smart Contracts, in particular, are algorithms that allow operations to be performed, verified, and automated (such as exchanging money between subjects at pre-established times) [3]. This allows the Ethereum Blockchain to be classified as an *Ethereum Virtual Machine (EVM)*, i.e., a machine made up of thousands of connected nodes capable of performing operations. The EVM is classified as a Turing Complete machine in which the Blockchain structure is not only a ledger but a real distributed state machine (potentially infinite tape). Therefore, the presence of Smart Contracts and DApps transform the Ethereum Blockchain into a tool which, based on the availability of resources, surpasses the potential of any cloud application [3]. The widespread consensus mechanism is also present on this Blockchain, where the transition from Proof-of-Work to Proof-of-Stake is being tested.

From these mechanisms, it is evident that the potential of the Blockchain is many and not limited simply to the financial sector. For example, one sector of the use of Blockchain technology is agriculture. Nowadays, the agriculture and agri-food supply chain involves many subjects, such as farmers, agri-food producers, distributors, retailers, and final sellers. They use a private database to manage critical product safety and origin information. Such information respects only regional regulations, leading to misunderstandings and increasing consumer safety risks. Moreover, these systems are vulnerable to a breach, or the loss of data [50]. Not only that, but lately, consumers have become more interested in the product's origin and quality. Additionally, other issues that are gaining prominence are:

- Food waste streams deriving from the expiration or spoiling of products;
- Market price differentials for similar agricultural commodities and the drive to harmonize prices;
- Fair trade characteristics of agricultural products.

As a corollary of the preceding trends, traceability in the agricultural value chain is gaining traction, has a critical role to play [50], and is likely to increase in importance over time.

The collection and analysis of Blockchain data have grown exponentially thanks to the Internet of Things (IoT) devices. These tools are devices connected to the internet that can communicate with each other [4]. Through the use of *ad hoc* network protocols (5G, Wi-Fi, ZigBee, Mobile Location-Based Services, Satellite communications, etc.), they allow the instantaneous exchange of information, which is why they find essential applications in points where there is a need to transmit data in real-time. Internet of Things (IoT) devices can be integrated with Blockchain technology to allow the device to process and transmit information for recording on the distributed ledger of the Blockchain. This combination of IoT devices and Blockchain technology has led to the development of intelligent agriculture and Industry 4.0, which utilizes new technologies and data analysis methods (such as machine learning and deep learning) to bring various benefits to the agricultural sector, including increased transparency in the process and connections between producers [9] and the ability to promptly prevent the consumption of contaminated products through the identification of physical, biological, or chemical risks via Blockchain [50].

The objective of this paper is to analyze the applications of Blockchain technology in the agriculture and agri-food sectors. However, given the broad scope of this topic, the focus will be on articles discussing specific Blockchain network architectures (such as Hyperledger) for the agriculture sector, analyzing ledger implementations in the agri-food supply chain, improving transaction transparency in this sector, and managing data from the agriculture sector through Blockchain.

The paper is structured as follows: the first section introduces the functioning of leading Blockchains (such as Bitcoin and Ethereum) and their applicability in various sectors. The second section identifies the main macro-level applications of Blockchain technology in the agriculture and agrifood sector. The third section presents the structural characteristics of the industry Blockchain network, with a focus on gateways and protocols. Finally, the fourth section provides a meta-analysis of existing literature, discussing articles grouped according to their applications in the agriculture sector.

2 Blockchain in agriculture and agri-food applications

One of the first reasons Blockchain technology can be considered beneficial for Agri-food sector is its intrinsic capability to guarantee traceability and transparency to the supply chain [6], allowing at the same time to have a simplification of the transaction processes. Recently Agriculture and Food (Agri-Food) supply chains management systems have been developed, which are responsible for tracking and storing orders and deliveries to guarantee transparency and traceability of the food production and transformation process. These characteristics have allowed, as a consequence, the showcasing of two other important

reasons for which the application of the Blockchain in Agri-food sector can be considered advantageous, that is the ensuring of the high quality and safety of the food products and simultaneously the protection and the improvement of the consumers' health [35] in such a way to solve problems like lack of social responsibility and poor environmental performance [6]. Finally, with a view to the search for greater transparency, equity of earnings between the parties, waste containment, and process optimization, Blockchain platforms are particularly advantageous for smart data analysis. Many problems in the agricultural chain, especially between cooperatives, farmers, and consumers, are due to a lack of information and communication tools between these parts. Blockchain-based frameworks could be effective methods to solve such problems and to bring toward a sustainable agricultural model. The strength point of such frameworks could be the storing of production and distribution information, as well as traceability. Thanks to the analysis of the flow of supply chain and logistics are possible to predict the demand for supply chain management and to make payment transactions of agricultural needs of farmers by analyzing stocks, raw materials, and price to the chain of distribution [45]. In such a way, Blockchain technology can help prevent issues like stock product price fluctuations, the low exchange values of farmers in prices because of the complicated flow distribution chain, the food decomposition. At the same time, the demand is high [45]. The data storage of information coming from production factors such as the quantity of water used, the number of fertilizers to be used according to seasonal trends, and the number of pesticides to be used can help to enhance company efficiency and have repercussions on the structure of the cost of production and therefore positive effects on the net income of the entrepreneur. Moreover, Blockchain has seen its implementation in IoT smart farming to use sensors and communication technologies to collect data from sensors and extract meaningful information to make intelligent decisions and gain profits to improve precision agriculture, enhance high crop yield, and employ efficient utilization of natural resources resources [12]. Besides, such an implementation has proved to store security-anomaly information securely and proactively mitigate similar attacks targeting other farms in the community (a Blockchain security monitoring for smart-agriculture IoT applications). All these data analysis applications can help to increase prices and protect the brand of agricultural products [39]. Therefore agri-food companies should adopt innovations such as the Blockchain since they would increase the value of production [51]. Blockchain technology can be used in different ways in the agricultural field and the agri-food industry as shown in Table 1, for example:

1. **Traceability and transparency:** the Blockchain can be used to transparently track and record the entire supply chain, from the origin of the product to the final consumer. This can help ensure that food is safe and sustainable and increase consumer confidence in food products.

2. **Contract management:** the Blockchain can be used to manage contracts for the production or purchase of agricultural products, making the negotiation and payment process simpler and more secure.
3. **Quality Certification:** the Blockchain can be used to record and certify the quality of food products, for example, by creating digital asset tokens that represent the product's value.
4. **Data Management:** Blockchain can be used to collect and store data on agricultural production, which can be helpful in better understanding farming practices and making informed land management decisions.
5. **Improving Efficiency:** Blockchain technology can automate some agricultural tasks, such as crop tracking or irrigation scheduling, increasing efficiency and reducing costs.
6. **Financing of the agriculture and agri-food industry:** Blockchain can be used to finance projects in the agri-food sector, for example, by creating digital asset tokens based on food production.

3 Blockchain architectural characteristics

Several types of Blockchain technologies can be used in agriculture as shown in Table 2 (in cases where the authors have identified a particular Blockchain), including:

1. **Public Blockchains:** these are open to anyone, such as the Bitcoin or Ethereum blockchain. They can be used to create digital asset tokens based on agricultural production or to trace the supply chain of food products.
2. **Private Blockchains:** these are only accessible to select participants, such as companies or agricultural organizations. They can be used to manage contracts for the production or purchase of agricultural products or to collect and archive data on agricultural production.
3. **Consortium-open Blockchains:** these are Blockchains that members of a specific consortium, such as farms in a particular region, can only access. They can exchange data or manage contracts to produce or purchase agricultural products.
4. **Hybrid Blockchains:** these are Blockchains that combine elements of public and private Blockchains. They can be used to trace the food products' supply chain or manage contracts to produce or purchase agricultural products.

Agriculture and agri-food applications		
Application	Description	Authors
Transparency and simplification of transactions	Through supply chain transparency (SSCT) and a transactions process simplification BC can make transaction processes simpler, low cost, transparent and faster.	[45], [6], [39], [46], [52], [43], [16], [14], [38], [21], [63], [29], [53], [34], [28], [11], [58]
Quantity of product information to guarantee product and brand quality	Tracking of product processes sell-brought actions, and transportation routes and more in general situations information, checks are made to avoid situations such as false labeling of products or undeclared imports	[4], [7], [6], [39], [26], [54], [42], [16], [38], [22]
Health product food safety	Knowing the physical, biological, or chemical agents used for growing, combined with information relating to the composition of the soil, the water used for irrigation, etc., is possible to have evidence relating to the food safety of a product and to act more promptly in stemming the spread of epidemics.	[26], [6], [10], [43], [16], [38], [23], [33]
Threatening of waste to certify circular economy	How product waste is treated to promote greater transparency economy model	[61]
Data analysis for prices prediction, more equitable distribution of earnings, and to optimize processes	Predict product price fluctuations, to promote a distribution of earnings (improving flow of supply chain and logistics), and to optimize processes.	[45], [39], [51], [17], [44], [43], [62], [21], [63], [22], [37], [53], [11], [56], [19], [25], [24], [15], [40]

Table 1: Main applications of the Blockchain to agrifood and the agricultural sector widespread in the literature

Blockchain technologies		
Technology name	Technology description	Authors
Ethereum	Flexible and modular open source platform which uses blockchain technology to develop and run smart contracts and decentralized applications (DApps). It is designed to be used in a public context.	[43], [39], [16], [38], [28], [11], [12], [26], [10], [44]
Hyperledger	Collection of frameworks, libraries, and standards for building blockchain-based applications and systems for use in business standardized and interoperable development environments. It is designed to be used in private business environments.	[21], [35], [11], [19], [15], [54], [45], [46]
Corda	Born to be used in the financial sector, it represents a permissioned Blockchain whose participation is regulated, differing from the previous ones.	[27], [58], [25], [24], [15]

Table 2: Main Blockchain technologies used in literature

5. **Distributed Blockchains:** these are based on a distributed network of nodes, which work together to validate and update the Blockchain's ledger. They can be used to trace the food products' supply chain or manage contracts to produce or purchase agricultural products.
6. **Permissioned Blockchain:** these are Blockchains whose decentralization is limited and the information to be transcribed in the ledger passes to the scrutiny of some designated nodes. On the other hand, there are permissionless Blockchains, in which validation is entrusted to any node.

3.1 Gateways and protocols

The Blockchain can securely collect data from the agricultural sector, such as information on the origin and quality of agricultural products and the production methods used. One way to secure data collection is by creating a digital ledger that allows the production chain of agricultural products to be traced from source to final destination. In this way, consumers can be sure of the origin and quality of the products they buy, while farmers can demonstrate the sustainability of their production methods. Not only that, but Blockchain can also be used to securely collect and store data on water, soil quality, pesticide, and fertilizer usage. This information can be used to promote sustainable agricultural practices and to ensure that producers meet food quality and safety standards. Furthermore, some activities can be automated, for example, by using sensors and IoT devices that automatically collect and transmit data to the ledger. This can reduce human errors and make data collection more efficient. Blockchain can securely and reliably collect data from the agricultural sector, providing reliable traceability of agricultural products and promoting sustainable agricultural practices. Several methods can be used to control the traceability and quality of a product through the Blockchain:

1. **Supply Chain Tracking:** the Blockchain can trace a product's journey from manufacturing to distribution, providing detailed information about the product's provenance and history.
2. **Digital Asset Token:** Digital Asset Tokens can be used to represent a product or service on the Blockchain physically. For example, a digital asset token based on milk production can track its origins and ensure it meets specific quality standards.
3. **Smart contracts:** Smart Contracts are automated code that runs on the Blockchain in response to specific events or conditions. They can be used to manage production or product purchase contracts, ensuring that agreed conditions are met.
4. **Open registries:** Open registries are public databases that can collect and archive data about the production or quality of a product. They can be used to ensure transparency and product quality.
5. **Data Analysis:** Data analysis can be used to collect and analyze data about production or quality to validate transactions and identify trends or patterns.

An Internet Protocol (IP) address is a unique number assigned to every device connected to the Internet. IP addresses are assigned to every device connected to the Internet and are used to identify the device and transmit data to it uniquely. There are several versions of IP, including IPv4 and IPv6 [20]. In

general, IP addresses are not stored directly on the Blockchain. For example, the ledger can be used to track transactions made by a device with a particular IP address or to collect information about a particular user's use of a device. As for phones, Blockchain can track calls made to or received from a phone or gather information about a particular user's phone usage. However, doing so may require using a private or open-to-consortium Blockchain, as public Blockchains may not provide the required level of privacy. Additionally, an application or service that collects and stores data on the Blockchain may need to track a phone's activities.

Geolocation is the process of determining the location of an object or individual in a specific geographic location. There are several ways that geolocation can be used in the Blockchain:

- Supply Chain Tracking, the Blockchain can trace a product's journey from manufacturing to distribution, providing detailed information about the product's provenance and history. Geolocation can record the locations where product exchanges have taken place during this journey.
- Digital Asset Token, can be used to represent a product or service on the Blockchain physically. For example, a digital asset token based on milk production can track its origins and ensure it meets specific quality standards. Geolocation can record the location of farms or farms that produce milk.
- Smart Contracts, can be used to manage production or product purchase contracts, ensuring that agreed conditions are met. Geolocation can be used to record the production or distribution location.

Telephone masts are devices that transmit and receive mobile phone signals. It is possible to use the Blockchain to control telephone masts, but this would require creating a private or open-to-consortium Blockchain in which data relating to the masts and their activities is recorded. For example, it is possible to trace calls made or received by a telephone mast or gather information on users' masts' use. Additionally, it may be necessary to use an application or service that collects and stores data on the Blockchain for antenna control. In this way, telephone mast operators could monitor masts' use and ensure they are used efficiently and meet quality standards. However, it is essential to note that controlling telephone masts through the Blockchain could involve processing sensitive data, such as information about mast users. Therefore, adequate security and privacy protection measures to protect this data are required. IP, geolocation, and phone masts can be used to track the activities of an internet-connected device, such as a phone. For example, Blockchain can track calls made to or received from a phone, using the phone's IP address and the geolocation of the phone masts used to make or receive calls. Additionally, the ledger can collect information about a user's phone usage, such as the

number of calls made or received.

Recently, always more required are systems to protect the names of products that come from certain places, possess particular traits, or have a reputation tied to the producing territory. Therefore, of a lot of importance are factors like how the product is made, its composition, and its eventual link to a specific geographical area. Blockchain technologies have been used in several ongoing projects and initiatives which involve agriculture and food supply chain applications. To ensure the quality of products and prevent fraud, the primary mechanism used is the Proof of Location (PoL). PoL is a type of cryptographic technique that allows a node in a decentralized network to prove that it is physically located at a specific location at a specific time. This can be useful in various applications, including supply chain management, location-based services, and asset tracking. For example, it would help ensure a product's territory-based quality and bio-organic characteristics in the agricultural field. There are several approaches to implementing proof of location in a Blockchain system. The most commonly used ones result in internet protocol (IP) addresses, smart device location-based service (LBS), and satellite validation. Another criterion can be used is the logistics companies vehicle tracking system data. IP addressing validation consists in taking the reported address in the IP header of the communicating device and querying it against the Internet Routing Registries. LBS validation consists in taking the information from a software service for mobile device applications that requires knowledge about where the mobile device is geographically located. Satellite validation is the process of testing and verifying the accuracy and reliability of a satellite-based system or device. A PoL is a way for someone to prove where s/he is. It comprises two parts: data that says where the validating entity is located and software that signs and/or validates that data. PoLs can be used for many things, like tracking packages, ensuring people are where they say they are, or finding out if an area is safe after a disaster. There are many ways to make a PoL, but they all have limitations.

In light of what has been observed so far in the literature, we believe that a possible way to ensure food quality and safety is the setting up of a 4-tiered validation process that makes use of IP addresses, intelligent device LBS, and satellite validation, with a nonmandatory logistics companies vehicle tracking systems information, that cross-references this information with that relating to the producer's possessions. First, agricultural producers must register their agricultural holding(s) to issue certificates. After that, using a predefined table of maximum yield per crop per hectare, the size of their holdings will be used to compute the maximum yield per crop. Suppose certification requests exceed maximum yield estimates plus a margin of safety. In that case, the supplier will be greylisted for a while as fraudulent activity will likely occur through importation and relabelling. This information will also be available to regulators, who might then initiate national jurisdictional checks. Any supplier abusing the certification system in this way shall be irrevocably blacklisted

and will not be allowed to use CERES as a supplier anymore.

4 Meta-analysis

Previously, the different applications to the agricultural sector were divided into different categories. Here, it is possible to analyze the sector bibliography in detail. The most frequently used terms connected to the Blockchain can be classified into three clusters: The first ones are the terms more focused on the traceability system and the involved stakeholders for tracking the quality and safety of products. The second ones are the terms focused on technological issues of Blockchain technology and architecture and the integration of the technology with the Internet of Things to improve the transaction and security of the technology. Finally, the terms more concentrated on the research development and the benefits of the Blockchain systems, such as efficiency and trust. Moreover, the terms primarily used in the title and abstract of the articles were traceability, transaction, IoT, safety, and food supply chain [41]. Chaganti et al. [12] propose a cloud and Ethereum Blockchain-based security monitoring solution for smart-agriculture IoT applications, which inform farmers on anomalies in real-time and can spread the information in the Blockchain network. Marchese and Tomarchio [35] study transparency in disseminating and storing information relating to product traceability through the implementation of an Hyperledger Fabric permissioned Blockchain, an architecture where participation is limited to a well-defined set of members. Again, Tende et al. [54] analyze the mechanism for assigning paper-based subsidy vouchers in Tanzania in the agricultural sector, developing a system of agricultural vouchers in the *Hyperledger Fabric* Blockchain network (a consortium-based Blockchain with Raft consensus). In particular, farmers use the *Ozeki NG SMS* gateway to receive vouchers and demonstrate their authenticity through the Blockchain, which allows registration in the CouchDB database in the decentralized Blockchain and receipt of the authorization on farmers' phones. Putri et al. [45] continue using the Hyperledger Blockchain by combining this technology with the use of IoT devices to make it easier to carry out faster the transaction process, thanks to the simplified ecosystems (in the perspective of Semarang District Agriculture Service). Bai et al. [6], based on the technology-organization-environment (TOE) theoretical framework, develop a hierarchical enablers framework for improving sustainable supply chain transparency (SSCT) by Blockchain technology in the cocoa industry. Still, in the cocoa industry, Quayson et al. [46] consider the supply systems in the emergent economies and the problems related to it, proposing the use of some Blockchains (Agrikore) as a tool to solve (or at least mitigate) the problems that may arise in the poorly structured African supply chain. Kawakura and Shibasaki [27] test the Corda Blockchain to replace competitors in the agricultural sector, studying how it can be optimal for information transfer. On

this same Corda Blockchain, Vangipuram et al. [58] combine finance features with the benefits of using a particular DApp to manage supply chain data; while Kale et al. [25] study the advantages or the election mechanisms [24]. dos Santos et al. [15], on the other hand, highlight how this Corda Blockchain or Hyperledger are not the most suitable for supply chain management. Awan et al. [4] focus attention on the importance of food safety (due to high health risks), presenting a “Combo Smart” that combines traditional and innovative agriculture through IoT and Blockchain. In this way, the IoT tools acquire context information (such as temperature, quality, and type of transport), while the Blockchain makes this information immutable and widespread. In particular, the authors recognize the advantages of this Combo to improve food traceability, increase farmers’ productivity, and solve some problems related to payments in the agricultural sector. Basnayake and Rajapakse [7] intervene in the verification of product quality, proposing a public Blockchain to allow access to any user and verify the quality of the food and its supply chain. In particular, the authors highlight how this type of architecture makes it possible to keep track of any changes to the product and allows farmers to submit valid certification requests to customers and competitors. All of this has been accomplished through the Ethereum Blockchain and allows for the instantiation of *DApps* for automatic control. Kamilaris et al. [26] analyze the possible uses of Blockchain technology in the food chain and highlight the transparency that could emerge with these tools in the supply chain. On the other hand, the authors show beyond the potential also the challenges that this technology meets, for example, from the political or economic point of view for the implementation. The paradigm of Blockchain makes it an appropriate alternative way to resolve issues that often result in financial loss, crop contamination, and food spoilage through its qualities of transparency, timeliness, traceability, security, and immutability [43]. In agriculture supply chain management, traceability is crucial to ensure food safety for increasing customer loyalty and satisfaction. The lack of quality assurance in centralized data storage makes us move towards a new approach based on a decentralized system in which transparency and quality assurance is guaranteed throughout the supply chain from producer to consumer. The provenance (tracing) system of agricultural products is essential for ensuring food safety. Recorded information includes the management operations (fertilizing, irrigation, etc.) with specific data structure [23]. Blockchain technology acquires transparency and traceability in the supply chain, provides transaction records traceability, and enhances security for the whole supply chain. A Blockchain-based fully decentralized traceability model, as defined by Ehsan et al. [16], can ensure the integrity and transparency of the system. Such a new model can eliminate most of the disadvantages of the traditional supply chain. Another solution, the Community Supported Agriculture (CSA) model, is efficient for solving the problem of the agricultural products origin and for sharing the market risk between consumers and producers. In the CSA model, consumers order and

pay for products in advance. Then, the producers will send packages of fresh products to consumers after a fixed period corresponding to the paid amount. A critical weakness of the CSA model is the lack of solutions to demonstrate the products quality, making consumers hesitant to order and pay money in advance. Blockchain technology can be used to track products through agricultural diaries recorded by farmers every day. By authenticating and protecting the integrity of information, consumers could track all production processes quickly and reliably. At the same time, producers can build and increase their enterprise branding by transferring product information transparently and responsibly [38].

The traceability of Agriculture food supply chain management is essential to ensure food safety and increase customer satisfaction and peer-to-peer productivity [34, 49], alone and in combination with IoT devices [11]. By following this path, Caro et al. [10] analyze possible traceability problems based exclusively on IoT devices, proposing *AgriBlockIoT*, a traceability solution based on (fully decentralized) Blockchain Ethereum capable of integrating data from IoT devices in real-time. Recently, Blockchain has been implemented in access control protocols to provide a better security mechanism when IoT devices are added to a network [5]. Wnsche and Fernqvist [61] analyze the agri-food chains showing advantages and disadvantages deriving from the application of Blockchain technology to reduce food waste. The combination of Blockchain and Internet of Things technologies provides transparent solutions for the traditional agricultural supply chain and opportunities to support progress and innovation through sustainable management tools and methods [53]. Furthermore, Lin et al. [32] identify as the ledger can satisfy the diverse needs in the ecosystem of agricultural products, e.g., increasing transparency of food safety and IoT-based food quality control, provenance traceability, improvement of contract exchanges, transaction efficiency and increase autonomy and intelligence in precision farming [56]. Eluubek kyzy et al. [17] analyze the agricultural supply chain's problems, focusing attention on agricultural producers' profit, proposing implementing a consortium establishment with Blockchain technology as a possible solution. With this in mind, the authors propose a cyber-physical system for product quality, propose a new consensus algorithm and define the profit allocation through the ant colony algorithm. Orjuela et al. [42] focus on the supply chain in agriculture by pushing for the decentralization of tracking systems through BigChainDB. This database can be used in a decentralized manner whose operation is similar to a Blockchain. Pombo-Romero and Ras-Barrosa [44], considering the production of clean energy through renewable sources such as photovoltaic irrigation systems, study the applicability of the Blockchain in the initial investment phases where the expenditure is deeper. The authors highlight how the decentralized financial (DeFi) tools on Blockchain Ethereum allow the creation of Smart Contracts to produce financial instruments useful for financing investments in the agri-food sector. Wang et al. [60] driven by the Covid-19 pandemic, focus on the qualification rate

and circulation efficiency of agricultural products that can be improved with the use of Blockchain traceability systems, simulating the activities through Agent-Based models. Bermeo-Almeida et al. [8] introduce the possibility of monitoring the security and quality of warehouse and transportation products from farmers to companies or measuring the quality of the transportation of a product along its supply chain. On the other hand, the vast complexity of the agriproducts supply chain limits the development of global and efficient transparency and traceability solutions [14]. It can implement a seamless connection between agricultural product production and marketing, enabling the transformation and upgrading of agriculture, thereby helping farmers increase their income and eliminate poverty [62].

Agriculture data are known to be messy, and analysts are concerned with the validity of data, especially given that other people may have impacted data quality at various steps along the data path. The ledger can be a possible solution to the analysts problem of uncertain data quality from prior data manipulation since it ensures data have not been inappropriately manipulated or documents what changes have been made by specific individuals. The data in the system can be traced, which increases transparency and improves decision-making efficiency in the scheduling process. In addition, this system adopts a crowdsourcing scheduling mode, entirely using idle agricultural machinery in society, which can effectively solve the problem of resource waste [63]. Thanks to the Blockchain, it is possible to create an agricultural IoT data management system to provide real-time IoT data collection, analytics, visualization, and device management [19]. Again, as defined by Hang et al. [21], Blockchain platforms can provide farmers with secure storage for preserving large amounts of agricultural data that cannot be tampered with. Besides, diverse processes of the farm can be executed automatically by using the smart contract to reduce the risk of error or manipulation. Furthermore, to identify the correct number of nodes and decrease the risks, Song and Li [52] engineer a Blockchain-enabled relay-assisted wireless network for sustainable electronic agriculture to minimize the Signal Noise Ratio (SNR).

Blockchain technology can be used to build an open, trusted, decentralized and tamper-proof system, which provides the fundamental mechanism to verify that the data of a transaction has existed at a specific time in the network [31]. In addition to ensuring the transparency and security of transaction information and privacy of enterprise information, can significantly improve the credibility of the public service platform and the overall efficiency of the system [29]. Also, it can be helpful, as defined by Nayal et al. [37], for mitigating supply chain risks caused by climate change, crop diseases, supply and demand uncertainties, and the long payback period; other than timely analysis and securing of intelligent climate and watering agriculture systems for smart water consumption in small and medium ruler agricultural fields [55]. Blockchains can eliminate the middleman and scale the product effectively, consequently helping the farmers to secure more profits. Moreover, ensures the product's

authenticity in real-time, providing the customers and peers with more information about the product as it is easier to trace the details of the product back and forth through the chain. This also enhances and regulates the price variations providing farmers with the best price they can expect for their product [22].

Experimental data show that sustainable electronic agriculture based on Blockchain technology brings excellent convenience to farmers' sales, increasing by 25% on average compared with traditional electronic agriculture, which will bring vigorous vitality to the sustainable development of agricultural products [30]. These tools become vital to solve the current food supply chain asymmetry, such as lack of standardization in data format, lack of regulations, and legacy information [28]. This way, E-agriculture (agriculture combined with ICT) can increase economic efficiencies, food safety and reduce uncertainty risk while achieving sustainable agricultural development [33].

5 Conclusion

Blockchain technology has the potential to revolutionize the way that agricultural sales and credit term agreements are managed. Using a decentralized and secure digital ledger, these agreements can be recorded and tracked in a way that is transparent, traceable, and resistant to tampering. Using Blockchain in agricultural sales and credit term agreements can increase efficiency, reduce the risk of disputes, and improve trust between parties.

In the context of credit term agreements, Blockchain technology can securely and transparently track the terms of the agreement, including the terms of repayment and any changes to the agreement. This can help to reduce the risk of disputes or misunderstandings, as all parties have access to a transparent record of the agreement. One potential application of the ledger in agricultural sales is smart contracts. These are self-executing contracts, with the terms of the agreement between buyer and seller written into lines of code. The code and the agreements contained therein are stored on the Blockchain, making them secure and transparent.

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