Blockchain for Agri-Food Supply Chain Traceability

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Abstract

The supply chains around the agri-food sector are, in economic terms, one of the most relevant activities at an international level, employing millions of people, mainly in developing countries. The complexity of this supply chain includes key aspects related to the identification of food, from origin to final consumption.
This article conceptually describes a proposal for developing a traceability system based on Blockchain and smart contracts as a disruptive technology, integrating tools for the consensus and participation of the parties involved in this supply chain. In this approach, incorporating the Public Participation Geographic Information System (PPGIS) is proposed as an information management mechanism. The different entities for the supply chain are described, including the inclusion of logistics operators (3PL). The results show a model for the implementation of Blockchain based on smart contracts and traceability tools such as PPGIS. This proposal facilitates the development of logistical aspects to increase the competitiveness of the agri-food sector.

Keywords
Smart contract, Geographic Information Systems, logistics, agri-food and barley.

1. Introduction
The supply chains around the agri-food sector are, in economic terms, one of the most relevant activities at an international level, employing millions of people, mainly in developing countries. In particular, agriculture and food supply chains have positioned themselves as an industry that generates trillions of dollars annually (Miloudi et al., 2020). These agri-food supply chains offer a response to the nutritional needs of people around the world, seeking to sustainably preserve natural resources, also promoting progress and quality of life in rural areas where food is produced, sown or harvested.

According to estimates by the Food and Agriculture Organization of the United Nations (FAO), the agri-food sector will have to increase its yields in a sustainable way by 70% by 2050. Given this scenario of growing demand for food, and that could lead to a food crisis, the need for "smart agriculture" is imminent and necessary to ensure the sustainability of the sector itself and of the supply chains that are interrelated with it. Generally, the products of the agri-food sector are used as inputs in some supply chains, where the consumer is usually the end customer (Borrero, 2019).

An agri-food supply chain is an extremely complex system (Dutta et al., 2020), which allows the circulation and distribution of agricultural products in different markets. The agri-food supply chain is also made up of different parties involved, including farmers, distributors, processors, wholesalers, retailers, and end consumers, who demand safe and high-quality products that include as much information as possible (Antonucci et al. , 2019). One of the main characteristics of these supply chains is that they are traditionally centralized and depend on a third party or intermediary (Granillo-Macías et al., 2018), to trade the products, so they lack transparency, responsibility, and audibility (Shahid et al., 2020). The geographical dispersion of farmers in rural areas, seasonality, and logistics requirements in food distribution are also relevant factors. (Miloudi et al., 2020) identifies the agri-food supply chain as a complex system dominated by factors such as food waste, expensive intermediaries, disconnection between suppliers and retailers, and sources of financing and limited payment options for Farmers. Small farmers' livelihoods

are especially vulnerable, as they may have difficulties assessing and managing traceability. In many cases, they do not benefit from investment opportunities that would improve their agribusiness.
According to (Galvez et al., 2018), the execution of traceability in food is also a problem that affects the agri-food sector since it is influenced by particular aspects such as 1) changing consumer preferences, 2) many demands overlapping and contradictory, 3) varying criteria and requirements for traceability by industry and product type and 4) long response times due to weak technical and information systems.

Finally, achieving food safety through tracking and storing orders and deliveries and providing transparency, traceability, and auditability characteristics are the main challenges and opportunities for traditional logistics information systems in agri-food supply chains (Caro et al., 2018).

With the development of next generation technologies, the information generated around the agri-food sector can be used to benefit aspects from food safety to transparency and logistics, offering the possibility of a smarter and more intensive development direction in this supply chain (Antonucci et al., 2019) (Baralla et al., 2021).

Using technologies such as Blockchain, Internet of Things, Global Positioning Systems, Cloud Computing, Artificial Intelligence and Big Data, as tools for large-scale collaboration between different stakeholders, the flow of information can be transformed, the flow of products and the flow of capital, through a set of network governance mechanisms (Fu et al., 2020). Food safety, food quality monitoring and control, traceability for waste reduction, analysis and reliable data exchange are some of the customer requirements, which can be addressed through blockchain-based technologies. (Lin et al., 2020).

The development of Blockchain applications focused on agriculture, presents favorable conditions for the improvement of various aspects in agricultural systems (Lin et al., 2020), especially for the administration of the supply chain and Internet-based systems of the Things (Galvez et al., 2018). According to the research carried out by (Duan et al., 2020), the Blockchain shows significant potential that could reliably address aspects of the agri-food sector. Food safety and quality stand out.

1.1 Objectives

This article aims to conceptually describe a proposal for the development of a traceability system based on Blockchain and smart contracts as a disruptive technology, which also integrates tools for the consensus and participation of the parties involved in this supply chain. In this approach, the incorporation of the Public Participation Geographic Information System (PPGIS) is proposed as a mechanism for the management of information in farmers. That potentially strengthens the confidence of the actors and parties involved that intervene in the different operations carried out in this chain. , which includes the distribution and logistics, transformation, commercialization, and consumption of agri-food products. The primary contribution of this article can be summarized as follows:

• The most relevant aspects of the proposals made by various authors are discussed to improve the performance of the agri-food supply chain, using Blockchain.

• A blockchain proposal is presented in the agri-food sector that integrates PPGIS as a collaboration and transparency mechanism for traceability.

• The integration of smart contracts is proposed to avoid intermediaries in the agri-food supply chain, suggesting the inclusion of logistics operators as actors for the distribution of products along this chain.

• The barley supply chain case study is presented as an example for applying Blockchain and smart contracts.

2. Literature Review

An agri-food supply chain, in a traditional way and with a decentralized logistics structure, is made up of various actors who receive or send information only to their customers or direct suppliers. For example, a supplier of inputs receives data from the farmer about the requirements for production or planting; at the other end of the supply chain, an end consumer sends information about his consumption requirements to a reseller. Each member of the agri-food supply chain, in this traditional scenario, makes its decisions independently of the decisions of its partners. On the other hand, when technologies such as Blockchain are integrated, the data is transmitted and shared in a synchronized way, making information about their inventory levels, products in transit and consumer sales data visible to all stakeholders (Figure 1).

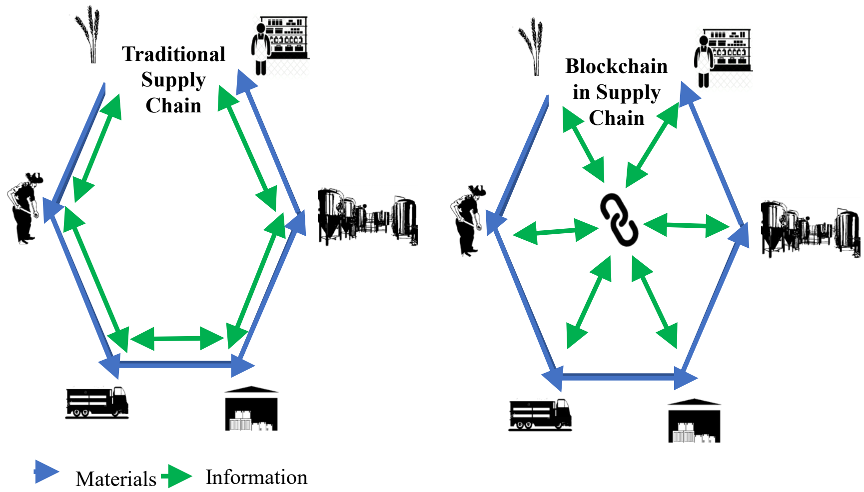

Figure 1. Blockchain in Agri-Food

In the agri-food sector, the use of smart contracts is also an advantage that supports aspects of monitoring, reliability, and traceability throughout the supply chain.

The development of reliable and robust technological applications for food traceability has been considered a central issue for the agri-food sector, mainly due to the constant risks of food adulteration. Cases such as meat contaminated with the "mad cow" disease that appeared in the United Kingdom, the discovery of a highly carcinogenic substance in flour for poultry and cattle in Belgium, or the food scandal in 2013 of horse meat that substituted veal in 4.5 million precooked dishes in Europe, demonstrate the importance for the consumer of being able to verify the nature of the products throughout the supply chain (Galvez et al., 2018).

(Accorsi et al., 2017) present a reference framework for the development of technologies in the agri-food supply chain, integrating aspects such as the nature of demand, the location of farmers, conditions such as climate, soil, and environment, access to natural resources, regulatory barriers, distribution networks, and logistics infrastructure, and packaging processes.

In the research carried out by (Galen, 2019), in which various organizations that have used blockchain technology to promote social impact in the agriculture sector were surveyed, the authors refer that these organizations use Blockchain mainly in the processes of management, registration, and verification of operations in the supply chain. (Galen, 2019) mention that specifically in agriculture, organizations apply Blockchain to improve transparency by improving the capabilities of tracking food from planting to final consumption. Eliminating intermediaries, allowing farmers to obtain more accurate information and obtain better access to markets are also some of the ends sought with the Blockchain (Galen, 2019).

Proposals such as the tracking of pork and mango sold by supermarkets, the export of grains, the certification of grapes, the distribution of farm eggs, the use of RFID tags to track cold chains, and the use of Internet of Things (IoT), are some of the applications based on Blockchain that are developed in the United States, Brazil and South Africa (Lin et al., 2020). In Italy, traceability problems are analyzed to guarantee the origin of agri-food products, which are made in this country, providing new technological solutions to stop food counterfeiting (Baralla et al., 2021).

Among the contributions that address the use of Blockchain in the agri-food supply chain, (Caro et al., 2018) proposes an entirely decentralized system for traceability called AgriBlockIoT, through blockchain implementations in Ethereum and Hyperledger, this system is linked through the Internet of Things (IoT) devices for data management and communication. The proposal of (Caro et al., 2018) also seeks to address certain problems, such as information inequality and inefficiency in food collection. (Galvez et al., 2018) presents the so-called AgriOpenData Blockchain, which, according to the author, is a system based on innovative digital technology that guarantees both traceability throughout the agri-food chain, as well as the processing of agricultural products in a public, transparent and secure. Another proposal, such as that of (Antonucci et al., 2019), addresses aspects such as the disclosure of information about ingredients and production methods, through the use of commercial blockchain applications, in the beer supply chain.

For the traceability of foods such as soybeans, (Salah et al., 2019) integrate a technological solution using Ethereum blockchain and smart contracts, with the purpose of tracking and carrying out commercial transactions, eliminating intermediaries during the supply, distribution and sale processes. . (Li et al., 2020) presents another example of the successful implementation of technology in the wood industry, in which Blockchain has been implemented to provide traceability from the moment of cutting to the transformation into usable materials. Under a transparent and traceable system, (Duan et al., 2020) conceptually describes an application for the food market in Malaysia that covers all aspects of the supply chain. In this conceptual model and based on the literature review, (Duan et al., 2020) identify as benefits of Blockchain: 1) improvement in food traceability, 2) improve transparency in the supply chain, 3) integration with Internet of Things devices and 5) support for improving the efficiency of food recalls.

(Salah et al., 2019) carry out a review of the literature, around technology and the agri-food supply chain, concluding that Blockchain still faces key challenges related to scalability, governance, identification registration, privacy, standards and regulations. (Dutta et al., 2020) also identifies functionalities that can be applied in the environment of the agri-food sector, such as the so-called "consensus mechanisms", which make Blockchain reliable, secure and transparent, where the decision to add a new block the system is taken through this consensus mechanism, in addition to the fact that the records are integrated into blocks linked through hash values. The hash function as an algorithmic way of generating unique IDs in the Blockchain, is used as a key element for data authentication (Lin et al., 2020). Finally, (Miloudi et al., 2020) presents a study on the challenges of the agri-food sector, highlighting food security, delayed transactions and data authentication, climate change, contamination incidents, food fraud, lack of trust and transparency. (Miloudi et al., 2020) conclude that IoT and geospatial technologies in the agricultural field can support the modernization of this sector, minimizing the disadvantages that exist between farmers and the different actors present along this supply chain.

3. Methods

Traceability through a system aims to record all the information related to the supply chain from operations with suppliers to the distribution of products, in addition to identifying and associating important data on environmental conditions and production methods. Our approach takes a multi-stakeholder perspective, integrating tools for participation in consensual decision-making.

The model suggested in this article presents a traceability scheme for tracking the product from origin to consumer, based on solutions proposed by (Shahid et al., 2020) (Borrero, 2019) (Salah et al., 2019) (Dabbene et al., 2014) using Ethereum blockchain and smart contracts. The characteristics of blockchain technology that are integrated in this model include 1) chain of blocks, where each block contains the data of all transactions and is connected with other blocks of the chain, 2) hashes, which are are chained and linked in a chronological order, 3) consensus algorithm for the validation of information, and 4) the use of smart contracts, with the advantage that these can significantly accelerate transactions and improve trust in Blockchain (Pournader et al., 2020). The potential of the Ethereum Smart contracts can be achieved by guaranteeing the quality of the products delivered to the client, through transforming the safety of agricultural and food products into an integrated intelligent system.

In general, the elements that make up this model are the following:
1.- Data layer made up of the interaction between the different entities or actors that make up the agri-food supply chain, identifying the roles of input suppliers, producers or farmers, logistics companies, processors, distributors, resellers and customers. It is highlighting that with Blockchain, the interactions and operations for the flow of products, materials, and information that take place between these actors are carried out together with auditable proof of delivery (Shahid et al., 2020).

2.- Blockchain layer that manages the data on transactional and delivery events integrated through a smart contract, in addition to integrating the Public Participation Geographic Information Systems (PPGIS) as a monitoring tool. PPGIS is an essential branch of Geographic Information System (GIS), with the advantage that it combines geographic information science with social sciences and the internet to make GIS available to the general public (Xiang & He, 2016), and of the different entities of the agri-food supply chain, with an emphasis on the farmer. In the agri-food supply chain scenario, PPGIS is proposed as a mechanism to empower farmers and producers in the different locations where it is produced and sown, adding value and authority to their spatial knowledge through the use of geospatial information technologies. In addition, PPGIS provides the support for sharing data, information and knowledge. Using PPGIS within blockchain smart contracts also seeks to offer community mapping, locating sources of food for livestock (water and grasslands), tree and plant species, mapping of risks in planting, areas of possible floods, elevations for the agriculture and areas that lack transportation for the distribution of products. The visualization of the spaces in the communities, the visual presentation of multiple realities in the farmers and producers, suggesting the provision of roads and rural routes for distribution and carrying out an inventory of natural resources available for production are also some of the additional aspects that are considered with the use of PPGIS.

3.- Finally, in a third level, the storage layer which is where blockchain transaction and event data are stored through a decentralized file system (IPFS). IPFS provides the hash of the stored file which is recorded in ethereum blockchain with a decentralized storage medium, taking advantage of low latency and scalability characteristics (Chen et al., 2017).

Using as an example a particular case of the agri-food supply chain of malting barley in Mexico, the following section details how the proposed system can achieve a solution for traceability through the management of the different parties involved based on Blockchain and contracts. smart.

4. Data Collection

Within grains and cereals, barley is the fourth most important crop in the world (FAO, 2020), grown in more than 100 countries. Barley grains are used mainly for feeding animals and in the production of beverages (Giraldo et al., 2019). Specifically, malting barley (Hordeum vulgare L.) is used as a raw material for production within industries such as beer. The production and export of food that takes place in Mexico is among the first worldwide (FAO, 2020), positioning this agri-food sector as a key element for the economic development of the country. At the international level, in 2019 the main exporter, in economic terms, of beer made from malt (a product derived from barley) was Mexico.

In this agri-food supply chain there are actors who assume different roles, for this case the entities that can interact within the blockchain system and smart contracts were identified. The functions and characteristics of each of these entities are summarized below:

• Seed company:
This entity is in charge of promoting the production of malting barley through a seed supply system, guaranteeing the permanence, continuity, and profitability of the participants in the supply chain. The seed company focuses on covering aspects of food safety such as safety, environmental conservation, and social responsibility.
This entity is also in charge of ensuring the quality and quantity of seeds that the malting industry requires through the provision of inputs such as fertilizers and nutrients used by the farmer during planting.

• Farmer:
The farmer is the first entity to invoke and, if necessary, create the smart contract to negotiate the purchase of seed and supplies with the seed company. In this scenario, the farmer is in charge of sowing and harvesting grains, assuming the initial responsibility of monitoring and recording the conditions of his crops. The conditions on sowing and harvesting can be recorded as suggested (Salah et al., 2019) through a decentralized file system as images. This information is stored in IPFS on various nodes that store the content of the file. The hash of the file's content is also recorded within the smart contract. In this proposal, the information provided by the farmer on planting conditions, crop locations, sources for water supply and inventory of natural resources, identification of roads and community gaps, as well as risks and access to means of transportation for the distribution, is registered in PPGIS so that it can

also be used mainly by other actors in the supply chain for a better understanding of the strategies to combat the disparities that farmers face during the planting processes. , harvest and distribution of grains.

• Logistics company:
Logistics company is the entity that manages distribution operations, executing logistics activities throughout the supply chain. This entity has characteristics similar to a 3PL, engaging in the functions of transportation, storage, inventory management, order processing and packaging, in addition to assuming the functions focused on the administration of information systems for the monitoring and traceability of goods. products.

• Maltera (grain elevator)
This participant buys the grain produced by the farmers. The malting machine verifies the quality through the evaluation of aspects such as the humidity with which the grain is delivered or the temperature and time with which it was stored. Once the quality has been verified, the grain is processed in the malting entity to convert it into malt, taking care of the physical and biochemical characteristics of the product throughout this process.

• Brewery
The processes of malting, grinding, filtration, cooking, fermentation, and maturation of grain, as well as the final packaging of beer are carried out by this entity.

• Distributor
The functions of a distributor are to maintain and control the storage of the final product for its later sale to resellers.

• Retailer
This entity purchases large quantities of batches of finished products from distributors. After the acquisition, the reseller sells in smaller batches of products to consumers, preserving the traceability and identification conditions with which they were manufactured.

• Customer
The consumer is the end user who buys and consumes the products from the reseller.

The seed company produces barley seeds according to certain specifications, granting the category of "certified seed" to seeds that meet the ideal requirements for sowing. As part of these specifications, the conditions in which the seed production is carried out are registered, verifying and inspecting the seed for sowing, from its origin, during its production process in the field, conditioning, storage and commercialization. The name of the seed company, the variety of the seed, the certifying agency or institution, quality (physical, physiological, phytosanitary and genetic) and brand of the seed, should be registered as suggested (Borrero, 2019; Salah et al., 2019; Shahid et al., 2020) using standardized identifiers. The purpose of these codes is to have a database made up of articles that are uniquely identified and traceable. The use of standard identifiers also allows the digital connection between products and transactions related to the processes carried out by the parties involved and entities in the agri-food supply chain.
The seed produced by the seed companies is bought by the farmers under certain conditions. The logistics company intervenes during this process, for distribution and transportation from the seed producer to the farmer's location. Details about seed growth are recorded using IPFS, during certain time intervals. The images on the development of the crop are stored in the smart contract by means of the IPFS hash of the file. The recorded characteristics include aspects such as 1) date of cultivation, 2) types of fertilizers used, 3) humidity, 4) chemicals applied in planting, among others.

5. Results and Discussion

Using PPGIS, farmers can record information not only on crop characteristics, but also on other key aspects of logistics and distribution. Due to the geographic dispersion and environmental factors in which the farmers carry out the sowing and harvesting. With PPGIS, it is possible to identify quality problems at different times and spaces. Environmental factors are made up of variables that are part of the agricultural environment including climate, soil, water, topography, biological and human factors. The data of these environmental factors are then registered in PPGIS with the purpose of offering information for the agricultural environment monitoring system that is registered in the smart contract on the blockchain layer.

Integrating the information from the data layer with PPGIS within the blockchain layer also allows addressing the identification of risk and uncertainty that is inherent in agriculture. The most common sources of risk present in the barley agri-food chain and that can be analyzed with PPGIS, include meteorological conditions, climate, diseases in the crop, natural disasters (floods and droughts) and market disturbances and the environment (Basualdo et al., 2015). The construction of the Smart contract with PPGIS can promote communication and involve the parties involved in an iterative process that refines the understanding of traceability and specific perceptions of the planting site.

Following the smart contract functions, the harvested product is sold by the farmers to the malting plant, verifying specific conditions that can alter the quality of the product, such as the percentage of moisture in the grain and the temperature. In the malt, during the operations carried out to process the grain and convert it into malt, the variables that evaluate the quality of the product must be recorded in the blockchain layer; these variables include: 1) moisture, 2) total protein in malt, 3) protein soluble in must, 3) viscosity of must, 4) sugar content, among others. The malt obtained is bought by the beer producing company, where it is processed to obtain the final product. Beer making is a very complex process due to the many chemical reactions involved, ranging from malting to final bottling. In this stage, quality aspects related to the chemical composition (protein and sugar content, alcohol and carbon dioxide concentration) are analyzed (Gonzalez Viejo et al., 2018). The final product is collected by the 3PLs for delivery to the different distributors. The distributor selects the types of transportation, routes, and warehouse locations available for delivery to resellers. Finally, resellers buy small quantities of the final product, from distributors or wholesalers, for direct sale to the final consumer. Throughout these downstream operations, in the supply chain, all product registration transactions, batch additions, and updating of transaction hashes are permanently stored in the storage layer. Transactions are written to the Blockchain to ensure that a product is successfully transferred between the different entities in the supply chain, ensuring the process of tracing the origin of the data.

In the storage layer, through IPFS and with the support of PPGIS, all images, data and records are digitally signed and attributed to a certain entity, within the supply chain. According to (Salah et al., 2019) because the information as uploaded by the entity, this means that the farmer is the owner of said action and is responsible for inaccurate or fraudulent images. In these cases, the smart contract can be programmed in an automated way to impose sanctions on entities if they act dishonestly (Borrero, 2019; Salah et al., 2019; Shahid et al., 2020).

6. Conclusion

The use of the Blockchain seeks to discourage data manipulation, preventing people from entering false or erroneous information or hiding information on the Blockchain. Although there are technologies based on the use of sensors and IoT devices to minimize the problems of capturing and obtaining information, Blockchain cannot, by itself, eliminate fraud in the food chain. When more available data is linked to the Blockchain, it will be easier to detect it, due to the possibility of using cross-checks and the immutability of the records. The great challenge for Blockchain in the agri-food supply chain is to connect the different technologies for traceability with models for decision-making, favoring the different entities that make up this sector.

In addition, the PPGIS provides clear visualizations of the disparities in access to transportation and resources experienced by some imagined farming communities and allows a better understanding of ways to combat these disparities.

Blockchain-based applications for the agro-food sector also look for aspects related to food safety, monitoring, and control of food quality. This proposal seeks to achieve traceability that favors reducing waste, the analysis of reliable operational data, and efficient exchanges of contracts and transactions to reduce economic costs, thus supporting small farmers.
These applications can be developed using existing blockchain-based technology tools to facilitate quick and easy developments. Based on different implementation scenarios of these applications, other computational and cryptographic techniques can be connected to provide flexibility to meet the requirements of different users.

Acknowledgements

The authors wish to express their gratitude to Universidad Autonoma de Hidalgo – Escuela Superior de Ciudad Sahagun, Facultad de Ingenieria – Universidad Panamericana and PRODEP, for the support given to carry out this research.

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