Establishing the requirements of a blockchain-driven supply chain system for the Agri-food industry

Presented by

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Abstract

In this master's thesis, we focused on the requirements of a blockchain-driven supply chain system for the agri-food industry. To achieve this, we studied 23 articles to implement a systematic literature review methodology. Our results allowed us to establish a list of requirements. Starting from a few research questions, we defined these requirements by analyzing the most frequently used components in the presented systems. These requirements focus on the types of data to be stored, the management of asset ownership transfer, the different technologies that help maintain a gap between the cyber world and the physical world, and finally, the type of blockchain to be used. All these requirements are presented and detailed in this master's thesis. However, we also took into account the fact that since all systems are different, we cannot provide definitive answers to our questions but rather establish broad lists with the most commonly used solutions.

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1—Introduction

1.1 Context

Today, the agriculture industry is under pressure due to the increasing world population and demand for sufficient, safe, and high-quality agri-food products. At the same time, the current food supply chain has become more globalized, and the dependency on imported food has increased globally by approximately 50% between the years 2006 and 2020. The increased distances between the locations of food production and consumption have amplified the concerns of consumers regarding food safety and quality[8].

However, one of the issues of today’s supply chain management systems is that they are often based on centralized systems: supply chain processes and product traceability data are managed by a single authority on which supply chain members rely to transfer and share their information. These centralized systems are often non-transparent, monopolistic, and asymmetric information systems. This can pose a serious threat to the security and reliability of the traceability information and make fraud, corruption, and data falsification easier[15]. Furthermore, another issue with such centralized systems is related to the risk of a single authority becoming the weak link and single point of failure. Also, operation throughput and scalability are limited.

So, ensuring high quality and safety of food products has become a key factor on one hand to protect and improve consumers' health and, on the other one, to gain market share.

The recent attention to food safety and product quality requires more reliable and efficient processes for the management of agri-food supply chains. Government authorities need to respond more promptly to food scandals and accidents to maintain customer confidence in the food industry. To this end, ensuring the traceability of food products allows consumers to provide consumers with a complete view of the different phases of product harvesting, processing, and distribution[3].

Due to the current centralization and the level of intricacy, verifying the provenance and quality requirements of individual items becomes nearly difficult. Furthermore, the food sector continues to rely heavily on paper records, and the present food traceability systems are not integrated or linked across all participants in the supply chain[5].

Information is vital for reducing costs, improving yield and quality (while reducing waste), increasing employees' productivity, and enhancing customer service. It helps to render the supply chain (and its stakeholders) more competitive in the market. Traceability, transparency, and auditability are important features that enable one to control (maintain) food quality and safety and increase customer satisfaction. Therefore, innovative logistics information systems in AFSCs should effectively provide the above-mentioned features[8]. Traceability evaluates food chain security. Every supply chain step must collect data to keep agriculture open and honest. Real-time traceability adapts to unexpected events. It helps, but it is not safer or better. Blockchain improves food traceability, quality, safety, and agricultural profitability. Blockchain data can instantly identify dangerous goods, preventing outbreaks and saving lives[2].

Furthermore, with commodity items that are blended (e.g., milk from several farms in a dairy) or dissected and mixed across the supply chain, one-up/one-down traceability can be easily lost (e.g., animals for meat production).[5] In this context, an important potential innovation capable of ensuring the traceability and authenticity of a product in the eyes of consumers, producers, and other economic stakeholders, is represented by blockchain technology (BCT)[11].

Real-time monitoring systems are becoming an important aspect of food supply chain logistics. Hence, the application of BCT in AFSCs is essential, as it enables one to create a decentralized, immutable, transparent, reliable, and automated system for real-time monitoring and decision-making. In the application of digital food traceability systems, IoT tools such as radio frequency identification (RFID) have been implemented in many cases, while the BCT-based traceability system is emerging as a potential effective solution[8].

In order to improve food safety and traceability in the food supply chain and to increase consumer confidence, distributed decentralized digital ledger technology, like BCT, offers a tamperproof, reliable, fraud-resistant, and trustworthy peer-to-peer network platform. Through the use of Blockchain technology, real-time risk point detection for food safety can reduce food fraud and contamination while also strengthening the mechanism for recalling affected batches of products[9].

Using this final information allows consumers to then reconstruct a complete history of the transactions related to a product during its life cycle. Transactions of the real world, involving transformations and exchanges of physical goods, proceed as usual[3].

In fact, systems using blockchain-related technologies for food control and traceability have seen great progress in recent years and, currently, the use of blockchain in supply chain management is almost doubling year on year[7].

In the agro-food industry, the requirements for a blockchain-driven supply chain system are vital. They ensure food safety, maintain high food quality, enable precise traceability, meet regulatory standards, improve operational efficiency, and enhance customer satisfaction. Having and meeting these requirements is crucial for the global success of the industry.

1.2 Research problem

This study aims to establish the requirements for a blockchain-driven supply chain system. Specifically, we will explore what are the similarities of all of these systems and if we can conclude by a constructed list of requirements which are often quite difficult and complex to determine. In this context, during this study, we aim to answer the question:

What are the main requirements for a blockchain-drive supply chain system for the Agri-food industry?

2—Background

2.1 Supply chain

The supply chain is a complex and complete system that covers all steps, resources, and transports needed to produce a product. This process begins with raw materials and culminates with the end consumer. Generally, a supply chain network involves various stakeholders, including:

- Suppliers
- Manufacturers
- Distributors
- Retailers
- Customers

The primary objective of supply chain management is to describe and optimize these processes. It enhances efficiency and improves overall operations, such as reducing costs, ensuring product quality, and maintaining traceability throughout the product's life cycle.

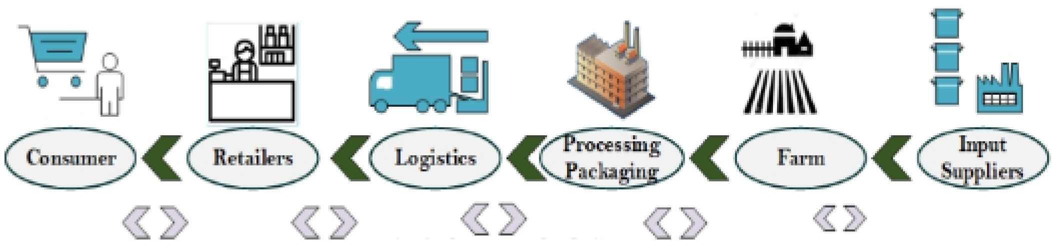

Figure 1 : typical example of a supply-chain process [5].

2.2 Blockchain

Blockchain technology, a peer-to-peer distributed ledger of accounts and transactions stored by all participants, was introduced by Satoshi Nakamoto in 2008 along with Bitcoin[14]. As a particular class of distributed systems, blockchain aims to address issues inherent in centralized systems[3]. Strong expectations exist for blockchain technology to solve problems in sectors requiring collaboration among untrusted actors, such as the agri-food industry[4].

A blockchain is a specific type of distributed database that securely and immutably stores data while ensuring transparency of the data history. It is based on a technological protocol enabling data exchange within the P2P network without intermediaries, as participants interact anonymously with encrypted identities through transactions. Each transaction must be validated by a community of users through a consensus process and then recorded in the ledger by adding it to an immutable chain of blocks held on every network node[4].

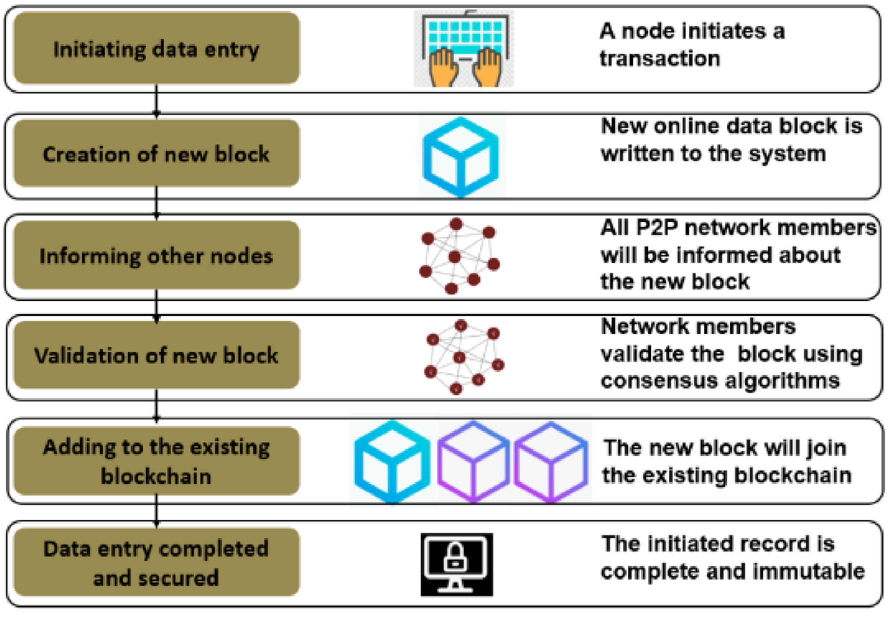

Figure 2 : Creation process of a new data block in an existing blockchain network [8].

Blockchain is an immutable and distributed digital ledger containing chained data blocks (see Figure 2). It is a ledger with a growing list of data records that are validated by the P2P network members/nodes. In BCT, a chain of data is created by immutably linking a new block with the previous block. Once data has entered the Blockchain, no one can alter them, as an attempt to corrupt the data in one of the blocks will render the following blocks invalid. This property of BCT enables one to tackle data modification problems. For instance, in traditional AFSCs, the modification of travel histories, ingredients, expiry dates, etc., by intermediaries, is one of the challenges in the food industry.[8]

Here is a table with a few of the main characteristics of blockchain technology:

Characteristic	Description
Decentralized system	Blockchain operates on a peer-to-peer network without a central authority, ensuring no single point of control or failure[14].
Integrity	Thanks to its decentralized nature and consensus mechanism, blockchain is resistant to censorship and tampering, providing robust data integrity[5].
Transparency	Blockchain allows all participants to view the same data, with each transaction being visible and verifiable[8].
Self-Execution	Smart contracts are self-executing contracts with the terms directly written into code[5].
Accuracy	Transactions on a blockchain are validated through consensus mechanisms, ensuring that only accurate and agreed-upon data is recorded[5].
Security	Blockchain uses cryptographic techniques to secure data, ensuring that transactions are protected from unauthorized access and alterations[10].
Immuabilité	Once recorded, data on a blockchain cannot be altered or deleted, providing a permanent and unchangeable record of transactions[10].
Availability	The decentralized nature of blockchain ensures high availability, as the network operates 24/7 and data is replicated across multiple nodes[13].

Figure 3 : Characteristics of blockchain.

2.2.1 Type of blockchain

The type of blockchain refers to the regulation of permission to the digital register and associated services. Based on reads and write control allowed to participants over block data, it is classified into three major types.

Public Blockchain: It enables everyone to access the network. Energy usage is high. Access to the block information is permitted for each participant on the blockchain network. These digital ledgers are distributed and freely accessible. The contract or transaction can be validated by any node, and information is made publicly available. The public blockchain is very anonymous when it comes to the participant's identity. The majority of cryptocurrencies commonly use it [9].

Private Blockchain: Only a genuine invitation can allow a participant to function as a node. Data privacy is ensured since only specific nodes on the system can access block data. It is not a completely decentralized system. The controller permits the nodes to view the data. It functions as a centralized, cryptographic-based organizational network. It applies to sectors like the banking system, securities foundations, etc …[9].

Permissioned Blockchain: Access to over-block data is only permitted by the system's verified and trusted nodes who meet the required standards. The blockchain network is controlled by authorized members, each of whom has a specific role and defined authorization. It combines elements of both public and private blockchains. Most of the industrial sectors like the healthcare sector, food sector, education sector, real-estate sector, agricultural sector, etc … can have applicability of permissioned Blockchain [9].

2.2.2 Blockchain in agri food

The BCT represents an innovative voluntary certification system capable of increasing transparency, efficiency, security, and safety, even in the food supply chains. In this sense, the authentication system ensures that products are in compliance with the information on labels and thus prevents food fraud [11]. this technology guarantees:

- Data integrity and provenance of documents and records on the blockchain[4].
- Immutability and transparency of data recorded on the blockchain, resulting in the traceability of agri-food products from root to retail[4].
- Compliance with the quantities of the products involved, based on the annual production of the land and the yield in the various stages of processing. This is achieved with the system of tokens, which are associated with the products and cannot be altered, as they are managed on a blockchain[4].
- Ability to retrace the entire supply chain, simply by accessing the blockchain, and public servers storing relevant documents, starting from the Id shown on the final product[4].

2.2.3 smart contract

A smart contract is a combination of data and code that encodes a set of transformations on that data. It exposes a set of operations that can be invoked by the users of the blockchain to change the state of the distributed ledger. The concept of smart contracts, therefore, makes this kind of blockchain a distributed execution environment of general-purpose programmable logic[3]. A frequently used example for simple understanding is the task of a drinks vending machine, which dispenses a predefined volume of drink after the required money is entered into the machine. The application of smart contracts in blockchain technology could be widely used in food supply chain (FSC) management systems to solve various food safety and traceability-related problems. Data interoperability, auditability, transparency, cost-reduction, tracing of products, authenticity, and integrity are the important benefits of BCT application with smart contracts in the FSC traceability system[9].

2.3 IoT: Internet of Things

Kevin Ashton created the term "Internet of Things'' in 1999. It is defined as a global network of linked physical objects also known as "things'', which are capable of gathering and transferring data without the need for human intervention. Embedded systems like software, electronics, networks, and sensors are often used in these devices to collect data about the environment, communicate data over a network, respond to remote instructions, and execute actions depending on that data[4].

2.3.1 Features and types of IoT

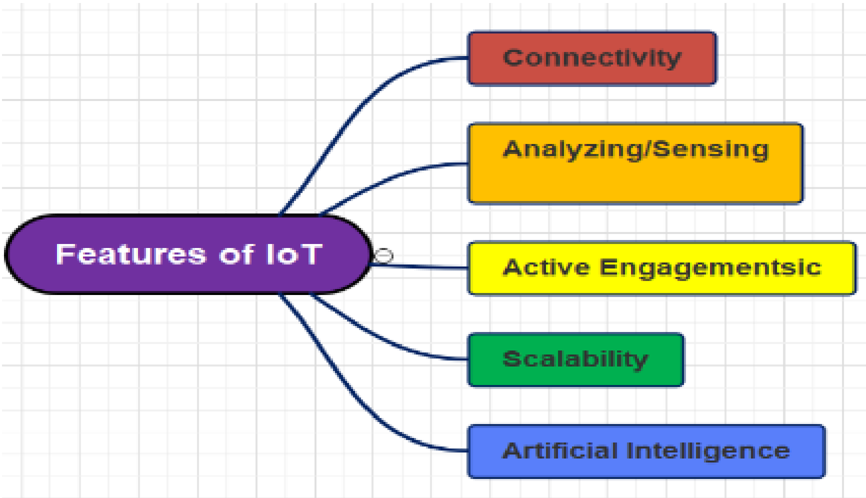

Figure 4 : List of IoT features [14].

Connectivity is the most crucial part of IoT. Without flawless communication among interconnected parts or devices, the IoT ecosystem, like sensors, compute engines, and data hubs, cannot function correctly. Radio waves, Bluetooth, Wi-Fi, and Li-Fi are all options for connecting IoT devices[5]. Analyzing and sensing is the next stage, where the data being collected is evaluated to develop efficient business intelligence once all necessary objects have been connected. Extracting information from the collected data is critical, as a sensor creates data that is useless unless correctly understood by humans[14]. Scalability is vital, as increasingly more elements are connecting to the IoT region every day. Consequently, IoT systems should be able to manage significant expansion. The amount of data created as a result is enormous, and it must be properly managed[5].

There are four major types of IoT, described as follows :

- IoT Sensors/IoT Devices: In IoT, the Sensors or small devices are essential components for collecting generated data from the environment. All the collected information having different levels of complexity might be difficult in some way. It might be as basic as a temperature monitoring sensor or as complex as a video-stream[10].

- Connectivity: The collected sensor's data should be transferred to the cloud server via a different communication data channel, for example, Mobile or satellite networks, Bluetooth, WI-FI, WAN, etc[14].

- Data Processing: The data has been processed by a software program which is collected by the sensors and transferred to the cloud. This is as simple as monitoring the readings of the temperature of air conditioners or heaters. However, some tasks, such as recognizing objects using computer vision on video, may be rather tough [4].

- User Interface: A User Interface is where an IoT device communicates with a user. A user interface is the visible and tactile part of an IoT system that users can interact with. It comprises presenting information in a way that benefits the user. The data must be made available to the end user in some form, which may be done by sending text messages, email alerts, or alarms on their cell phones and notifications[14].

3—Related work

In this section, we are going to do an examination of the related studies. We will discuss the goal of each work and on what makes our research different. The table below shows us the different reviews made related to the blockchain-driven supply chain system for the Agri-food industry.

Reference	Type	Article	Domain	Date	Goal
[16]	Systematic review	Blockchain Technology to Support Agri-Food Supply Chains: A Comprehensive Review	General	2023	It's a SLR which aim to understand the state of art related to the application of blockchain in the agri-food sector in GENERAL
[17]	Systematic review	Exploring the Hype of Blockchain Adoption in Agri-Food Supply Chain: A Systematic Literature Review	Trends	2023	This work aims to identify the main research themes, research gaps, and the direction of future research on the impact of blockchain adoption in the agri-food supply chain.
[19]	Systematic review	User Interface of Blockchain-Based Agri-Food Traceability Applications: A Review	Interface	2021	This paper aims to review existing works from user interface perspectives.

Figure 5 : List of related works

This work is different from them in two main points. First, this thesis specifically addresses the general requirement for blockchain implementation in the agri-food sector, unlike the existing systematic literature review which covers topics like the state of art in general[16], trends, adoption hype[17], and user interface[19]. This work dives into the essential requirements that must be met for a successful blockchain integration in these supply-chains.

Also, we have a good potential impact of understanding and meeting these requirements. By addressing this fundamental aspect, this thesis not only contributes to the theoretical understanding but also offers practical implications for these systems.

4—Methodology

3.1 Approach selection

In this study, we decided to use the systematic literature review approach (SLR) to review the existing research on blockchain-based supply chain systems for the agri-food industry. This approach allows us to discover relevant sources based on the research topic and also provides a synthesis of this topic. It also can provide an overview of the current literature in a particular domain/subject and identify areas where there is a lack of information or more research is needed. Thanks to this approach, we will be able to show the main shortcomings in the current resource on the blockchain-driven supply chain system for the food industry and offer suggestions for a potential further study.

We chose to follow four steps in this study, all established by Kitchenham[1] :

- “Defining and specifying the research question(s)”[1] : This is the most important part of a systematic literature review, because the search, the data extraction and the data analysis are made according to these research questions.
- “Identification of research”[1] : The aim of this part is to find as many studies relating to the research question as possible.
- “Data extraction, monitoring and synthesis”[1] : Here, we need to extract as much data as possible, preferably stocked in a table; then, make a synthesis.
- “Formatting the main report”[1] : Finally we have to discuss the results.

3.2 Defining the research questions

- **RQ1 : What types of data are crucial to collect throughout the food supply chain to ensure traceability and transparency in a blockchain-driven system?**
  The purpose of this RQ is to uncover product and technology information that consumers and producers need to collect to trace products knowing that at each stage of the supply chain, different data may be required.

- **RQ2 : How are asset ownership transfers managed between different stakeholders off the supply chain ?**
  For this RQ, the goal is to determine if asset ownership transfers are managed and how it's done.

- **RQ3 : What technologies are used to bridge the gap between the cyber world (blockchain) and the physical world (sensors) ?**
  The purpose of this RQ is to identify the technologies most used for maintaining a connection between the blockchain and the real world.

- **RQ4 : What type of blockchain is used for this type of system ?**
  Here we try to determine which type of blockchain is used and if we can propose an answer for these systems.

3.3 Identifying relevant studies

3.3.1 Keywords and query

As part of this literature search, we used MIAGE SCHOLAR, an interface providing access to search engines and scientific databases to find our research. Here is the list of keywords of this study:

Keywords : **blockchain - supply-chain - Agri food - Agro food- traceability - requirement**

With the goal to identify our relevant studies, we need to create a custom search query including a combination of our keywords. Here is the query built :

“TITLE-ABS-KEY(supply chain) OR (TITLE-ABS-KEY(blockchain) OR TITLE-ABS-KEY(DLT)) AND (TITLE-ABS-KEY(Agri food) OR TITLE-ABS-KEY(agro food) OR TITLE-ABS-KEY(Agro food industry)) AND TITLE-ABS-KEY(traceability) AND PUBYEAR > 2019”

After this initial search, we have a total of 207 articles without any filter. We selected only articles which respect all of the eligibility criterias (inclusion + exclusion).

3.3.2 Eligibility Criteria

In a SLR method, for improving the selection and reducing the number of irrelevant sources, we need to choose some criterias which will help us during the filtering phase.

Inclusion Criteria	Exclusion Criteria
Blockchain-Based	Language : study written in English or French.
Agri-food topic	does not address supply chain
Accepted paper (Open access)	Irrelevant : content out of scope
	Does not include traceability

Figure 6 : List of inclusion and exclusion criteria.

For the inclusion criterias, studies must focus on blockchain technology, this will ensure relevance to our research theme. The studies should address applications of blockchain in the agri-food sector, guaranteeing sectoral relevance. Additionally, documents must be preferably open access, ensuring they are credible and also accessible for in-depth analysis.

About the exclusion criterias. First, the documents selected must be written in English or French to ensure our comprehension. Unreliable sources will be excluded to ensure the credibility of the information analyzed. Any study whose content is not relevant to the research topic, even if it mentions blockchain, will be excluded to maintain focus on specific aspects of the study. Finally, studies that do not address traceability will be excluded, as one of the primary goals of the research is to examine the use of blockchain to improve traceability in the agri-food sector.

3.3.3 Selection of Sources

As said earlier in section 3.3.1, we found a total of 147 articles, we filtered them in different steps. First with the base of articles we started by filtering based on title and availability, with this filter 157 articles were removed, after this step 50 articles are remaining. Then another filter based on abstract and conclusion for all articles potentially usable, after this one, 18 articles were eliminated. This step resulted by leaving us with a total of 32 articles. Finally, we made a filter by a complete reading of all articles, with this last step, we excluded 9 other articles which leaves us with a total of 23 articles for this literature review.

3.3.4 Other sources and snowballing

Our other sources come from the “Snowballing” method, which consists in selecting articles quoted in articles we have already selected, with this method we can enlarge our references without going off topic. Generally the snowballing articles are more specific and centered. Finally we have added a total of 5 articles with this method, which ended up to a total of 28 studies. Here is the PRISMA flowchart summarizing the documentary research process.

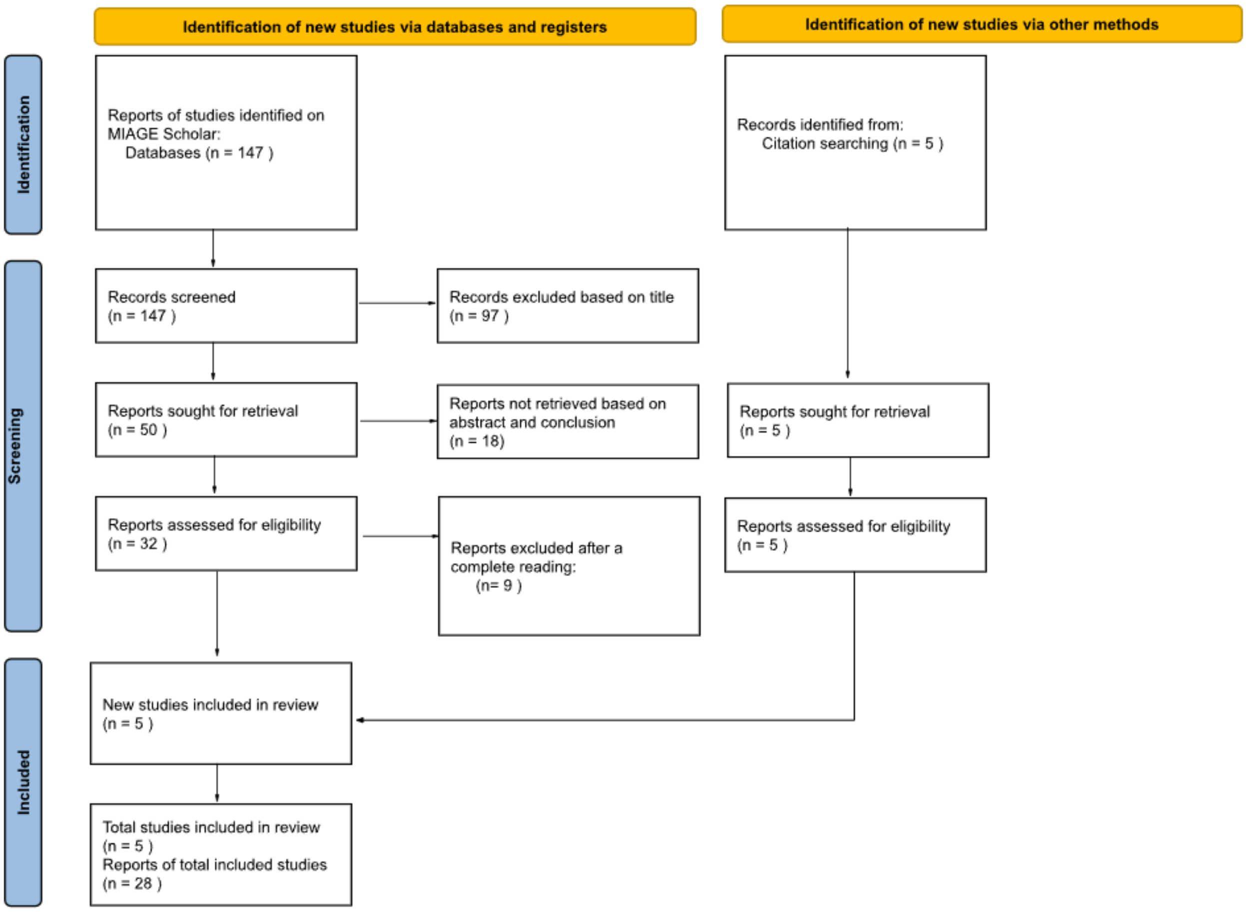

Figure 7 : The PRISMA flow chart summarizing the documentary research process.

3.4 Data extraction, analysis, and synthesis

The last part starts by the data extraction, to be able to extract easily our data from each article we have created a table (extraction form) linking data, information and the related RQ. The table number 3 summarizes this form.

Information	value	Research Question
Traceability and transparency	Yes	RQ1
Food domain	Global food, Fresh food	RQ1
Type of data	any	RQ1
Stakeholder	Suppliers,Manufacturer, Storage, Distributors,Retailers, Customers	RQ1
Data transfer	Yes	RQ2
Ownership	Yes	RQ2
Token	Yes,No	RQ2
Data Storage	On chain, Off chain	RQ3
Iot	List of IoT	RQ3
Communication	Any	RQ3
Tools	List of tools	RQ3
Blockchain	Any	RQ4
Consensus	Any	RQ4
Type of Blockchain	public, permissioned, other	RQ4

Figure 8 : Data extraction form.

4—Results

In this section, we show the main results obtained after the analysis of the selected papers. Results are divided into 5 parts, each one based on the research questions identified previously. The main goal is to answer each of them in detail.

4.1 RQ1 - What types of data are crucial to collect throughout the food supply chain to ensure traceability and transparency in a blockchain-driven system ?

4.1.1 context

Due to the current centralization and the level of intricacy, the current supply-chain systems express a lack of traceability and transparency[5] and as we know, blockchain technology can resolve this problem. But now we need to establish what type of data need to be collected and are crucial to clarify these deficiencies and where to store them. Because, storing irrelevant data can make traceability and transparency more complex, especially in this sector.

For more context we have 8 articles that address and explain this issue,

References	type of data	Food domain
[3]	precise data	global food
[4]	precise data	global food
[8]	global data	global food
[20]	global data	Fresh food
[21]	precise data	global food
[22]	precise data	global food
[23]	global data	global food
[24]	global data	global food

Figure 9 : List of studies addressing about data collection

4.1.2 Analyse

As shown in Figure 9, data are presented in 2 ways. [3],[4],[21] and [22] address precise data and [8], [20], [23], and [24] address a global data description for each stakeholder. For a better presentation of data, we will separate 50% of the studies in a graph and the other 50% in a table. In addition, all of them are addressing agri-food in a broad sense with some examples of precise products.

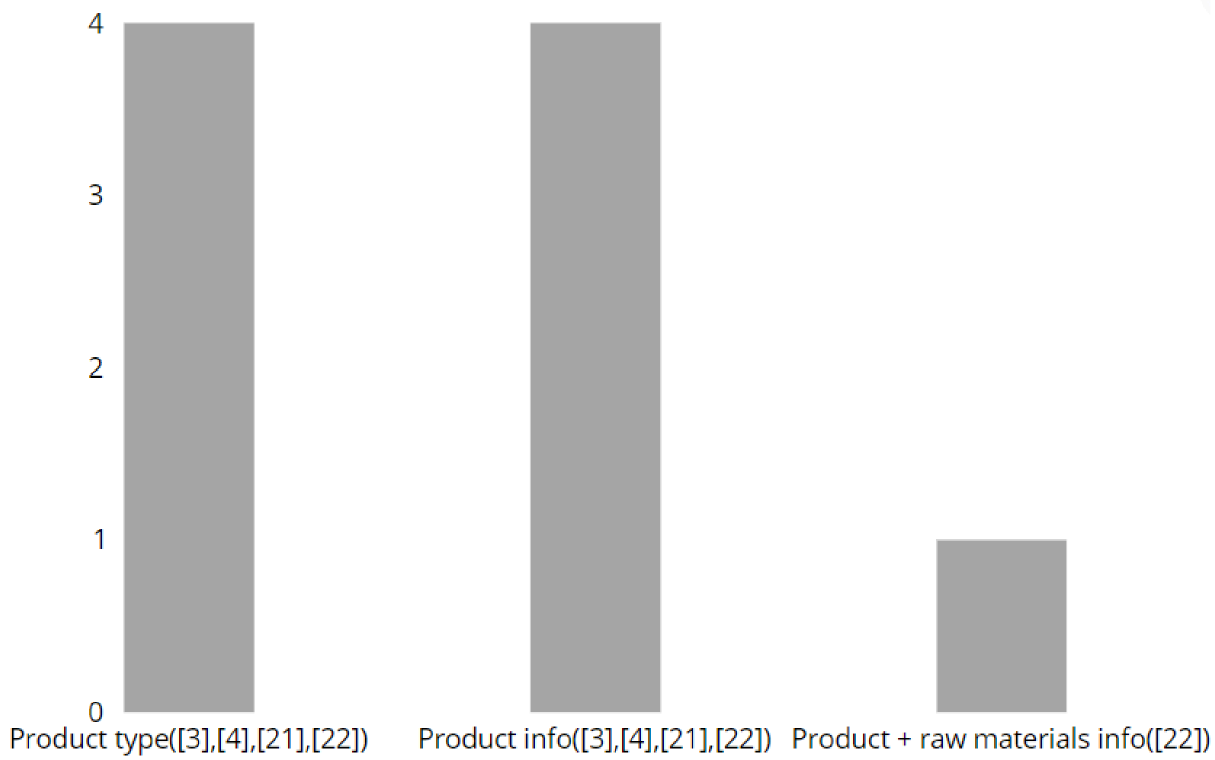

Figure 10 : Data collected in [3],[4],[21] and [22].

In Figure 10, we can see that we have 3 main types of data collected. The first is a product type criteria because [3],[4],[21] and [22] need to collect and store the product type in their system. This allows us to differentiate between potential products, as we have to take into account all the products traced, not just one.It provides an easier traceability. The second is a product info criteria, these same 4 studies also need to collect product-related information. Here, the fields may vary, but globally these studies store the name, id, size, date of production, place of production, and sometimes the owner, when there is a transfer of ownership like [4]. The last one is more specific, as it includes information about the product itself, as well as the raw materials in its storage. The idea in [22] is that Ingredients and raw materials must be grouped into units with similar properties for an optimized traceability and transparency. In [22] it says that there are three types of traceable units: batch, trade unit and logistic unit. A batch is a quantity going through the same processes. A trade unit is a unit which is sent from one company to the next company in a supply chain, for example a box or a bottle. The logistic unit is a type of trade unit such as a pallet, container and so on.

In the next Figure (figure 11) we have a lot of information because the studies [8], [20], [23], and [24] present data collected in every stage of the supply-chain so we have more tracing data.

Supply-chain Stage	[8]	[20]	[23]	[24]
Input supply	stakeholders id, seed type and amount, fertilizer type and amount, pesticide type and amount, feed type and amount	crops, fertilizers, pesticides, supplier-farmer transaction	raw materials information (seeds, pesticides, fertilizers), transactions with farmers	Location, owner, Sold date, Facility condition, sanitation, certificates, Irrigation, use of fertilizer and pesticide
Producer	product, id product, feeding condition, data related to product, location, date, weather condition	farm, cultivation process, farming practices, weather conditions	information of farms, farming practice, cultivation process, weather conditions, transaction with provider and processors	x
Processing	factory location, processing technology and method, date of production, origin, packaging information, quality status, expiry date	Factory & it’s equipment, processing methods, batch numbers, factory-producer & factory distributors transactions	information of factories, processing ways, transactions with farmers and distributors	Production date, Processing parameters (temperature, time), Packaging information, Storage condition, Lab testing results, Safety compliance

Storage	warehouse number, entry and exit time, light, moisture, temperature, storage quality	x	x	quantity, package date, package condition, food properties (weight, moisture, appearance, texture)
Distribution	vehicle, personnel id, transport route, cold chain information, delivery date, product ownership transfer	shipping details, storage conditions, followed trajectories & duration, transaction with retailers	transportation details, storage conditions (temperature and humidity), transaction with processors and retailers	GPS info during transportation, Ship & deliver details, Transport condition
Retailer	responsible operator id, receiving date and time, location, temperature, humidity information from trailer, nutritional value	food quality & quantity, expiration date, storage conditions and duration	information about the product (quality, quantity, price; expiration dates)	location, labeling (expiration date, receiving date), storage condition, inventory information, sanitation practice.
Consumer	consult information about products	all the information related to the food item since the beginning	products information from providers to retailers	visual information, consumer-friendly app

Figure 11 : Data collected in [8], [20], [23], and [24].

As we can see in the figure 11, the data collection is really detailed, since at each step new information must be traced. Furthermore, as each system is different, the solutions in [8], [20], [23], and [24] may have differences, but we focus on the similarities of these systems presented in figure 11.

For the Input supply, [8],[20],[23] and [24] are pretty similar. All of them store raw materials information like seeds, pesticides, fertilizers, crops and feed depending on the final product. [24] is more precise with more data like Location, owner, sanitation, certificates and irrigation. These data are really important and only one study stores them, but we will not take these data into account as they are too specific. [23] store an important thing, the transaction with farmers, which allows a better transparency with the origin of a product.

About the producer,[20] and [23] are storing information about farms, the farming practice and the cultivation process. [8],[20] and [23] store the weather condition with [8] that has more precision such as location and feeding conditions. Finally [23] is also storing transactions with the provider and processor like the last step.

Processing stage is more global, because depending on the product every process is different. But overall [8], [20], [23] and [24] store the factory information, the processing methodologies, parameters and methods

The storage stage mentioned in [8] and [24], they store basic data like warehouse information, entry and exit time, quantity and other information related to the food property like light, moisture, temperature and texture.

Distribution needs to store only information related to transport and transport conditions. As presented by [8],[20],[23] and [24], we need shipping details, gps data, and storage conditions in the vehicle such as temperature and humidity. [8],[20] and [23] are also addressing about ownership transfer in this stage and store the transaction with retailers

In the retailer stage, [8],[20],[23] and [24] don't have new data, they just display and store current data like information about the product (quality, quantity, price and expiration dates), and the sanitary practice with the temperature and the humidity information.

The last stage is the consumer, here [8],[20],[23] and [24] are unanimous. The consumer adds nothing but he can have access and consult all the information related to the products from the beginning.

Finally, as precise before, the agri-food industry is general. The product can be either meat or cereals and depending on the product the data needed for optimal traceability and transparency can vary. Figure 11 contains much the same data as Figure 10, but in greater detail and separated along the chain, so by regrouping the two previous figures we can establish a list of general data needed for these types of systems for better traceability and transparency.

4.2 How are asset ownership transfers managed between different stakeholders off the supply chain ?

4.2.1 context

For this question, it is important to understand the usefulness of product ownership management and the contexts in which this information is crucial. First of all, it's important to have ownership transfer management in place in order to enhance a number of factors, such as authentication, traceability, transparency and customer confidence [8]. It also simplifies dispute management and improves operational efficiency. Even if it's not mandatory, taking into account the transfer of ownership helps to meet regulatory requirements, increase the value of assets and it is highly recommended to take this part into account for these systems. Here's a figure showing the items that will be used in this analysis part.

Reference	smart contract	ownership transfer	token
[3]	yes	yes	no
[4]	yes	yes	yes
[8]	yes	yes	no
[10]	yes	yes	no
[13]	yes	yes	no
[18]	yes	yes	no
[20]	yes	yes	no
[22]	yes	yes	yes
[27]	yes	yes	no

Figure 11 : List of articles related to assets ownership transfer.

4.2.2 Analyse

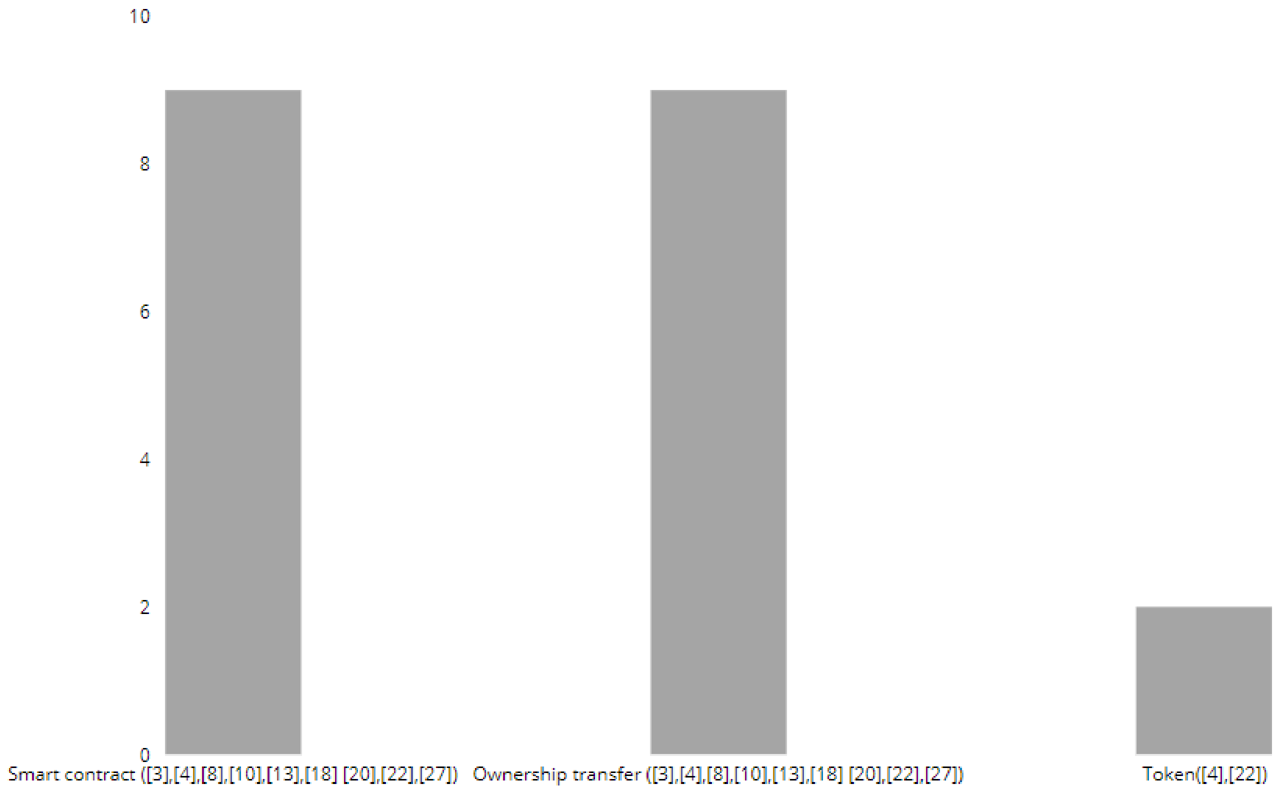

Figure 12 : Number of studies addressing smart contract, ownership transfer and tokenization.

The chart in figure 12 illustrates the number of studies addressing smart contract, ownership transfer and tokenization. The significance of transactions in the transfer of ownership cannot be underestimated because it allows an almost perfect traceability and immutability[3].First we can see that all the systems presented ([3],[4],[8],[10],[13],[18] [20],[22],[27]) address smart contracts and ownership transfer. These systems present a transfer at each stage of the supply chain that enables each stakeholder to play its part and become a temporary owner for the duration of its action at a certain stage in the supply chain [8], [10], [27].

For these systems we can see that utilizing smart contracts is also crucial because they automate processes, which is particularly beneficial given the extensive number of transfers and stages in these supply-chains. This automation reduces both the time required and the dependence on third parties, enhancing overall efficiency, reducing fraud risks and reliability [13], [22].

Also, few systems like [4] and [22] by linking the supply chain products to a token. This linkage reduces the complexity of the transfer, as different stakeholders only need to transfer the digital twin of the product (the token). Furthermore, in these articles, tokens play a crucial role in the management and traceability of assets throughout the agri-food supply chain [4][22]. Each token represents a specific quantity of a material, good or asset, and is created, transferred and burned according to the transformations and transactions that occur between the different actors in the supply chain[4]. The use of tokens ensures that each unit of a product is transparently and immutably tracked from its source to the end consumer, guaranteeing that only authentic and certified quantities of products are handled [4][22]. In addition, tokens facilitate the automation of smart contracts, which execute and record transformation and documentation events on the blockchain[4]. By combining tokens with the Internet of Things (IoT) and the Interplanetary File System (IPFS), this model enables transparent and auditable management of product quality from farm to fork, meeting the transparency and food safety requirements imposed by European regulations[22]. In short, tokens provide an effective and innovative solution for supply chain management, integrating blockchain technology to guarantee the integrity and provenance of agri-food products [4][22].

Here is a short comparison between [4] and [22] about the tokenization :

Commonalities	Differencies
➔ Token usage ➔ Immutable traceability ➔ Smart contract automation ➔ Compliance and Safety	➔ Asset representation ➔ Technology Integration ➔ Token Creation and Destruction Mechanisms

Figure 13 : Tokenization comparison between [4] and [22].

As we can see in figure 13, even if we decide to represent the products digitally via tokenization, the systems are still different and vary according to the exact use case. But with this technique we can find out some common points that are not dependent on use cases, but are quite general like the token usage or an easier smart contract automation.

Finally we can establish that the asset ownership transfer management may be carried out in different ways. But in the end it doesn't matter how they are done, they all depend on the transactions in the blockchain. These transactions are carried out between stakeholders, whether through the transfer of tokens or not. We need to have this transfer at each stage of the supply chain to maintain traceability and link each step to its stakeholder. These transactions need to be automatized with smart contracts to save time and improve security.

4.3 What technologies are used to bridge the gap between the cyber world (blockchain) and the physical world (sensors) ?

4.3.1 context

For this question, it is important to understand how current technologies can be integrated to bridge the gap between digital data and the actual physical conditions of products, in order to establish requirements for this type of system. These technologies are separated into several parts, we have real-time data collection thanks to Iot, immutable and transparent data recording thanks to blockchain and more precisely facilitated by smart contracts, data storage whether on chain or off chain and finally the different means of communication between data and products. Here we have a figure which represent all the studies related to the technologies used to bridge the gap between these 2 worlds :

References	Data storage	IoT	Communication	smart Contract
[2]	off chain - IPFS	Iot sensor temperature, humidity, location	edge devices and gateways	Yes
[3]	off chain - IPFS	Iot devices, temp, humidity, GPS location	edge devices and gateways	Yes
[4]	off chain - IPFS	Iot devices temp, weight, ph, locations	RFID, NFC	Yes
[5]	on chain	Iot sensor track inventory, monitor environmental conditions	edge computing Iot gateway, RFID and NFC	Yes
[7]	on chain	Iot sensor temperature,	RFID , Oracles	Yes

		location, and humidity		
[8]	on chain	Iot sensor temp, humidity, sound, pressure, location	RFID, NFC wireless connection (bluetooth) wired connection (LAN/WAN)	Yes
[9]	on chain	Iot sensor temperature, humidity, location, environmental conditions.	RFID, QR code, NFC, edge computing	Yes
[10]	off chain - IPFS	Iot such as temperature, relative humidity, gas concentration, and pressure	RFID, NFC, raspberry pi unit	Yes
[11]	on chain	Iot sensors temperature, humidity, and travel time(during transport and storage)	RFID, QR codes	Yes
[12]	off chain - IPFS	X	QR code	Yes
[13]	on chain	X	RFID, NFC, WSN (wireless sensors networks)	Yes
[18]	off chain - IPFS	Iot sensor temperature, track locations, humidity, and CO2 concentration	RFID , QR codes, wireless communication (bluetooth, lorawan)	Yes
[20]	off chain - IPFS	Iot sensor temperature, humidity, soil moisture, and weather conditions + camera	RFID, QR code, WSN	Yes
[21]	on chain	X	QR code	Yes
[22]	off chain - IPFS	Iot device temperature, track locations, humidity	RFID, NFC	Yes
[23]	on chain	Iot sensors temperature and humidity during transportation	RFID, NFC QR code	Yes

		and storage.		
[24]	on chain	Iot sensors temperature, humidity and location with gps	RFID , api interface	Yes
[26]	on chain	Iot device for temperature and location	RFID	Yes

Figure 14 : List of technologies used to bridge the gap between cyber and real world.

4.3.2 Analyse

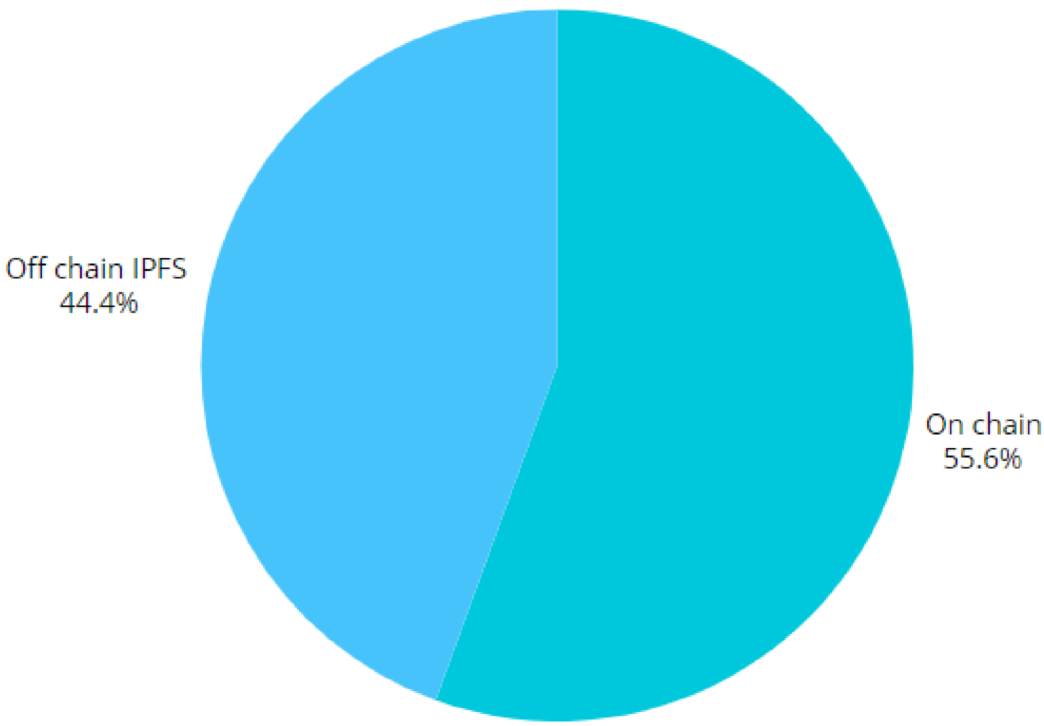

Figure 15 : Data storage distribution related to studies.

About the data storage, figure 15 shows us 2 types, the On chain storage with [5],[7],[8],[9],[11],[13],[21],[23],[24] and [26] which represent 55,6%. The second one is the off chain storage with studies [2],[3],[4],[10],[12],[18],[20] and [22] which represent the others 44,4%. Most solutions use On chain storage because it allows a direct data nature, it is mainly used for critical transactions and data requiring maximum security and immutability[24]. But for these systems it's not always a good idea because there's also the high cost of gas, potential scalability problems and a slower network if a lot of data is stored, which can be the case with supply chain systems[22].

To counter these problems, off-chain storage exists. In the case of large data, rather than storing the raw data directly on the blockchain, it is useful to store a link to the data, and a short information able to identify the data. This pattern, known as Off-Chain Data Storage, consists in storing the hash digest of the raw data on-chain[4]. For example, we have IPFS, the interplanetary file system is a decentralized method of storing data that gives maximum throughput,reduced latency,and scalability. The choice between storing data on the blockchain or off-chain via IPFS depends on the specific needs of the application, the associated costs and the nature of the data to be stored.

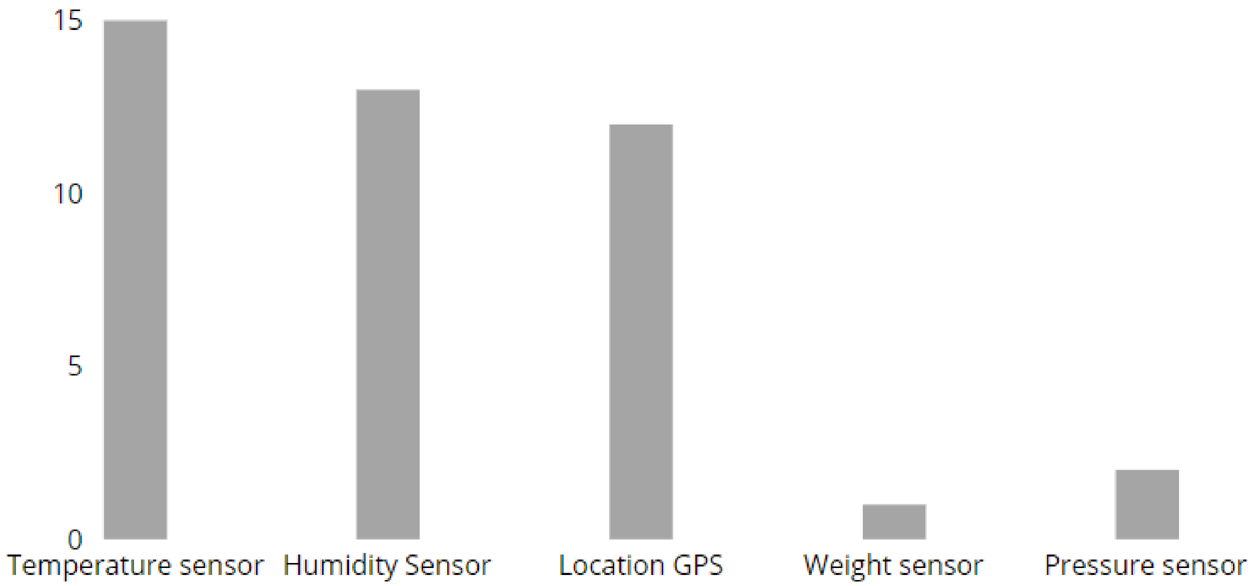

Figure 16 : List of Iot used in these systems.

Figure 16 shows the list of Iots used in these systems, and as we can see, there's quite a lot of choice when it comes to sensors. The temperature sensor is used in 15 different studies, the humidity sensor in 13 studies, 12 for the location GPS, 2 for the pressure sensor and finally 1 for the weight sensor. All of them allow direct monitoring of the required data. For example, the temperature sensor can be used during transport, but also during storage, to ensure that temperature requirements are always met, or the location sensor can be used in the same stages to trace the route taken, or to guarantee that the product has come from the specified location[3].

Based on this figure, we recommend you to use Iot sensors to respect your requirement and in the majority of the studies these are the temperature sensors, the humidity sensor and the location gps.

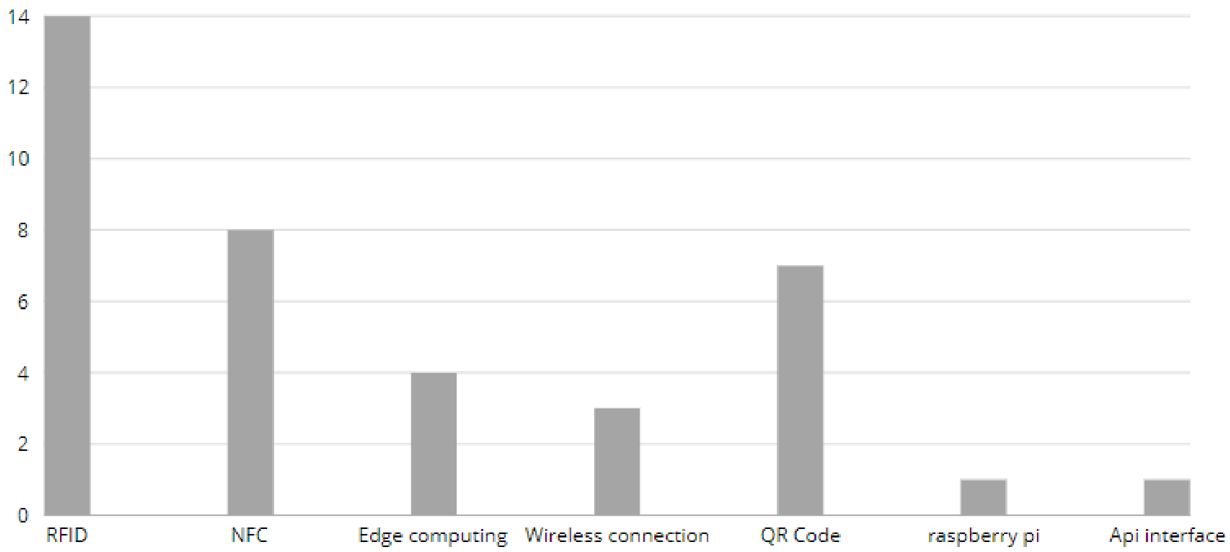

Figure 17 : List of communication technologies used.

This figure shows us the communication technologie which allow the blockchain technologie and the sensors to maintain a gap between each other. There are 7 solutions presented and all of them are useful depending on the context. Some of them are mostly used and others are less used solutions. The three most widely used technologies are RFID, NFC and QR Code.

RFIDs are a perfect match for blockchain, as the information collected via RFID tags can be automatically recorded on the blockchain, ensuring immutable and transparent product traceability. What's more, they can be read remotely, enabling automated product tracking throughout the supply chain[5].

As for NFC, it enables proximity interaction, for example, to verify the authenticity of a product, offers smartphone accessibility and, above all, provides an additional layer of security, which is crucial for protecting sensitive data in the supply chain [18]. And finally we have QR codes, the choice of which is fairly simple and logical. They provide a direct link to the blockchain at an efficient cost (relatively cheaper than RFID and NFC), but above all they're easy to use [21].

4.4 What type of blockchain is used for this type of system ?

4.4.1 context

In this part, we will answer the question : What type of blockchain is used for this type of system?. First of all, it's important to answer this question to define the technical and functional requirements of these systems. By reviewing the 12 studies dealing with this subject, we will be able to understand the different blockchain technology used and their different applications in these systems. Being able to select the most appropriate solution will guarantee the security, efficiency, transparency and flexibility of asset traceability. Here is a figure representing all the studies that will help us establish requirements for the type of blockchain to be chosen.

Reference	Blockchain type	Blockchain	Consensus
[2]	Permissioned blockchain	Ethereum/Polygon	Zero-Knowledge Proofs
[3]	Permissioned blockchain	Hyperledger	Raft
[4]	Permissioned blockchain	Ethereum	Proof of stake
[5]	Permissioned blockchain	X	X
[7]	Permissioned blockchain	Hyperledger	X
[8]	Permissioned blockchain	X	X
[9]	Permissioned blockchain	Hyperledger	X
[10]	Public blockchain	ethereum	Proof of stake

[22]	Permissioned blockchain	X	X
[23]	Public blockchain	X	Proof of work
[26]	Permissioned blockchain	Hyperledger	X
[27]	Public blockchain	X	X

Figure 18 : List of article related to type off blockchain

4.4.2 Analyse

As shown in the previous figure we are interested in 3 types of data to best answer this research question. The blockchain type, the blockchain used and its consensus. Here is the distribution of the type of blockchain used in the literature in the figure 19 :

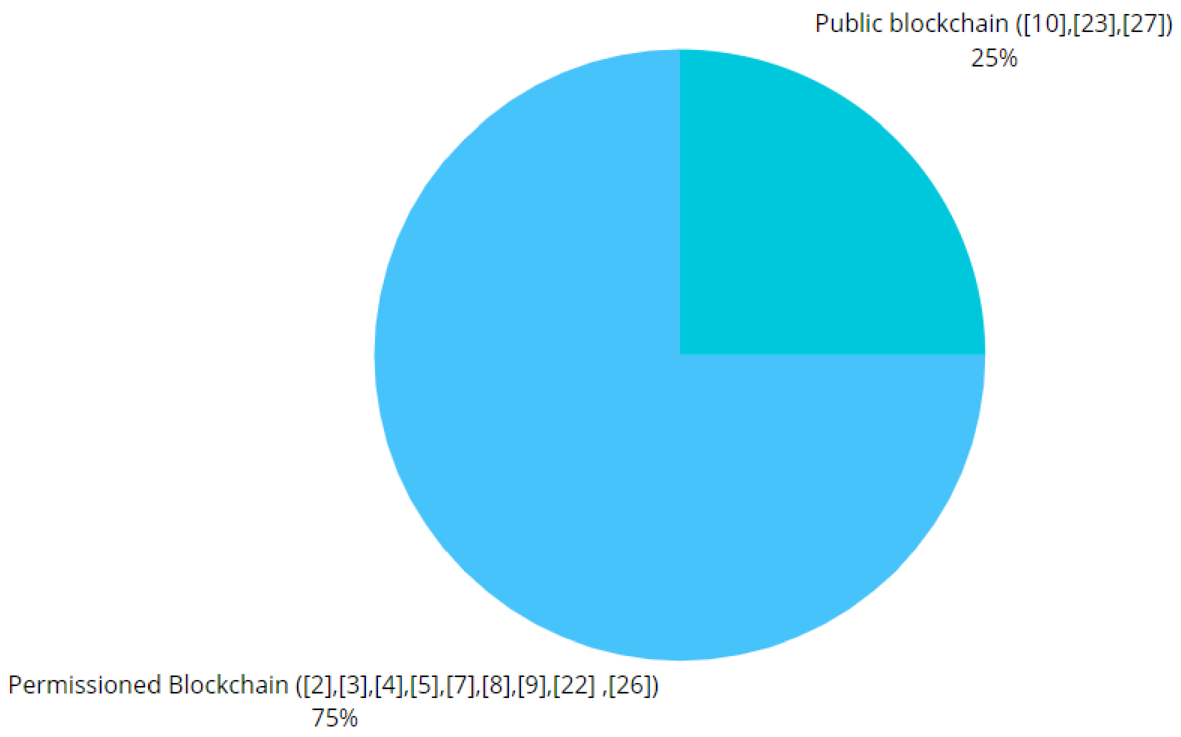

Figure 19 : Distribution of blockchain type related to studies.

As shown in figure 19, we have a distribution of 75% permissioned blockchain and 25% public blockchain. With such a large distribution, it's natural to wonder why there are so few public blockchains. First of all, you need to know that the 2 choices are feasible, and that the choice will depend on the supply chain. However, if distribution is so inequitable, it's because most systems believe that permissioned choice is the best solution.

Type of Blockchain	Advantages
Public Blockchain	➔ Transparency and traceability[10],[23] ➔ Immutability and Data Security[23] ➔ Decentralization and Trust[10],[27]
Permission Blockchain	➔ Data control and security[2] ➔ Efficiency and Performance[9] ➔ Privacy[26] ➔ Governance and Management[2] ➔ Interoperability and Integration[2]

Figure 20: List of advantages for the blockchain types.

With the previous figure , we determined some advantages for each type of blockchain. But as if the public has some good advantages, in general, we recommend using a permissioned blockchain. Because in the case of a classic supply chain there are a lot of challenges for a public blockchain like scalability and cost issues, especially if the number of transactions increases significantly. In addition, managing sensitive data on a public blockchain can raise confidentiality issues, although solutions such as encryption can mitigate this problem[27]. And by using a permissioned blockchain, we can still offer customers complete and transparent product traceability. This ensures that sensitive information is protected, while enabling customers to verify the integrity and origin of the products they buy[2],[3].

The next figure address about the blockchain used in these studies:

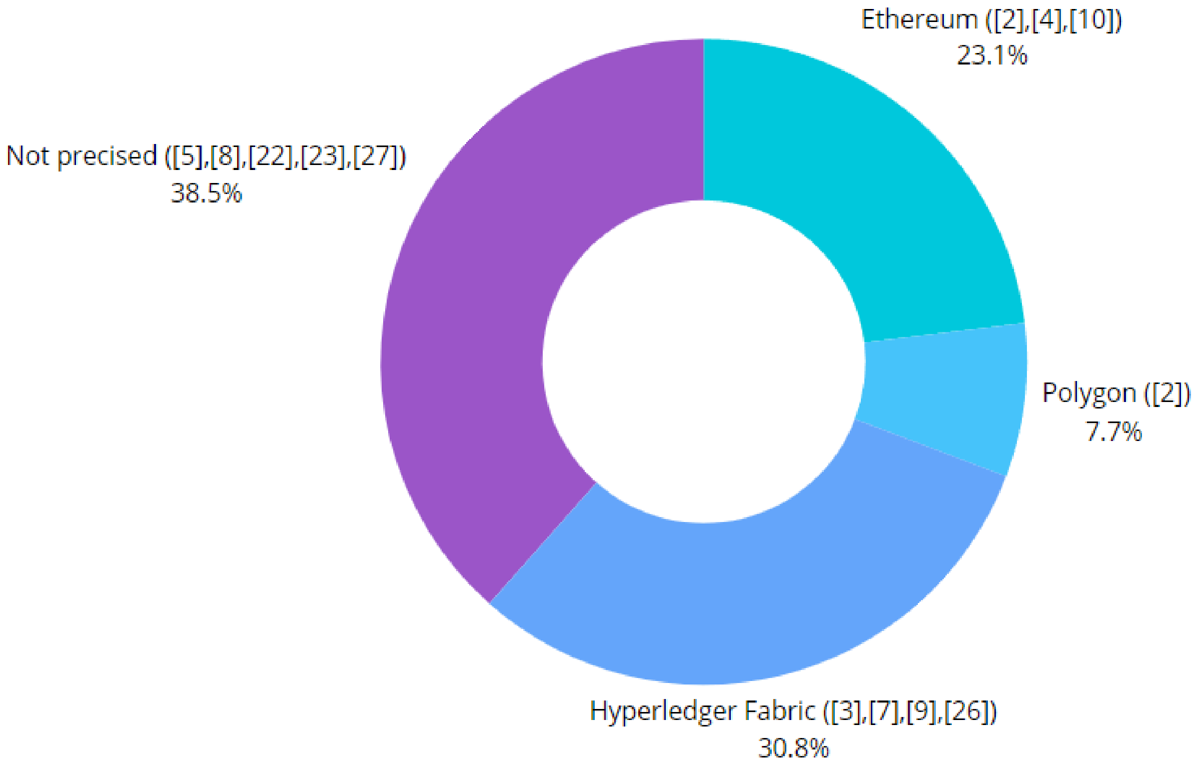

Figure 21 : Distribution of blockchain used in these studies.

About the blockchain distribution, we can see with the last figure that we have 4 main possibilities presented in our studies. Ethereum, Polygon, Hyperledger Fabric and unknown blockchain. [2],[4] and [10] use Ethereum and represent 23,1%, [3],[7],[9] and [26] use Hyperledger with 30,8%, [2] use also Polygon with 7,7% and finally [5],[8],[22],[23] and [27] does not address about the blockchain used. The choice of blockchain does not necessarily depend on the type of blockchain, for example [2] uses ethereum which is a public blockchain, however this study uses a permissioned blockchain. On the subject of distribution we can see that Hyperledger is the most widely used, which respects figure 19 on blockchain types because Hyperledger is reputed to be a permissioned blockchain with many qualities such as modularity and flexibility, interoperability with other systems and support for smart contracts[3].

Studies [5],[8],[22],[23] and [27] does not specify which blockchain is used, they only specify the type of blockchain and the solution in question, they represent the largest share in the previous figure with a total of 38.5% which proves once again that the blockchain used does not really have a significant impact on the solution.

These studies also deal with a large number of consensuses. Here are some of the consensuses used :

Consensus	Definitions	References
Proof of Stake	A consensus algorithm where validators are chosen to create new blocks based on the number of tokens they hold and are willing to "stake" as collateral. Validators are incentivized to act honestly to earn rewards and avoid losing their staked tokens.	[4],[10]
Proof of Work	A consensus mechanism where miners compete to solve complex cryptographic puzzles to validate transactions and create new blocks. The first miner to solve the puzzle is rewarded with cryptocurrency. This process requires significant computational power and energy.	[23]
Zero-Knowledge Proofs (ZKPs)	A cryptographic method allowing one party to prove to another that a statement is true without revealing any information beyond the validity of the statement itself. ZKPs enhance privacy and security in blockchain transactions.	[2]
Raft	A consensus algorithm designed for simplicity and ease of implementation. Raft ensures distributed consensus by electing a leader who manages the replication of log entries to other nodes, thus maintaining a consistent state across the system.	[3]
Practical Byzantine Fault Tolerance (PBFT)	A consensus mechanism that tolerates Byzantine faults, meaning it can reach consensus even if some nodes in the network act maliciously or fail. PBFT involves a series of message exchanges and voting among nodes to agree on the next block to be added to the blockchain.	[9]
Not precised	x	[5],[7],[8], [22],[26],[27]

Figure 22 : Consensus used in the presented solutions

As we can see in the previous figure, for a supply chain system, several consensuses can be used, among our studies there are already at least 5 different consensuses proposed. The choice of consensus is crucial to the success and efficiency of a blockchain-based supply chain solution. It determines the solution's performance, security, scalability and regulatory compliance. Organizations need to carefully assess their specific needs and choose the consensus mechanism that best meets their operational and strategic requirements. So for the consensus part, we don't propose any consensus in particular because they are very variable and depend on the type of solution needed.

4.5 Discussion

Throughout this analysis, we have studied articles proposing blockchain-driven supply chain solutions in the agri-food industry in an attempt to answer the initial research problem concerning the requirements of this type of system. However, after lengthy research, only article [4] speaks of requirements, and even then these are only requirements for off-chain data storage. Without requirements, systems lack the necessary robustness and flexibility needed to handle real-world applications effectively.

In order to find out more about these requirements, we have processed all the details present in these systems, to be able to answer our 4 research questions.

Research question 1 describes the type of data needed to be stored. Indeed, it is imperative to collect accurate and relevant data at every stage of the supply chain, from product creation to sale. For this reason, we recommend storing the data presented at each stage, such as weather conditions during production, or temperature during transport.

Research number 2 teaches us that it is imperative to manage the transfer of asset ownership and that our system must respect this transfer. This transfer is produced on an ongoing basis via transactions between stakeholders, to keep track of the supply chain. A good optional use is tokenization which represents assets digitally and simplifies the transfer process.

Question number 3 focuses on the cyber-physical divide. For this part of the requirement, the system must be able to enable connection and communication between the blockchain and the physical world. For this requirement, the use of technological devices is highly recommended, whether they be IoT devices such as temperature sensors, off-chain storage solutions such as IPFS for storing heavy data, or the use of communications technologies such as RFID or NFC tags, which are mandatory to guarantee traceability and keep track of assets. The integration of IoT devices and appropriate communication technologies is essential to ensure that physical and digital data are synchronized and reliable.

The last research question is more focused on the blockchain technology that will be used to manage and maintain the supply chain system in question. In its analysis, we have seen that permissioned blockchains are more widely used than public ones, as they are more adaptable for supply chain systems due to better control, privacy, and efficiency. Examples include Hyperledger Fabric and permissioned implementations of Ethereum. However, this choice remains free and variable depending on the objectives of the system in question, and although permissioned blockchains are generally preferred for these systems due to their greater control and efficiency, it is also possible to use public blockchains depending on the specific needs of the system.

Finally, while this research has established a list of prerequisites for blockchain-driven supply chain systems in the food industry, it's important to note that each type of system is unique. As such, we cannot guarantee a universal set of requirements. Determining specific requirements is a crucial step that must be established and drafted in advance by those wishing to embark on the implementation of such systems. Future research should focus on refining these requirements and testing them in real-world applications to further validate their effectiveness and address any emerging challenges.

5—Conclusion

In this study, we examined the research problem: What are the key requirements of a blockchain-driven supply chain system for the food industry?". To provide the best possible answer to this problem, which is very rarely explicated in proposed solutions, we established several research questions that enabled us to analyze the subject in the best possible way.

We have seen from our meta-analysis that the requirements of this type of system can be broken down into 4 main areas. Data collection for traceability and transparency, management of asset ownership transfers, different technologies to maintain a gap between the cyber world and the physical world, and finally the choice of the type of blockchain to be used.

In the course of this research, we were able to draw up a list of prerequisites for blockchain-driven supply chain systems in the agri-food industry. However, it should be noted that these are prerequisites to be established for this type of system, but the answers identified are not mandatory to follow, as every type of system is different. Here we present the most frequently used prerequisites and their usefulness, having tried to generalize these systems as much as possible. First of all, we've identified that

By establishing these foundations, this dissertation provides a solid basis for the design and implementation of blockchain supply chain systems in the agri-food industry. The recommendations presented here should be tailored to the specific needs of each project to ensure successful and efficient implementation. Future research can build on these findings to refine and validate these requirements in real-world contexts, contributing to the continuous improvement of traceability and transparency in agri-food supply chains.

Appendix

Studies extraction

Number	ARTICLES	DATE	RQ1	RQ2	RQ3	RQ4
[2]	Scalable Blockchain Technology for Tracking the Provenance of the Agri-Food	2023	NO	NO	YES	YES
[3]	A Blockchain-Based System for Agri-Food Supply Chain Traceability Management	2022	YES	YES	YES	YES
[4]	Automatic Generation of Ethereum-Based Smart Contracts for Agri-Food Traceability System	2022	YES	YES	YES	YES
[5]	Agriculture-Food Supply Chain Management Based on Blockchain and IoT: A Narrative on Enterprise Blockchain Interoperability	2021	NO	NO	YES	YES
[6]	Tokenizing circularity in agri-food systems: A conceptual framework and exploratory study	2023	NO	NO	NO	NO
[7]	Use of blockchain in the agri-food value chain: State of the art in Spain and some lessons from the perspective of public support.	2023	NO	NO	YES	YES
[8]	The Role of Blockchain Technology in Promoting Traceability Systems in Agri-Food Production and Supply Chains	2023	YES	YES	YES	YES
[9]	Blockchain technology in food safety and traceability concern to livestock products	2023	NO	NO	YES	YES
[10]	A Blockchain-Based Traceability System in Agri-Food SME: Case Study of a Traditional Bakery	2021	NO	YES	YES	YES
[11]	Blockchain and consumer behaviour: Results of a Technology Acceptance Model in the ancient wheat sector	2023	NO	NO	YES	NO
[12]	Quality enhanced framework through integration of blockchain with supply chain management	2022	NO	NO	YES	NO
[13]	Adoption of Blockchain Technology for Enhanced Traceability of Livestock-Based Products	2022	NO	YES	YES	NO
[14]	Analysis of IoT and Blockchain Technology for Agricultural Food Supply Chain Transactions	2023	NO	NO	NO	NO
[15]	An agri-food supply chain traceability system for China based on RFID & blockchain technology	2016	NO	NO	NO	NO
[16]	Blockchain Technology to Support Agri-Food Supply Chains: A Comprehensive Review	2022	NO	NO	NO	NO
[17]	Exploring the Hype of Blockchain Adoption in Agri-Food Supply Chain: A Systematic Literature Review	2023	NO	NO	NO	NO
[18]	Augmented System for Food Crops Production in Agricultural	2022	NO	YES	YES	NO

	Supply Chain using Blockchain Technology					
[19]	User Interface of Blockchain-Based Agri-Food Traceability Applications: A Review	2021	NO	NO	NO	NO
[20]	Bridging the gaps in traceability systems for fresh produce supply chains: Overview and development of an integrated iot-based system	2021	YES	YES	YES	NO
[21]	FoodSQRBlock: Digitizing Food Production and the Supply Chain with Blockchain and QR Code in the Cloud	2021	YES	NO	YES	NO
[22]	Blockchain in Agri-Food Traceability Systems: a Model Proposal for a Typical Italian Food Product	2020	YES	YES	YES	YES
[23]	Effective Management for Blockchain-Based Agri-Food Supply Chains Using Deep Reinforcement Learning	2020	YES	NO	YES	YES
[24]	Blockchain: A new safeguard for agri-foods	2020	YES	NO	YES	NO
[25]	Blockchain-Based Agri-Food Supply Chain: A Complete Solution	2020	NO	NO	NO	NO
[26]	An Agri-product Traceability System Based on IoT and Blockchain Technology	2019	NO	NO	YES	YES
[27]	Blockchain-based traceability in Agri-Food supply chain management: A practical implementation	2019	NO	YES	NO	YES

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