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Agri-food safety optimized by blockchain technology: review

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Seguridad agroalimentaria optimizada por medio de la tecnología blockchain: revisión

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Iván González-Puetate[1,4]*, Carmen Marín-Tello[2] and Henry Reyes Pineda[3]

ABSTRACT

Blockchain technology is a distributed database, an innovation tool in the agri-food supply chain in processes such as production, distribution, marketing. In this research work, the blockchain technology application in agri-food security processes was evaluated, establishing the best conditions for its adoption in companies, this proposal synthesizes the contributions as a disruptive technology, for this, the information was collected from the period 2018-2020 from the Scopus and Web of Science bases, performing an analysis of the information using the Atlas TI 8.4 software, establishing the focus of the research on a network of codes suggested by some authors. It was found that the contribution of Blockchain for the years of study was traceability 26%, supply chain 17.5%, technological development 10.4%, trust 9.8%, among others. It is concluded that establishing the theoretical link between technology and traceability processes in supply chains, traceability in the agri-food sector is essential to certify information of interest to the stakeholder group. This is because traceability is the transcendental element of the food safety system that allows guaranteeing control in the supply chain when processes are being recorded and enriching the databases, which can be available to the final consumer to check the details of the production cycle and that technological elements generate competitiveness in companies with blockchain in their procedures, promote high levels of transparency, data security, decentralization, among other terms associated with trust, and a better relationship with the consumer is developed and a greater number of sale increasing profitability.

Keywords:
Agri-food sector
Blockchain technology
Food supply
Health surveillance
Traceability
Trust

RESUMEN

La tecnología Blockchain es una base de datos distribuida, una herramienta de innovación en la cadena de suministro agroalimentario en procesos como: producción, distribución, mercadeo. En este trabajo de investigación documental se evaluó la aplicación de la tecnología Blockchain en los procesos de seguridad agroalimentaria, estableciendo las mejores condiciones para su adopción en las empresas, esta propuesta sintetiza los aportes como tecnología disruptiva, para ello se recolectó información entre 2018 -2020 a partir de las bases Scopus y Web of Science, realizando un análisis de la información utilizando el programa Atlas TI 8.4, estableciendo el foco de la investigación en una red de códigos sugeridos por algunos autores. Se encontró que el aporte de Blockchain para los años de estudio fueron trazabilidad 26%, cadena de suministro 17.5%, desarrollo tecnológico 10.4%, confianza 9.8%, entre otros. Se concluye que, estableciendo el vínculo teórico entre tecnología y procesos de trazabilidad en las cadenas de suministro, la trazabilidad en el sector agroalimentario es fundamental para certificar información para el grupo de interés. Esto porque la trazabilidad es el elemento trascendental del sistema de seguridad alimentaria que permite garantizar el control en la cadena de suministro cuando se están registrando los procesos y enriqueciendo las bases de datos, que pueden estar a disposición del consumidor final para verificar los detalles del ciclo de producción y que los elementos tecnológicos generen competitividad en empresas con blockchain en sus trámites, que promuevan altos niveles de transparencia, seguridad de datos, descentralización entre otros términos asociados a la confianza y se desarrolle una mejor relación con el consumidor y mayor número de ventas aumentando la rentabilidad.

Palabras clave:
Sector agroalimentario
Tecnología blockchain
Suministro de alimentos
Vigilancia de la salud
Trazabilidad
Confianza

[1] Facultad de Ciencias Económicas, Administrativas y Contables. Universidad del Quindío. Colombia. ivanr.gonzalezp@uqvirtual.edu.co
[2] Facultad de Farmacia y Bioquímica. Universidad Nacional de Trujillo. Perú. cmarin@unitru.edu.pe
[3] Facultad de Ciencias Agroindustriales. Universidad del Quindío. Colombia. hreyes@uniquindio.edu.co
[4] Facultad de Medicina Veterinaria y Zootecnia. Universidad de Guayaquil. Ecuador.
* Corresponding author

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INTRODUCTION

The world economy is undergoing dramatic changes, driven largely by the availability of digital information at high speed that allows the exchange of assets quickly, in real-time, and with remote sensors that generate a line of traceability, blockchain technology along with other digital tools are currently making inroads in the financial, pharmaceutical, agri-food, and other sectors. The generation of knowledge of ICT (Information and Communication Technologies) is in its initial stage. This research evaluated the application of blockchain technology (BT) in the agri-food supply chain, the strengths of the implementation of blockchain technology in agri-food innovation processes, and the influence of BT on the competitiveness of agri-food supply chains. This technology is constantly growing, the dynamism of its applications is of interest to businessmen, entrepreneurs and research and innovation personnel because they are in constant search of its implementation in the production, distribution, marketing processes and consumption of raw materials, by-products, and processed foods (Saberi *et al.,* 2019; Torky and Hassanein, 2020).

The information generated by economic transactions, the exchange of information and product tracking, creates a traceability system, which allows the end customer to perform a reliable control of the food or service. Blockchain technology establishes commitments, business, audits, certifications, or validations in real-time, with simultaneous verification of information by users. Advances in this monitoring system would allow those in the supply chain to establish more rigorous control, indicating improvements in quality and safety standards. Systematic adoption in the agricultural sector would help in local, national and international negotiation processes, establishing a reliable and dynamic intervention with instant feedback, to speed up a decision making (Feng *et al*., 2020; Mahyuni *et al*, 2020).

The pace of technological and business innovation has increased over the last few years, making it difficult to develop business models that maintain sustained profitability over time. It should be emphasized that the internet enables the creation of new business models with instant global reach (Alvarez, 2018).

Blockchain technology after cryptocurrencies and their transactions without the need for an intermediary and in a secure manner, passed to the second generation through smart contracts, allowing to establish the relationship through external conditions that are executed or not. Subsequently, the third generation of blockchain arrived, which consists of decentralized applications. These generations use the blockchain with the internet of things (IoT), in such a way that sensors are utilized to transmit information to the blockchain and allow smart contracts to be executed. Also, blockchain technology could work together with artificial intelligence establishing a possible fourth-generation (Beltrán, 2020).

To estimate the relationship between innovation and profitability, a cluster analysis was performed, using the benefit ratio: cost of productive activity studying adoption and speed in innovation processes. The highest rates of innovation are related to the production and conservation of natural resources (75%), allowing farms with ancestral production and greater innovation to present higher profitability (Espejel *et al*., 2019).

The use of productive programs through networks that facilitate greater integration and partnerships between companies is one of the main pillars to sustain competitiveness, and the generation of an enabling environment for business are some indicators of interest in business competitiveness for the Organization for Economic Cooperation and Development (OECD) (Ibarra *et al*., 2017).

By optimizing the production chain of the agricultural sector in Colombia will be possible to take advantage of agro-industrial waste, reducing environmental impacts with the reuse of potentially polluting waste and with high disposal costs, also by gradually reducing the consumption of fuels from petroleum, emission of CO_2 and other pollutants; additionally, the optimization of the production cycle may generate employment at each stage, favoring unskilled labor and rural sectors, boosting the growth of the agricultural areas (Duque and Fúquene, 2020).

BT is an emerging technology with initial development and little experience of incorporation in supply chain companies. These companies developed Origin Chain, which is a blockchain-based traceability software that restructures the current system by replacing the

central database with blockchain. Both qualitative and quantitative analysis of Origin Chain's software was also demonstrated. Based on our experience and analysis, finding that the structural design of smart contracts has a great impact on the quality of the system (Xu *et al*., 2019).

Likewise, Eskardillo computer technology (ESK), is a tool with a smartphone terminal that is based on three principles: i. systematic recording of individual data (milking control, productivity, genetic merit, morphology), ii. phylogeny, processing and interpretation of big data and iii. interactive feedback to the farmer to optimize animal selection. Unquestionably, the management of big data favors the decision-making process to optimize modern enterprises to maintain sustainable intensification (Belanche *et al*., 2019).

Applications such as iSolve or BlockRx and their private companies look to the blockchain to develop proprietary technologies, it is interesting to underline decisions that seek to optimize the daily operability in markets, the protection of confidential information and the development of new drugs or the efficient distribution of drugs along the entire supply chain. It is also important the advantage of drug origin verification, through the implementation of smart contracts leaning towards new services (Preukschat *et al*., 2017).

Vertical integration is a type of supply chain governance with research opportunities for the implementation of sustainable approaches (corporate social responsibility, green supply chain management, industrial ecology, stakeholder theory, circular economy and sustainability science), mainly in small and medium-sized poultry supply chains. Furthermore, Brazilian environmental legislation still needs to be revised to align with the Sustainable Development Goals (SDGs) because the legislation will not guarantee sustainable management and efficient use of natural resources (Pohlmann *et al*., 2019). It is essential for poultry farmers to systematically collect data from the production environment to be successful in their production activities, where a sensor network was used to record poultry management data, which is then preprocessed using machine learning techniques. The results obtained were validated and compared with the action plans generated by a human specialist and bibliographic references. The analysis suggested that the action plans derived from the proposed model follow with acceptable accuracy (Ribeiro *et al*., 2018).

Studies show that to obtain greater competitiveness, companies should make improvements such as the search for new markets, project more work on achieving bar codes for all products, staff training programs, take advantage of support programs both for the acquisition of equipment and its management and use, according to current requirements and trends, and seek alternatives for collective certifications such as designations of origin, which can be more economical, but with recognition and value-added (Torres *et al*., 2020).

The growth of the industry in different sectors makes Colombia an economic power of reference in the region. For this reason, the different productive sectors must generate initiatives aimed at innovation and implementation of new technologies such as blockchain to make a competitive leap in global markets (Cardona and Orozco, 2019).

Likewise, the analysis conducted allowed testing that investments in innovation have caused an increase in the productivity of small and medium-sized companies in Mexico. Investment in research and development (R&D) did contribute positively to investment in innovation. The small and medium-sized companies that invest the most in innovation are not only those with the largest budgets or the most R&D plans but also those that regularly carry out technological activities, such as acquiring licenses, updating processes, modifying products or developing their technologies. Innovation is a competitive advantage for companies with the skills to capitalize on it. Lately, it has been recognized that there are relentless and triumphant innovation processes in small and medium-sized enterprises in Latin America (Kato-Vidal, 2019).

Innovation, known as digital opportunity trust (digital opportunity trust, DOT) is an entrepreneurship solution to address difficulties in the agricultural market, innovation based on the synthesis of tacit knowledge (knowledge based on experience in agriculture and agribusiness) and codified knowledge (based in computer programming) builds the space of innovation opportunities to positively address agricultural problems (Relf-Eckstein *et al*., 2019).

The supply chain for agribusiness products is in an incipient stage, with isolated operational problems, with little attention to their interdependence, which can be attributed to the fragmented nature of the supply chains themselves and the lack of integrated transportation and information infrastructure. The main factors related to successful integration are human resources, organizational strategies, information and information technologies implemented by the organization, with the last two being of more weight according to the authors (Bustillos and Carballo, 2018).

Logistics processes occur at all levels, but especially important are the logistics of procurement and distribution of finished products. An inefficient logistics process can generate a loss of customers and a decrease in both regional and national market share, which ultimately means losses for the company. Larger companies have logistics schemes that guarantee the timeliness and quality of the processes (Benavides-Sánchez *et al*., 2018).

The above background allows evidencing that the emerging blockchain technology is a tool of great interest to innovate in productive and operational processes in the agricultural sector, this multiconnected network with the simultaneous online participation of several users, allows performing a systemic control of each process, reliable transparent management in businesses or companies that transfer and track their commercial procedure.

MATERIALS AND METHODS

The present work was carried out through the qualitative method to understand the concepts of blockchain technology. The information was processed using the specialized analytical recording technique (RAE), and the Atlas TI 8.4 software was used for the analysis. In addition, technical sheets were made to optimize the analysis.

RESULTS AND DISCUSSION

The characteristics of BT need to be evaluated in order to make decisions for the benefit of users. Therefore, the following factors were analyzed in the review:

Traceability. Blockchain technology brings a new hope in quality control systems that ensures traceability from post-harvest and food distribution through nodes with its stakeholders in the value chain (Varghese *et al*., 2019). In addition, it enables traceability of the food and ingredient supply chain is very difficult for retailers in the event of a foodborne illness outbreak.

It can be added that upstream (producers) and downstream (distribution and marketing) members of the supply chain require the development of information bases related to traceability to provide evidence of state regulatory compliance to the most demanding customers and control bodies (Casino *et al*., 2020). Small producers or retailers can monitor the current capacity of distributors and be directly connected to place new orders using the entire traceability system to collect relevant information such as delivery time, batch size, storage and transportation conditions (Kayikci *et al*., 2020).

Trust. Blockchain technology allows the company to generate a relationship of trust with its consumers, through decentralized verification, strategically solving the customer churn that marketing managers face. Also, decreasing costs related to attracting new customers through advertising and promotions (Ramírez, 2020). Technological trust refers to the performance and availability of blockchain by using encryption as the main strength, developing privacy features and security, establishing significant factors for the adoption of blockchain technologies (Gökalp *et al*., 2020). In addition, technology plays a key role in improving collaboration through rapid trust-building among the numerous actors involved in relief operations in case of natural disasters or health issues (Dubey *et al.,* 2020).

Data security. Currently, supply chains have been enhanced to their maximum expression by incorporating technological tools such as social networks where the use of digital platforms for education at all levels, teleworking, procurement of food, pharmaceutical, cleaning products, among others. Especially blockchain technology for the realization of transactions in real time between different designated parties, establishes security and immutable conditions. In addition, blockchain can be used to monitor public health surveillance data (Porcelli, 2020). Food safety can be improved through traceability with blockchain solutions since these can be used to take advantage of the information from each node in the supply chain, this data is more reliable and tamper-proof thanks to the blockchain feature, which guarantees the quality of food (Varghese *et al*., 2019).

Thanks to greater transparency and higher quality of transaction details, blockchain brings improvements in food safety and quality, such as product sustainability and consumer awareness (Tripoli and Schmidhuber, 2018).

Transparency. Blockchain technology is a tool that will represent a new method of trust and transparency without the need for third parties, in addition to generating control, process agility and observation of the data embedded in the nodes. Demonstrating information and trust can be relevant for the growth of companies, since it allows to substantially change the operation of the world economy and industry today (Avila, 2018; Vargas, 2018). Blockchain technology can evidence some benefits for consumers such as product traceability and information transparency. This is particularly useful, especially in agri-food companies, where customers are concerned about the composition and its effect on the organism, demonstrating the origin of products and components, with ethical and responsible production (Cardona and Orozco, 2019). In addition, it can be established that food safety, value chain efficiency and transparency are effectively improved by ensuring high transparency, stability and reliability of the agri-food value chain. Finally, it can provide liquidity, more accurate record-keeping and high transparency of ownership (Zhao *et al.*, 2019).

Decentralization. Blockchain is the newest technology, it is a distributed digital that can record transactions in multiple sets of blocks. It is a decentralized system that does not rely on a single entity for safekeeping, which ensures security (Varghese *et al.*, 2019). Key technological components such as communication protocol decentralized storage, smart contracts and cloud are necessary to build a blockchain system (Zhao *et al.*, 2019). Also, blockchain-based transactions are being tested in many sectors, such as finance, manufacturing, energy, and government. They are also being used in relation to agri-food supply chains. The adoption of this technology promises to offer a transparent, decentralized and secure transaction process and can reduce transaction costs (FAO, 2019). In addition, BT with its technological infrastructure allows databases to be decentralized and updatable in real-time, thus allowing applications, proprietary and third-party services to be within reach of mobile devices, solving new customer needs (Pino and Prado, 2019).

Factors influencing the implementation and competitiveness of the supply chain

The results of the documentary research on the application of blockchain in agri-food safety processes show that several factors allow strengthening the implementation and influence the competitiveness of the supply chain.

In Table 1, it is recorded that most of the authors established that traceability (26%) was the main term to determine conditions for initial adoption of the blockchain system in their companies, considering that the digital traceability of products is a modern tool to know the conditions of each input, product or service. The second factor reported with the greatest influence is the supply chain (17.5%) where processes are enriched with various details gathered in databases, which can be available to customers or consumers to verify the specific information of each product. In third place, technological development (10.4%) is observed as an influencing factor with the support of information and communication technologies: big data, cloud, internet of things, radio frequency identification, data analysis among others, since applications integrated into the blockchain can allow companies to manage production processes and promote new levels of competitiveness and profitability in the agri-food sector.

The term trust (9.8%) ranks as the fourth most important factor according to the authors, because trust is associated with transparency, data security, decentralization and interoperability, which together add up to (29.1%) that allow real-time monitoring of stakeholders. This partnership develops a high level of security among producers, traders and consumers to develop and conclude various negotiations within the supply chain.

Strengths of blockchain implementation in agri-food innovation processes.

In the following section, the strengths of the implementation of blockchain technology in innovation processes were evaluated (Table 2), identifying the importance of each code establishing an interaction between the following terms: trust, data security, transparency, decentralization and interoperability, traceability in the supply chain was also identified as the main component, according to the assessment of the authors.

Table 1. Factors that most influence the competitiveness of the supply chain according to publications in the years 2018-2020.

Terms	No.	%	Main authors (> # of references in the review)
Traceability	393	26	Zhao *et al*., 2019; Helo and Shamsuzzoha, 2020; Sunny *et al*., 2020; Feng *et al*., 2020.
Supply Chain	265	17.5	Saberi *et al*., 2019; Kayikci *et al*., 2020; Helo and Shamsuzzoha, 2020.
Technological development	157	10.4	Torky and Hassanein, 2020; Zhang *et al*., 2020; Lu, 2018.
Trust	149	9.8	Ramírez, 2020; Mahyuni *et al*., 2020; Dave *et al*., 2019.
Data security	127	8.4	Qian *et al*, 2020; Li *et al*., 2018; Dutta *et al*., 2020; Zhao *et al*., 2019.
Competitiveness	117	7.7	Gloet *et al*., 2020.
Sustainability	111	7.3	Saberi *et al*., 2019; Kamble *et al*., 2020; Mahyuni *et al*., 2020.
Transparency	94	6.2	Casino *et al*., 2020; Dubey *et al*., 2020; Astill *et al*., 2019.
Decentralization	51	3.4	Varghese *et al*., 2019; Dutta *et al*., 2020; Lu, 2018.
Cost reduction	30	2.0	Gloet and Samson, 2020; Astill *et al*., 2019; Longo *et al*., 2019.
Interoperability	20	1.3	Lu, 2018; Saberi *et al*., 2019; Lezoche *et al*., 2020.
TOTAL	**1514**	**100**	

Table 2. Network of factors and associated codes to establish the strengths of blockchain implementation in agri-food innovation processes, review in the Period 2018- 2020.

Factor	No.	%
Traceability	393	47.1
Trust	149	17.9
Data security	127	15.2
Transparency	94	11.3
Decentralization	51	6.1
Interoperability	20	2.4
TOTAL	**834**	**100**

The research established two important lines to identify the strengths for the adoption of BT, traceability (47.1%) is the main element that is directly related to various monitoring processes and transmission of information from the origin of inputs to the sale or consumption of food, a tool that allows increasing the level of linkage of this system in the agri-food sector, the second network of codes is represented by the term trust (17.9%), establishing a high degree of association with data security processes, transparency, decentralization and interoperability terms, which can provide the appropriate level of credibility in each of the procedures of production, development, distribution and marketing of agri-food products to generate an easy adoption of blockchain technology.

Interaction between the levels of strength for BT implementation.

The interaction of the code network concerning the level of strength and its association for blockchain implementation in agri-food innovation processes can be observed in Table 3.

Ultimately, BT presents strengths where it increases conditions for tracking, recording, transmission and automated analysis of data by using a transparent, secure and intelligent network with the ability to communicate

Table 3. Strengths of blockchain implementation in agri-food innovation processes.

Main elements	Contribution in blockchain	Reference
Traceability	Improve yield by providing security and full transparency. Timely identify the source of food production.	(Feng, Wang, Duan, Zhang *et al.*, 2020).
	Develop an internal traceability system, improve traceability performance in food processing.	(Qian *et al.,* 2020).
	Ensure traceability and authenticity in the food supply chain.	(Galvez *et al.*, 2018).
	Improve traceability performance by providing full security and transparency.	(Astill *et al.*, 2019).
Trust	Reliable data storage with integrated privacy and management.	(Kayikci *et al.*, 2020).
	Its transparent, autonomous and secure nature can eliminate any possibility of manipulation, bias or error.	(Mahyuni *et al.*, 2020).
	Creates a bond of trust with users.	(Dave *et al.*, 2019).
Data security	Reducing the role of intermediaries in the network.	(Saberi *et al.*, 2019).
	Immutable data records, distributed storage and controlled user access.	(Mahyuni *et al.*, 2020).
	Ensuring data integrity and preventing tampering.	(Zhao *et al.*, 2019).
	Re-engineering business processes to improve security.	(Dutta *et al.*, 2020).
Transparency	Providing evidence of regulatory compliance to both state authorities and demanding customers.	(Casino *et al.*, 2020)
	Significant positive influence on the transparency of the operational supply chain.	(Dubey *et al.*, 2020)
	Increases the ability to track goods and reduces the need for a third party to monitor the network and control information.	(Ronaghi, 2020)
	Generates information security and integration of different stakeholders.	(Cardona and Orozco, 2019)
	Brand consumption increases when more information from the producer can be verified.	(Ramírez, 2020)
Decentralization	Create a new non-centralized programmable intelligent ecosystem.	(Lu, 2018)
	Minimize dependencies between organizations.	(Mahyuni *et al.*, 2020)
	Decentralized structure, distributed notes.	(Dutta *et al.*, 2020)
Interoperability	Agri-food 4.0, development of the sector based on digital technologies, as well as the process of interoperability between them.	(Lezoche *et al.*, 2020)

useful information in real-time to manage the supply chain (Dubey *et al.*, 2020; Ronaghi, 2020).

Influence of blockchain technology on supply chain competitiveness.

It is important to determine the conditions of greater influence of blockchain technology with greater economic and social profitability within an agri-food supply chain, considering that competitiveness is fundamental to automate traceability and transmission of information of productive and operational processes, with efficient and reliable security measures (Table 4).

Table 4 reports the conclusions of experts from the agri-food and technology sector who positively linked the adoption and application of blockchain technology in supply chain processes to the competitiveness factor (17.2%), the codes technological development (23.1%), sustainability (16.3%) and cost reduction (4.4%), which allowed to establish themselves as the main tools that could lead the company to stand out in the market, the supply chain code (39%), evidences the activity of blockchain in agri-food processes, it can be added that this relationship is growing in recent years due to the wide interest of professionals through scientific publications. In relation to the competitiveness that would be achieved with the application of blockchain technology, studies report that trust can be generated among stakeholders, which will allow them to inspect the record of the entire supply chain.

Table 4. Network of factors and associated codes to determine the influence of blockchain technology on the competitiveness of agri-food supply chains, review in the period 2018- 2020.

Factor	No.	%
Competitiveness	117	17.2
Technological development	157	23.1
Sustainability	111	16.3
Cost reduction	30	4.4
Supply chain	265	39
TOTAL	**680**	**100**

Stakeholders can comprehensively track information to determine the traceability and authenticity of each food product. In addition, BT can contribute significantly to sustainability (Galvez *et al*., 2018).

Also, a rapid evolution known as Industry 4.0 is taking place, comprising new digitization technologies such as blockchain and IoT that provide competitive advantages in supply chain users. The use of these new technologies is expected to improve process efficiency, speed and quality, which for perishable food products, in particular, is of great importance. Also, these technologies can improve product traceability and authenticity, which are valuable for domestic and export markets (Gloet and Samson, 2020).

When some external information or a sudden change in metrics occurs, management can target and investigate the next levels of metrics for detailed analysis. Acceleration of the decision-making cycle, through reliable real-time data, enables the growth of supply chain metrics, where speed in obtaining actionable information from data is a competitive feature. The control mechanism of performance metrics has remained similar: the loop has been accelerated, and data provide a valuable source of insight into the details and micromechanisms of operations (Helo and Shamsuzzoha, 2020).

Cost reduction. The adoption of traceability systems in the agri-food production chain by government institutions mainly covers legal and logistical aspects. The methodology is considered complex and costly, and nowadays they give greater consideration to the efficiency of logistical processes. Also, the importance of sanitary safety and the characteristics of the consumer market has increased (Ribeiro et al., 2020). The data and transactions carried out in the chain are recorded in the blockchain using smart contracts. The blockchain system is more efficient, more secure, more transparent and avoids intermediaries, resulting in lower costs for cooperative members, while generating greater confidence in distributors, supermarkets and consumers, developing a long-term benefit for small farmers and cooperatives (Borrero, 2019). A properly redesigned supply chain can achieve synchronization of tracking information across all business domains. In addition, the use of smart contracts can help reduce the time and costs required for supply chain reengineering (Dutta *et al*., 2020).

The food supply chain with IoT and blockchain-enabled applications can develop systems with increased cost-effectiveness, therefore the overhead associated with the technologies should be minimized and the resulting increase in transparency should translate into increased revenue for the company (Astill *et al*., 2019). The adoption of blockchain avoids the expenses of bank transfers, currency exchange, overhead and intermediation costs, it also reduces the use of paper in documents, certificates and printed reports (Pino and Prado, 2019). In addition, it promotes the efficient use of time and resource consumption to validate a transaction from days to seconds (Galvez *et al*., 2018; Avila, 2018).

Technological development. History has shown that technological advances that generate productivity gains prevail, blockchain technology will continue to be adopted throughout the global economy, shaping the future of that of agriculture, provided that productivity gains are real (Tripoli and Schmidhuber, 2018). Adoption of Industry 4.0 technologies is suggested as a strategy to establish agile processes in the supply chain ecosystem, seeking to meet dynamic demand, establishing collaborative networks and shared responsibility for a sustainable future (Sharma *et al*., 2020).

Intermediaries on the blockchain platform can provide basic functions without participating in the platform and service to both the producer and the consumer. The blockchain service provider helps its customers to integrate the platform with blockchain into their existing IT infrastructure and, in addition to consulting and implementation offers customization of the platform to meet specific customer requirements such as encryption, time chain and immutability (Tönnissen and Teuteberg, 2019). Industry 4.0 can generate the transformation towards a smart factory, when a fully articulated human-machine interaction is achieved, resolving the information asymmetry of technology, processes and collaborators. The complexity of this change lies not only in the lack of clear implementation guidelines in literature and structured information but also in enabling and convincing companies and operators about the advantages in their processes (Longo *et al*., 2019).

Sustainability. Agri-food supply chains play an essential role in achieving the UN Sustainable Development Goals, i.e., SDG 2 by ending hunger through achieving food security and improved nutrition and SDG 12 by ensuring sustainable consumption and production. Therefore, there is a need to investigate the impact of risks and build resilient agri-food supply chain organizations (Sharma *et al*., 2020).

The electronic sites used different technological tools to fulfill purposes such as promotion and awareness to the consumer about the importance of food selection, labeling, not throwing away leftover food but recycling it, making a new one. Helping small producers to reach, directly and without intermediaries, their products to consumers or a local market. Benefiting producers, as it lowers their costs, provides them with visibility and reduces poverty, as well as end buyers since they have the opportunity to follow the product they consume from harvest to sale (Porcelli, 2020). Blockchain technology can contribute to the sustainability of the social supply chain, distributing information in a stable and immutable way strengthening the sustainable building of the supply chain. Since information cannot be altered without the approval of accredited officials, blockchain can prevent corrupt users or organizations from illegal seizure of property. In addition, blockchain technology can block nefarious individuals and hold the dishonest accountable for both their social and individual misdeeds (Saberi *et al*., 2019).

Supply chain. The blockchain is formed through a series of connected blocks, where transaction history can be easily traced through previous blocks, making the technology transparent and reliable. Each block contains its own unique identification and has the hash of the previous block, ensuring secure transactions. All transactions are validated and recorded by the users of that network; they are also time-stamped, ordered chronologically are connected to the previous block and are irreversible once added to the network (Dutta *et al*., 2020). The current agri-food sector is transforming its integrated and centralized systems to shared and distributed systems. Most of the proposed frameworks to achieve higher performance are based on blockchain technology and cloud computing, which aim to provide secure, energy-efficient, and high-efficiency systems to agri-food manufacturers (Zhao *et al*., 2019).

Blockchain-based digitization and traceability can be used both in plants and in the animal food chain. However, the

Table 5. Influences of blockchain technology on the competitiveness of agri-food supply chains.

Main elements	Contribution of blockchain	Reference
Competitiveness	Great opportunity to establish automation.	(Lu, 2018).
	Collecting data from multiple stages within supply chains.	(Astill *et al.*, 2019).
	Traceability is the key to developing operational efficiencies and improving customer service.	(Varghese *et al.*, 2019).
	Track data and real-time location to generate key performance indicators.	(Dutta *et al.*, 2020).
	Minimize fraud and errors in supply chains, increase quality and safety of food products.	(Mirabelli and Solina, 2020).
	Greater autonomy and intelligence in managing precision agriculture in a more efficient and optimized way.	(Torky and Hassanein, 2020).
	Feed and pasture control, along with an increase in milk production and quality.	(Beltrán, 2020).
	In a trusted decentralized system, the consumer is willing to pay more for the same product.	(Ramírez, 2020).
Sustainability	Improved collaboration through rapid trust building among various stakeholders in operations.	(Dubey *et al.*, 2020).
	More social and transformative sustainability trends.	(Gloet and Samson, 2020).
	Decrease the need to transmit electricity over long distances.	(Mahyuni *et al.*, 2020).
	Improvements in production efficiency and reduction of resource and food waste.	(Astill *et al.*, 2019).
	Improved sustainable water management.	(Zhao *et al.*, 2019).
Cost reduction	The blockchain-based smart contract will have a big impact on transaction costs because the network executes it automatically.	(Mahyuni *et al.*, 2020).
	Saving time to make effective decisions based on objective data.	(Lezoche *et al.*, 2020).
	Elimination of middlemen to validate customer identification, information governance and transaction security.	(Pino and Prado, 2019).
Technological development	Deliver operational excellence by partnering with smart technologies.	(Zhang *et al.*, 2020).
	Introducing solutions for chronic safety and yield challenges in precision farming systems.	(Torky and Hassanein, 2020).
	Optimizing batch blending with AI, quality forecasting with big data and credible traceability with blockchain.	(Qian *et al.*, 2020).
	Facilitating the development of a distributed peer-to-peer network with high security, scalability and a well-structured cloud system.	(Li *et al.*, 2018).
	RFID (radio frequency identification) and IoT (Internet of Things) provide real-time information or data.	(Dutta *et al.*, 2020).
	Drive data-driven digital supply chain.	(Kamble *et al.*, 2020).
	Using sensors and drones, support data collection.	(Lezoche *et al.*, 2020).
	With distributed software architecture and advanced computing, can exchange information between chain players.	(Ronaghi, 2020).
	IoT and smart contract integration is dramatically elevating blockchain applications.	(Sunny *et al.*, 2020).
	IoT, big data analytics and visualization can help organizations achieve operational excellence in conducting life cycle assessment to improve supply chain sustainability.	(Zhang *et al.*, 2020).
Supply chain	Responsibility for distributing correct information.	(Kayikci *et al.*, 2020).
	Improve information exchange and flow of disaster relief funds.	(Dubey *et al.*, 2020).
	Store chemical analysis data in chronological order, so that it is impossible to manipulate later.	(Galvez *et al.*, 2018).
	Apply an algorithm to obtain a Food Quality Index (FQI).	(Varghese *et al.*, 2019).

challenges for such implementation are varied depending on different industry needs, workforce skill set and technical capabilities. But blockchain has great potential to save time, increase customer confidence, and reduce costs and risks in the food chain (Longo *et al*., 2019). Data in an agri-food supply chain are collected from all four supply chain processes, i.e., planning, sourcing, manufacturing, and delivery. However, the planning and delivery processes contribute greatly to the development of data analytics capability compared to the sourcing and manufacturing processes. The agri-food supply chain was found to use different resources for data collection and analysis (Kamble *et al*., 2020).

The significant benefits of this blockchain system in supply chain management can be increased distributed value, the satisfaction of a greater number of demands at the same time, improvements of input-output responses and customer cost can be easily boosted. It can be added that blockchain improves the visibility of supply chains, enabling automation of processes, eliminating middlemen and enabling real-time tracking through traceability, privacy and data management techniques, which are the cornerstones of supply chain reengineering (Dave *et al*., 2019).

In general, looking for strategies to highlight the agri-food sector companies in the global market, the participation of BT in production and operational processes can develop substantial improvements by integrating technological elements to ensure traceability procedures, allowing a sustainable development in business (Dutta *et al*., 2020; Sunny *et al*., 2020).

CONCLUSIONS

Blockchain technology is an innovative tool with the ability to create new profitable ecosystems with great support from society for economic and scientific development, it should be clarified that, in the last decade, growing economies stand out among other things for high investment in technology.

The review showed that a high level of integration of information and communication technologies aims to improve production and operational processes in the agri-food sector, streamline decision-making, production cycles and transport times, generating offers of innovative products in line with the real behavior of the market.

The study had several limitations, which can be addressed by future researchers, the research was focused on the agri-food supply chain, discarding pharmaceutical, maritime and unprocessed fresh food processes. Multiple production sectors should generate targeted initiatives with blockchain implementation to establish a competitive footprint in national companies and global markets.

The key to the relationship between blockchain and logistics is in the integration of their processes through sensors, automating documentation, incorporating real-time information and reducing the probability of human error, the studies reviewed highlight the strengths of this association generating importance in the elements such as traceability, trust, data security, transparency and decentralization as main features. This latter element becomes relevant in countries such as Colombia and Peru, where the agri-food chain is centralized.

State organizations responsible for the control of contaminated products could standardize surveillance concepts, developing computerized and proven processes of the supply chain in real-time, these procedures may have a high level of response and action in the prevention of foodborne diseases.

With the integrated involvement of the cloud, artificial intelligence, data analysis and the transmission of information in real-time using the Internet the accurate flow can be increased, enabling the authenticity and transparency of agri-food traceability systems. Determined that elements such as technological development, sustainability and cost reduction contribute to the quest to compete in globalized environments.

Finally, blockchain technology can improve supply chain sustainability by decreasing resource use, optimizing consumption and food quality, competitive companies aim to be efficient and scalable to address these issues in the long term. Operational staff training and knowledge development can be the key to success for early blockchain adoption, this training process should have a playful character to facilitate and increase the

number of collaborators that promote a positive impact on society.

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