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Review

Industry 4.0 and Beyond: A Review of the Literature on the Challenges and Barriers Facing the Agri-Food Supply Chain

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Abstract: In recent years, the Industry 4.0 concept has gained considerable attention from professionals, researchers and decision makers. For its part, the COVID-19 pandemic has highlighted the importance of managing the agri-food supply chain to ensure the food that the population needs. Industry 4.0 and its extensions can address the needs of the agri-food supply chain by bringing new features such as security, transparency and traceability in line with sustainable development goals. This study aims to systematically analyze the literature to address the challenges and barriers against the application of industry 4.0 and its related technologies in the management of an agri-food supply chain. Currently, despite the large number of publications, there is no clear agreement on what Industry 4.0 is, and even less its extensions. The next revolution that includes new technologies and improves several existing technologies brings additional conceptual and practical complexity. Consequently, in this work we first determine the main components of I 4.0 and their extensions by studying the literature, and then, in the second step, define the agri-food supply chain on which I 4.0 technologies are applied. Two well-known databases—Web of Science and Scopus—were chosen to extract data for the systematic review of the literature. For the final evaluation, we identified 24 of 100 reviewed publications. The results provide an exhaustive analysis of the different I 4.0 technologies and their extensions that are applied in regards to the agri-food supply chain. In addition, we find 15 challenges that are classified into five major themes in the agri-food supply chain: technical, operational, financial, social and infrastructure. The four most important challenges identified are technological architecture, security and privacy, big data management and IoT (internet)-based infrastructure. Only a few articles addressed sustainability, which reaffirms and demonstrates a considerable gap in terms of the sustainable agri-food supply chain, with waste management being the one that has attracted the most attention. This review provides a roadmap for academics and practitioners alike, showing the gaps and facilitating the identification of I 4.0 technologies that can help address the challenges facing the efficient management of an agri-food supply chain.

Keywords: industry 4.0; agri-food supply chain; sustainability; agri-food 4.0 supply chain; agri-food 4.0; supply chain 4.0; food waste management; water management; agriculture 4.0

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1. Introduction

In recent years, the concept of Industry 4.0 (I 4.0) has attracted the attention of practitioners, researchers and decision makers, and its applications have been studied in multiple industrial sectors. Despite the large number of academic and non-academic publications, there is still no clear definition of I 4.0. Several technologies, such as Radio Frequency Identification, Internet of Things, Cloud Computing are considered I 4.0 components, and in some cases, by themselves define I 4.0. In order to standardize language and set the context for this article, we first tackle the problem of defining I 4.0.

In 2011 the German government representative used industry 4.0 term as a steadily growing industry that considerably affects our lives. This speech was about how digitalization and new technologies revolutionize the organization of global value chains [1]. As a pioneer country in manufacturing, Germany introduced the idea of integrated industry by launching I 4.0 initiatives in 2011 for its high-tech strategies [2]. I 4.0 is known with different terms in scientific publications such as "Fourth Industrial Revolution", "smart manufacturing", "Industrial internet" or "integrated industry" [3]. Moreover, the other terms suggested by [4] are "smart factories", smart industry", "digital manufacturing", and "smart production". I 4.0 itself is a concept that is applicable through different technologies. The number of technologies is growing and with emerging new technologies it would become more and more. We first determine its main component by studying the literature [3,4] and is more relevant to the supply chain research area.

1.1. Industry 4.0 Key Technologies

Four items were found as principal components, including cyber-physical system (CPS), internet of things (IoT), smart factory, and internet of services (IoS). The study [4] proposed the four mentioned technologies to introduce a coherent definition of I 4.0. Furthermore, [3] study suggested these four technologies as the fundamental technology components of I 4.0 in logistics which are explained as follows:

1.1.1. Cyber-Physical Systems (CP), and Their Application in the Agri-Food Industry

CPS has been invented to respond to the necessity of developing a connection between the physical and virtual worlds [5]. Thus, CPS is the transformative technology that manages the interaction between computational capabilities and physical assets [6]. CPS accomplishes its goal by using different sensors, communication devices, and actuators. The application of CPS in agri-food has recently been studied in two topics of smart agriculture and smart farming [7,8]. Precision agriculture is one of the achievements of CPS application in the agriculture industry, with more efficient performance and resource-saving outcomes [9,10]. Precision agriculture is possibly defined as Wireless Underground Sensor Networks, by implementing communication between computers and physical assets with sensors under soil [11] or underground sensor networks to control the quality of soils [11–13].

Furthermore, some papers discuss how CPS application can bring traceability to agri-food systems [14,15]. The application of such systems, in reality, is a challenging task [16–18].

1.1.2. Internet of Things (IoT), and Its Application in the Agri-Food Industry

IoT is considered the main initiator of I 4.0, which became popular in the early 21st century [19]. Physical devices such as equipment, machines, products, etc., are connected virtually at different and remote locations. These items that perform as physical access points are controlled and monitored by cyber systems [20,21]. "Things" are the entities with physical features in a physical property. These "Things" are incorporated flawlessly in a virtual network system that makes IoT, an information system [22].

IoT in the agri-food supply chain helps suppliers and consumers locate products quickly and display product details, leading to choosing fresher products with the help of sensors. IoT helps retailers monitor the food quality and let them waste management of the products that their expire date is close and reduce energy consumption by managing the temperature at the store, freezers, etc. IoT increases traceability, a prerequisite feature for accomplishing previous acts [23].

1.1.3. Internet of Services (IoS), and Its Application in the Agri-Food Industry

IoS might play a key role in the future of industry. Concepts such as software as a service (SaaS), service-oriented architecture (SOA), or business process outsourcing (BPO) are closely associated with the IoS. Barros and Oberle [24] (p. 6) propose a broader definition of the term service, namely "a commercial transaction where one party grants temporary access to the resources of another party in order to perform a prescribed function and a related benefit. Resources may be human workforce and skills, technical systems, information, consumables, land and others". IoS has not been discussed in the agri-food supply chain so far which shows a potential gap for this technology in this area.

1.1.4. Smart Factory and Its Application in the Agri-Food Industry

We have presented CPS, IoT, and IoS so far, which are the main components of I 4.0. The interaction of COS over the IoT and IoS enables a smart factory [3]. Smart factory works in decentralized manufacturing in which "human beings, machines, and resources communicate with each other as naturally as in a social network" [19] (p. 19). Smart factory in the agri-food 4.0 supply chain could be defined as "smart farming" or "smart agriculture".

Smart farming empowers farmers to apply more dependable control. Real-time, on-site processing data reduces time-consuming. Data is transmitted by cloud system for further analysis. IoT devices such as multiple sensors help cover more areas in the remote and expansive coverage areas [25,26]. Data stored within the cloud is also used by processing plants to resolve operational management problems [27].

This study aims to study the I 4.0 challenges in the agri-food supply chain. Therefore, it is necessary to define the agri-food supply chain precisely. Scholars in agricultural economics and management disciplines first proposed agri-food supply chain [28,29]. Agri-food supply chain management, first proposed by a group of Dutch researchers, manages the supply of raw materials for agricultural production, production processing, and product distribution and logistics [30,31]. This term has been mostly used in two research fields agricultural-related disciplines (e.g., agricultural science and agricultural economics), and business management disciplines (e.g., supply chain management and operational research). Based on [32], we consider agri-food supply chain as one of the four terms "agricultural supply chain", "agricultural value chain", "food supply chain", and "food value chain".

The application of I 4.0 in the agri-food supply chain is also known as the agri-food 4.0 supply chain. Furthermore, agri-food sector could be considered in bioeconomy definition [33] which defines an economy based on renewable biological resources.

2. Materials and Methods

In this study, we applied a systematic literature review (SLR) which was proposed by [34] and developed by [35]. This SLR mainly comprises five steps: research questions definition, search strategy design, study selection, quality assessment, and data extraction.

In the first step, we devise some research questions that should be addressed through this SLR. The questions are regarding the objective of this research. Afterward, in the second step, based on research questions, we come up with a search strategy to find the most relevant publications to the research questions. This step contains both sub-categories: finding the search keywords and determining the literature databases. In the third step, study selection criteria are formed to determine the narrow the most relevant study with respect to addressing the research questions. In the next step, we apply a quality assessment in which we set up some quality checklists to speed up the assessment process. The final data is gathered to answer the research questions in the last step, data extraction.

2.1. Research Questions

This SLR aims to recognize challenges ahead of industry 4.0 application in the agri-food supply chain. Towards this aim, six following research questions have been formed by the authors:

- RQ1: What classifications of agri-food products have been discussed with the emergence of industry 4.0? RQ1 aims to identify the agri-food products that have used the industry 4.0 context. By answering this question, scholars have a better understanding of potential research in the agri-food industry, and it demonstrates which products have adapted industry 4.0 technologies compared to others.

- RQ2: Among industry 4.0 technologies, which one has gained more attention in the agri-food supply chain considering product classification? (Which technology in which agri-food products). We defined four key technologies above: IoT, CPS, IOS, and smart factory for agri-food supply chain. It is essential to realize if there are only mentioned technologies in the agri-food supply chain or other technologies contribute to the supply chain.
- RQ3: What percentage of the literature addressed sustainability in the agri-food 4.0 supply chain? (Based on three aspects of sustainability). The all-new types of supply chains try to address sustainability in a specific way, and the new technologies facilitate this process with their unique features. This research question aims to find out how many of the selected articles addressed sustainability.
- RQ4: How does Industry 4.0 contribute to a sustainable agri-food supply chain? This research question aims to explore how industry 4.0 addresses sustainability in the supply chain. It focuses on the sub-classification of sustainability in the agri-food supply chain.
- RQ5: What challenges are ahead of applying industry 4.0 (I 4.0 adoption) in the agri-food supply chain? This research question aims to find the challenges of applying industry 4.0 in the agri-food supply chain. Practitioners need to know the challenges in advance to contemplate solutions.
- RQ 6: What are the main discussed themes in the agri-food 4.0 supply chain? Based on the answer to the previous question, this research question focuses on classifying challenges. We display a better perspective of challenges in an organized category with the answer.

I 4.0, with disruptive technologies and interconnected machinery, aims to improve production efficiency, which helps suppliers serve better to their customers. The proposed questions attempt to find out the obstacle against I 4.0 as well as how these technologies address sustainability within agri-food supply chain. In this regard, the first question classifies the agri-food products to find which agri-food products have taken advantage of I 4.0 technologies so far. The second question attempts to find all technologies used in agri-food supply chain and shows which technology has been used in what types of agri-food products to demonstrate the research in this context. The third and fourth questions address the sustainability and aim to find in which manner I 4.0 influences on sustainability of agri-food supply chain. Finally, the last two questions address the challenges and barriers of I 4.0 in the agri-food supply chain and picture different themes which will help practitioners and scholars to have a general picture of challenges from different perspectives.

2.2. Search Strategy

The search strategy includes three sub-classifications: search keywords and literature databases, which are explained in detail as follows:

2.2.1. Search Keywords

The following steps were done to find the search keywords [35]:

- Derive major keywords from the research questions;
- Identify alternative spellings and synonyms for principal keywords;
- Check the keywords in the relevant articles or publications;
- Use the Boolean OR to incorporate alternative spellings and synonyms;
- Use the Boolean ASTERISK to replace multiple characters to find the terms that have different appearances with the same meaning;
- Use the Boolean AND to connect the significant keywords;
- Find relevant references for defining the main scope of the research.

We added the last step as a new important step to address the scope of the research. In the scope of this SLR, industry 4.0 is a widely used concept that has several distinct technologies that contribute to I 4.0. As mentioned in the Introduction Section, it is necessary to define I 4.0 precisely; otherwise, the research cannot address the research questions properly because there would be many out-of-scope references in the result. To tackle this problem based on [3,4], I 4.0 has four main components, including CPS, IOT, IOS, and smart factory. However, after reading the articles by the authors, we concluded that the terms "smart farming" and "smart agriculture" are used interchangeably in addition to smart factory. Consequently, we added these two terms to the search keywords step. In the search keywords, in order to search for any group of characters before or after a term we add an asterisk (*). This function is available in both WOS and Scopus.

The search keywords result are shown as follows:

(*agri* OR "*food*" OR "*agro") AND ("internet of things" OR iot OR cps OR "cyber physical system*" OR ios OR "internet of services" OR "smart factory" OR "smart farm*" OR "smart agriculture ") AND ("supply chain*" OR " logistic*") AND ("industry 4*" OR "I 4.0" OR "agri-food 4" OR "agriculture 4" OR "the fourth industrial revolution" OR "smart manufacturing" OR "industrial internet" OR "integrated industry").

2.2.2. Literature Databases

Two well-known literature databases comprising the Web of Science (WOS) and SCOPUS were used for this SLR. Clearly, the two mentioned search engines are the most famous and completed search engines. This research aims to answer research questions considering the application of the fourth industrial revolution in the agri-food supply chain. Thus, the search keywords were used to search for peer-reviewed publications. The search keywords covered article title, abstract, and keywords provided by the author and publication for both WOS and SCOPUS. As the agri-food 4.0 supply chain concept and its applications are novel, we have not applied any time restrictions in our research.

2.3. Study Selection

Search phase 1 resulted in 101 peer-reviewed publications (see Figure 1). In both WOS and SCOPUS there is an option that lets the authors filter articles based on their document type, which is a part of the exclusion criteria. This SLR only considers journal articles, conference papers, and book chapters. After applying exclusion criteria and based on the document type criterion, 67 publications remained. We derived all references through the next step and eliminated duplicated publications by Mendeley software. Twelve duplicated articles were deleted through this step. These 55 remaining peer-reviewed publications went through the inclusion criteria, and only 24 articles remained in the pre-final step. In the last step, we applied a quality assessment. Although all publications received different scores, any publications have not been removed through this step and passed this assessment. The authors found out that the number the publications were few and this could be an explanation that is why all of them remained. The other description is that we define the scope of the research accurately, which leads us to a few numbers of articles. In other words, both preciseness of the scope of this research and the novelty of the topic concluded in a few publications but entirely related ones.

The defined inclusion and exclusion criteria are as follows:

Inclusion criteria:

- Only the studies that addressed the I 4.0 technologies based on the scope of this research will be included;
- Only the studies that addressed the agri-food supply chain will remain in this SLR;
- For the research that has both journal version and conference version, only the journal version will be included;
- For duplicated publications of the same study, only the newest and the complete one will be included.

Exclusion criteria:

- Duplicates are eliminated by Mendeley and a final revision by the authors;

- In the "Document type", we applied a filter by excluding article reviews, conference reviews, editorials, and short surveys in this research;
- Check the keywords in the relevant articles or publications; The authors omitted other languages such as Germany, Chinese, and Russian.

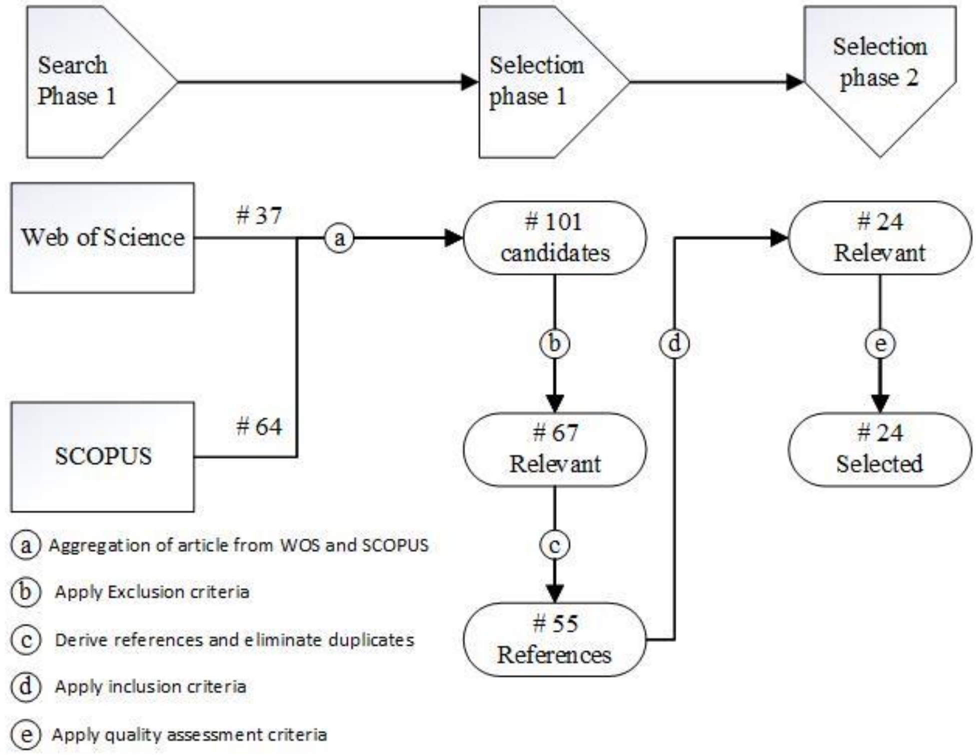

Figure 1. Search and selection process.

As we mentioned earlier, this SLR has two main scopes to find the industry 4.0 challenges in the agri-food supply chain. The first scope is about the I 4.0 that should discuss at least one of the four main components, IOT, CPS, IOS, and smart factory [3]. The second scope of this SLR is the agri-food supply chain, which we defined in the introduction. The included publications in this research should discuss at least one of the four supply chain as follow: "agricultural supply chain", "agricultural value chain", "food supply chain", and "food value chain". Finally, there is no time restriction regarding the novelty of the scope of this research. All publications have been published since 2015 based on our search keywords.

2.4. Study Quality Assessment

The quality assessment is a process in which we weigh the retrieved quantitative data in meta-analysis [35]. Since the results are too few, a meta-analysis is unsuitable for this SLR. Instead, we only use the result of quality assessment. After applying quality assessment, there would not be any changes in the number of outcomes. There is a reason to justify why there is no reduction in the selected articles after using quality assessment. The number of publications is too few, which shows how accurate and in detail the scope of this SLR is defined.

We devised five main questions and 17 criteria to assess the quality of selected articles which are shown in Table 1. Some of the questions were derived from [36]. Question 1 to question 4 are quantitative that has two answers: "Yes" or "No" which answers are scored as follow: "Yes = 1", and "No = 0". The other 17 criteria are scored in the same manner with answers "Yes = 1", and "No = 0". Question 5 is qualitative which is scored as follow: Excellent quality = 1, good quality = 0.67, Fair quality = 0.33, Poor quality = 0. To calculate the final score for a publication, each question has a weight, which is multiplied by the determined score for that question or criteria, and finally, we sum the scores. The weights are defined by authors based on their relevance to the scope of this research which are classified into two sub-categories; five main questions and 17 criteria. As the questions have higher importance, they have bigger weights than the criteria. These five questions aim to assess how close the selected articles are to the agri-food 4.0 supply chain area based on the above definition of the agri-food 4.0 supply chain.

Table 1. Quality assessment questions and criteria.

No.	Criteria or Question	Weight
QA1	Are the aims of the research clearly defined?	7
QA2	Is industry 4.0 adequately described?	10
QA3	Is the agri-food supply chain sufficiently defined?	10
QA4	Does the research address sustainability?	10
QA5	How well does the evaluation address its original aims and purpose?	8
C1	Less than 15 words	1
C2	Keyword in title	1
C3	Present a logical structure in the Abstract	2
C4	The introduction has a high-quality context	2
C5	The introduction mentions the Hypothesis	5
C6	The problem is defined in the Introduction	5
C7	State of the Art is in a logical order	5
C8	Has an appropriate Content of theoretical framework	4
C9	The methodology is explained in detail	5
C10	Data in the Results is available	3
C11	Results are consistent with the objectives	3
C12	Present complementary graphs for the text information	2
C13	Findings are discussed in relation to objectives	5
C14	Results are compared with the state of the art	3
C15	The conclusions correspond to the stated objective(s)	4
C16	Present future research	3
C17	References match	2

Moreover, 17 criteria assess how much the selected publications' general quality is close to scientific research, from article title to references. If a paper obtains 50% of the total score or more, it will be included in the SLR. In this study, all 24 articles received the minimum requirement. The criteria and the final score for each article are shown in Appendix A Table A1.

2.5. Data Extraction

After obtaining the target articles for answering the research questions, the articles were gathered into a separate excel sheet to find the challenges against the agri-food 4.0 supply chain.

3. Results and Discussion

This section includes four subsections that present our findings through this SLR. First, we explain the 24 selected articles in terms of publication year, and document type. Afterward, in the following parts, we answer the research questions. The last sub-section contains the answer to RQ5 and RQ6.

3.1. Overview of Selected Articles

We found 24 peer-reviewed publications that meet our SLR requirements. The first study was published in 2016. The distribution of the publications based on publication year is shown in Figure 2. There is enormous progress in the number of Publications between 2020 and 2021, which shows this area has gained more popularity since 2019. Thus, this Table affirms the novelty and importance of this new research area.

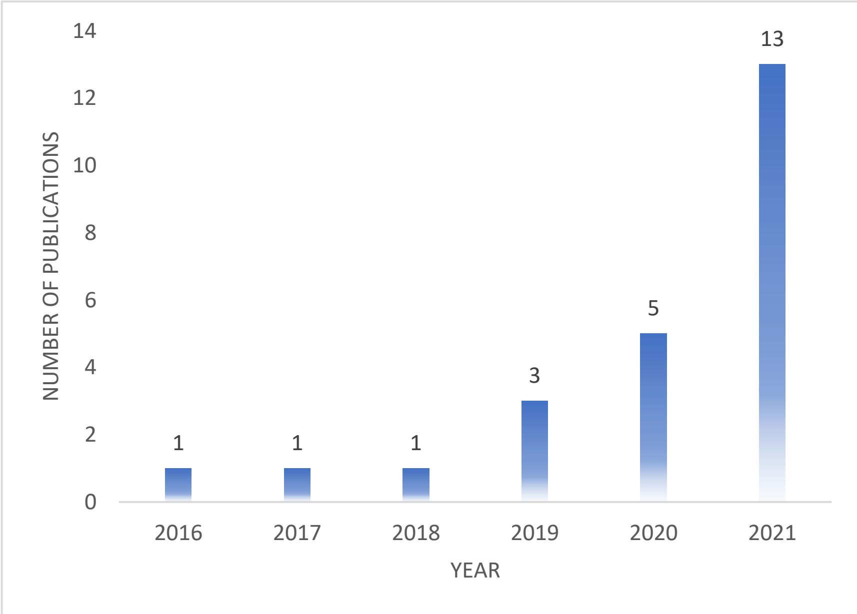

Figure 2. Distribution of publications based on year.

Regarding document types, Figure 3. displays the number of Publications according to their document type. The blue color shows the number of Articles which is equal to 18, and conference papers are displayed by orange color, which is equal to 5, and there is only one book chapter among this SLR.

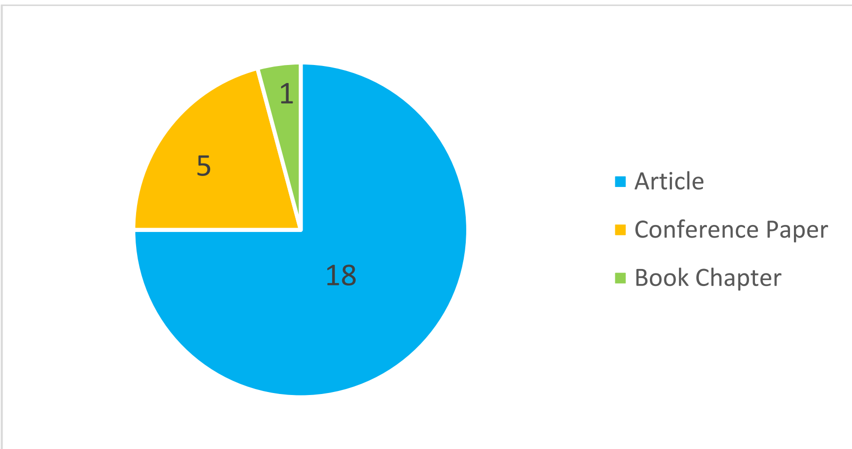

Figure 3. The number of articles based on the document type.

The quality assessment result is shown in Table 2. The quality score was calculated in scale 1 and all studies obtained more than 50% and were selected for final SLR. This Table demonstrates that more than 66% of studies have a high or very-high quality level.

Table 2. Quality assessment score result.

Quality Level	Of Studies	Percent
Very high (0.85 ≤ score ≤ 1)	3	0.125
high (0.7 ≤ score < 0.85)	13	0.54
Medium (0.5 ≤ score < 0.7)	8	0.33
Low (0 ≤ score < 0.5)	0	0
Total	24	100

The distribution of articles in journals is broad, and only Computers in Industry journal has two published articles among all selected studies.

3.2. Types of Agri-Food Products (RQ1)

This SLR aims to classify agri-food products. In the research [37], a general agri-food product classification was proposed by the authors, including (1) bulk cereals, (2) root vegetables and tubers, (3) sugar and sweeteners, (4) meat, (5) dairy products, (6) fruit, (7) vegetable oils, (8) other. We classified the 24 selected articles into five different categories in terms of agri-food products considering the classification in [37] which are shown in Figure 4. These five classifications include (1) fresh fruits or vegetables, (2) cold chain, (3) packaging, (4) food, and (5) agriculture. In [37], fruits and vegetables are two distinct classifications, however, we consider them in one category since the literature addresses their freshness as well as considering both of them in a single article. Thus, we consider fresh fruits and vegetables one class. Seven Publications refer to fresh fruits or vegetables that seem the most important or the most discussed subject in this area, and it is due to the perishability of these products. The second classification, cold chain, includes fisheries industry meats, or any other material that ship by cold supply chain and refrigerators, in which there are five articles. Packaging as a third classification is a new class we add to [37] because the only two articles that refer to packaging and discuss the importance of packaging in the agri-food supply chain in a general perspective. Finally, we proposed two general categories. Ten remained articles discuss food and agriculture products, respectively. These two terms, "food" and "agriculture" are general terms that do not refer to a specific product. We selected these titles because these two categories contain research papers more associated with general frameworks and review papers. Although these publications discuss the agri-food supply chain they do not concentrate on any specific products. This sub-section and Figure 4 answer the first research question.

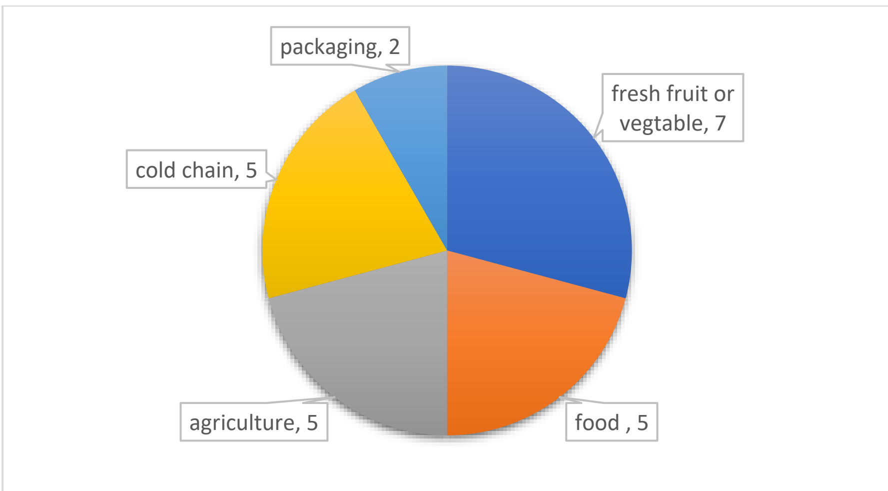

Figure 4. Classification of publications based on agri-food products based on the number of studies.

3.3. Types of Technologies (RQ2)

The answer to research question 2 is shown in Figure 5, which demonstrates the distribution of industrial 4.0 technologies based on agri-food products. As we defined before, industry 4.0 has four main Keys, including IoT CPS, IOS, and smart factory.

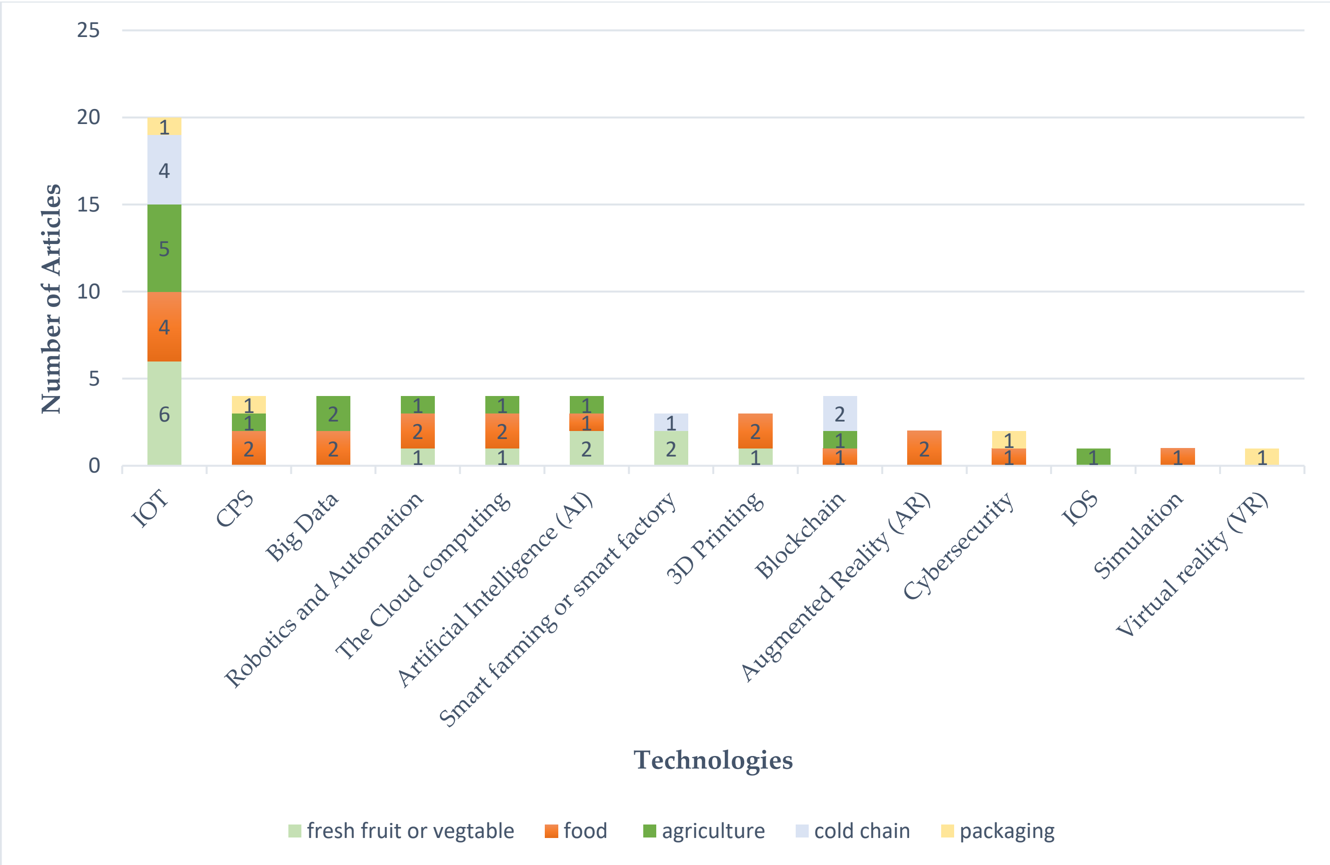

Figure 5. Industry 4.0 technology distribution based on agri-food products.

The authors read all articles through the selected publications and found out that some other technologies play roles in the agri-food 4.0 supply chain. IoT has attracted more attention compared to other technologies. Other technologies that the authors found are big data, robotics, and automation, cloud computing, artificial intelligence (AI), 3D printing, blockchain, augmented reality (AR), cybersecurity, simulation, and virtual reality (VR). Some articles addressed more than one technology in their research; for this reason, the number of technologies is more than the total number of selected papers. Our findings in this section cover nine technologies that were used to systemically review circular supply chains in and application of I 4.0 in the circular economy [38].

3.4. Sustainability Area (RQ3)

This section presents our findings in terms of sustainability. Only nine articles from 24 selected articles addressed sustainability which shows a gap regarding sustainability in this field. The distribution of sustainability is illustrated in Figure 6. Of these nine articles, only one addressed the social aspect, and all of them addressed the environmental aspect of sustainability.

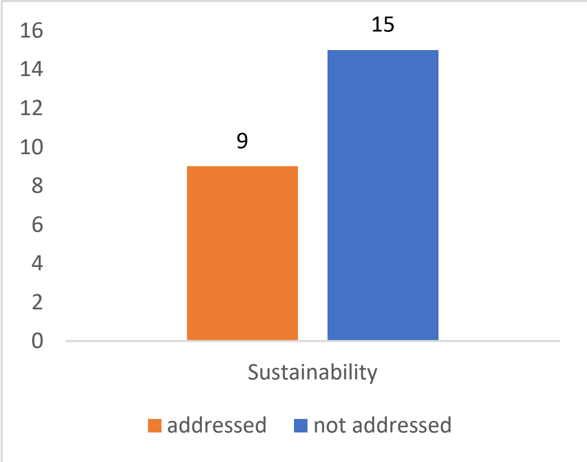

Figure 6. Distribution of sustainability in the literature.

3.5. The Contribution of I 4.0 in a Sustainable Agri-Food Supply Chain (RQ4)

This section aims to address research question 4; how I 4.0 contributes to the sustainable agri-food supply chain. When it comes to the environmental aspect of the agri-food supply chain, waste management attracts more attention due to the perishability of products in this value chain. Then, water management has the second step. Finally, only one paper addressed energy consumption management. The information is shown in Figure 7.

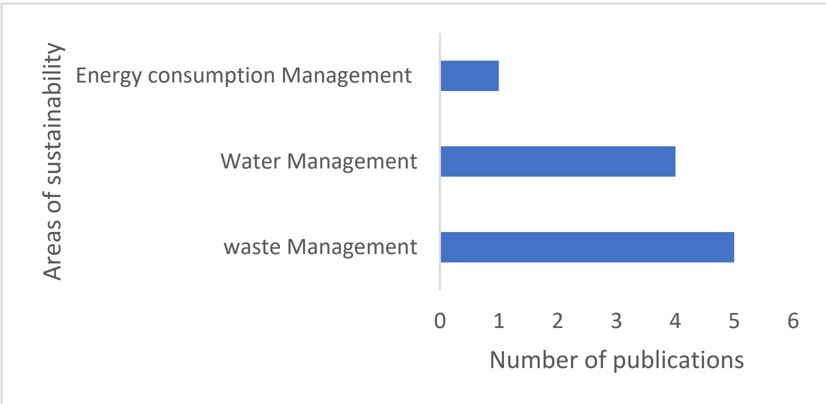

Figure 7. Areas of sustainability.

3.6. Challenges and Themes in the Agri-Food 4.0 Supply Chain (RQ5 and RQ6)

This study aims to find challenges in the agri-food 4.0 supply chain. To find the challenges, first, we read all the articles and found four papers that addressed challenges directly for different technologies but not specifically the industry 4.0 concept [13,16]. Then we reread the publications to see which article addresses which challenge. Among the four papers that addressed challenges directly, three [13–16] addressed challenges regarding IoT adoption in the agri-food supply chain. In [39], the authors studied challenges regarding different technologies, including IoT, Robotics and autonomous systems, AI, big data analytics, and blockchain. There are both common challenges and unique challenges mentioned in these four articles. We reread the challenges and tried to integrate the challenges that were mentioned with different names while they had the same characteristics. Finally, we reached 15 challenges and five themes. The themes and challenges are illustrated in Table 3.

Table 3. Challenges and themes in the agri-food 4.0 supply chain.

Themes	Challenges	References	Number of Observations
technical	Security and privacy	[20,23,39–46]	10
	Wireless power transfer and ambient energy harvesting	[39]	1
	Big data management	[20,47–50]	5
	Reliability, availability, and robustness	[20,46]	2
	Developing IoT-based cloud system	[40,43]	3
	Technological architecture	[20,27,42,45,49–57]	13
infrastructural	IoT-based infrastructure (Internet)	[39,40,44,45,48]	5
	lack of governmental regulations	[23,48]	2
	Standardization	[20,23,44]	3
operational	High energy consumption	[39,45,47]	3
	Scalability	[23,39,40,44]	4
	Interoperability	[20,39]	2
	Congestion and overload issues of IoT	[40]	1
financial	High implementation and operating costs	[23,41,58]	3
social	Lack of human skills and educational issues	[39,45,48,58]	4

As the number of challenges in this area is extensive, we aim to classify challenges to make them more sensible for scholars and future research. In [55], the article's authors classified IoT adoption challenges into five main themes, including technical, financial, operational, social, educational, and governmental, and fourteen challenges. We kept the four technical, financial, operational, and social themes, and we added a new classification called infrastructural themes. This study considers the educational theme as a subsection of the social theme because the terms education and society have been widely used close to each other. Moreover, the related governmental challenges are a sub-category of an infrastructural problem. We explain each of them separately below.

3.6.1. Technical Theme

After reading, analyzing, and interpreting the selected article, we concluded seven challenges that we consider technical challenges. Each challenge is described separately as below:

- Security and Privacy

Security and privacy have been widely proposed as a significant ongoing issue regarding I 4.0 technologies [43,44], more specifically, security issues associated with IoT technologies [20,23,40]. In industry 4.0, a huge amount of data is generated and distributed through a wireless sensor. Four extensive areas, including data authentication, resistance to attacks, client privacy, and access control regarding security and privacy, must be addressed [20,23]. Network and some parts of this data are about users and their private information, interaction, etc.

In other papers, security is considered cybersecurity [41,45,46] which refers to the security related to cyberspace and the link among physical assets and objects. According to the assertion in [41], insufficient cybersecurity awareness and a lack of educated and skilled people in the cybersecurity area can diminish security and raise risks. Due to an enormous number of stakeholders in the agri-food supply chain, such as farmers, manufacturers, wholesalers, retailers, and consumers, the supply chain is vulnerable to cyberattacks [46].

Blockchain, a fast-growing technology, is proposed as an infrastructure to share data in the agri-food 4.0 supply chain [39,42]. By combining IoT and blockchain, Grecuccio et al. [42] proposed a framework to reduce security in the food supply chain and increase traceability. Although blockchain, like other I 4.0 technologies, is vulnerable to cyber-attack, three key characteristics, including data storage, decentralized network, and peer-to-peer communication, intensify security and privacy considerably [39].

- Wireless power transfer and ambient energy harvesting

This challenge is only presented in [39], which seems a significant issue for applying I 4.0 appliances in the agri-food supply chain. Liu et al. in [39] propose a challenge for recharging small sensors necessary in farms such as underground, underwater, livestock, and trees. Replacing the batteries in these appliances seems unachievable. Wireless power transfer is a good solution by recharging the batteries through electromagnetic waves. However, underground, underwater, and long-distance wireless networks are issues ahead of this solution. Likewise, ambient energy harvesting is another potential solution for this challenge. Some research papers studied and showed that harvesting energy from rivers, movement of vehicles and fluid flow, and the ground surface is possible [39]. Nevertheless, as the converted electrical energy is limited, power conversion efficiency should be further improved.

- Big data management:

Big data has been at the center of attention in the SCM and many studies have addressed it recently. For example, in [59], the authors asserted that big data-driven SCM could facilitate the barriers. Moreover, big data management extensively used with I 4.0 in several contexts. In agri-food supply chain 4.0, it has been mentioned as big data, data management, and big data analytics [47–49]. The devices, appliances, and sensors generate numerous big data that need to be collected, stored, processed, and distributed through different networks. This abundance of data should be managed [20]. Some of the challenges in big data management are data storage, searching, sharing, analyzing, and data visualization. Since the amount of data rises daily, the mentioned challenges need high-end hardware and software and continuous upgrade of the system. The other challenge with respect to big data management is data insecurity [46].

- Reliability, availability, and robustness:

Reliability and availability of IoT devices and services are potential issues in the agri-food supply chain. There might be various failures in the system, such as hardware failure, software issues, malicious attacks, and limited energy. Consequently, the robustness and reliability of I 4.0 services are a significant challenge [20]. Both device failure and link failure, which lead to communication failure, can cause financial risk. In research by [20], authors propose a three-layer architecture for IoT-driven agriculture in which reliability is one of its main features.

- Developing IoT-based cloud system:

A cloud system is used in the I 4.0 context as an intermediary space to link devices and appliances through its network. Yadav and Garg, in their article [40], consider cloud-based development as a challenge ahead of IoT technologies. However, another research [40] considers cloud-based systems pricey and proposes a blockchain system and direct communication of IoT devices through blockchain.

- Technological architecture:

Khan and Altayar [20] propose technological architecture as an obstacle ahead of IoT adoption. They assert that it is necessary to develop, maintain and integrate a robust technological architecture that comprises all IoT-related technologies, such as cloud computing, artificial intelligence, blockchain, wireless technologies, machine learning, big data analytics, and data center and server technologies [20]. Thus, an open technological architecture ensures the integration of different technologies, scalability, mobility, interoperability, modularity, and openness in a heterogeneous environment. This study proves that technological architecture is the most important challenge based on our findings, because it has attained more attention in the literature than the other challenges in which 50 percent of the selected publications addressed this challenge.

A sustainable food supply chain was designed for IoT-enabled e-commerce food enterprises by applying a lateral inventory share policy [56]. Another study by Almadani and Mostafa [51] presents a systematic integration model of a multi-vendor agricultural production system that uses data distribution service middleware to facilitate communication among production systems.

The cocoa bean traditional assessment method is carried out by humans and takes a lot of time. Adhitya et al. [27] used artificial intelligence classifier methods for textural feature extraction to decrease the assessment time process and cocoa bean waste. Reducing food waste is a contribution to a sustainable supply chain. Jagtap et al. [52] designed a framework to diminish food waste as well as energy and water based on IoT-based devices. Other research [49], studied how cyber-physical systems can contribute to sustainable food systems by using machine learning techniques. Likewise, Mondragon et al. [50], proposed a two-layer conceptual approach in the fishery industry by using IoT devices and digitalization. Furthermore, a software framework that lets IoT devices communicate through blockchain was proposed by [42]. In [48], the author designed a module that uses AI-based IoT devices to ripen the fruits when they are shipped by in the container.

Moreover, Sharma et al. [54] proposed a framework with CPS concentration to improve productivity in the agricultural supply chain. In addition, a three-layer architecture proposed by [42] that is energy efficient, cost effective, heterogeneous, secure, and reliable to use IoT in agriculture based on cloud computing. Finally, the paper by [55] designed a model based on I 4.0 technologies to collect food traceability data through the supply chain and transform it to the consumer to improve the quality of products.

3.6.2. Infrastructural Theme

This theme presents three different infrastructural challenges. These challenges are IoT-based infrastructure, lack of governmental regulations, and standardization. Each challenge is discussed as follows:

- IoT-based infrastructure:

Infrastructure for IoT-based devices and services is another challenge in the agri-food 4.0 supply chain. Accessibility to the internet, the primary service of Industry 4.0, is low in the agri-food sector. In [40], the authors studied the lack of internet accessibility in the Indian agriculture supply chain. The availability and collaboration of a diverse range of services such as AI, CPS, IoT, IoS, blockchain, cloud systems, and so on need a high-quality infrastructure in the supply chain [48]. When it comes to infrastructure, implementation issues arise related to hardware installation challenges and changes in the processes [44]. Likewise, installing these infrastructures needs a high cost [45].

A robust wireless network is necessary to apply I 4.0 technologies in the agri-food supply chain. However, it is an issue because of several causes that negatively affect the wireless network. For example, temperature variations, humidity, human presence, and movements of animals lead to signal fluctuations [39]. Hence, a robust wireless network is vital to coping with weather conditions and the agricultural environment.

- Lack of governmental regulations:

The government plays a key role in the agri-food 4.0 supply chain. Poor regulations in IoT applications may create food safety issues and decrease traceability [60]. In [48], Yadav et al. demonstrated that the collaboration of government organizations, NGOS, and food processing organizations could enable I 4.0 in the agri-food supply chain. Laws and regulations should support the development and extension of I 4.0 in supply chain management, especially in the agri-food sector, which has important consequences on social health and poverty [23].

- Standardization:

Smart agriculture and global communication need standard protocols to prevent ambiguity and facilitate efficient and smooth integration among different vendors and data safety through cloud networks [23]. Standardization helps devices and digital appliances interact efficiently. This challenge becomes more important when it comes to the global supply chain between various continents with different regulations, responsibilities, and standards [44]. The complexity of I 4.0 technologies even makes it more difficult to define a unified standard for the interaction of sensors, software, devices, actuators, and networks with their own predefined protocols [20]. Lack of standardization has always been a challenge for most new technologies [23].

3.6.3. Operational Theme

This theme attempts to address the barriers regarding the operational aspect of I 4.0 technologies in the agri-food supply chain. The main challenges are high energy consumption, scalability, interoperability, proper connection of ASC entities and IoT technology, and IoT congestion and overload issues. The issues are explained as follows:

- High energy consumption:

Blockchain has gained more attention for this challenge. Due to the high energy consumption of blockchain technology, especially by coal and fossil-based energy, it is a thought-provoking barrier [39]. High energy consumption leads to a high cost of energy that makes it a barrier in the agri-food supply chain. To cope with this issue, scholars in [58] proposed adopting renewable energy to reduce costs in the long-term and meet sustainable development goals for reaching a green planet and mitigating climate change.

- Scalability:

Agri-food 4.0, with growing technologies such as IoT, blockchain, etc., includes an incredible size of devices and nodes that need to connect in the future. Thus, scalability has been mentioned as an ongoing challenge that should be addressed in agri-food 4.0. Some papers presented the scalability issue in IoT [23,40]. The middleware approach is proposed by [40] to provide a flexible service with a huge number of devices that can communicate with each other at one position,. The other research by [44] discusses the importance of servers' scalability in IoT. Scalability in blockchain is presented as an issue in [39] since the transaction speed in blockchain networks such as Bitcoin and Ethereum are so low compared to visa transactions.

- Interoperability:

The nature of I 4.0 works with devices that produce data, and they need to communicate with each other through diverse networks. When it comes to the agri-food supply chain, it contains several layers, including thousands of devices and communication. Therefore, I 4.0 technologies should have the capability to communicate and exchange data between devices. This capability is called interoperability, an issue in the agri-food 4.0 supply chain. The information exchange needs an interoperable environment. Interoperability generally has four types; technical, semantic, syntactic, and organizational [20]. This challenge has been studied for two technologies: IoT and blockchain [20,39]. Different sorts of blockchain networks can hardly communicate with each other, and there is a necessity for interoperable communication protocols [39].

- Congestion and overload issues of IoT:

This issue is similar to the operational challenge proposed by [61] to study collaboration in an industrial symbiosis network in the circular economy. The complexity of the supply chain and collaboration among its players was previously introduced as an issue. Given the complexity of the SCM network in which each layer in SCM uses several devices as well as fast-growing technologies and the existence of big data in the network system, facing congestion and overload of IoT devices is an inevitable challenge in the agri-food 4.0

supply chain. The congestion occurs when multiple devices produce information and want to load their data through the network [40]. It is necessary to find a solution for this issue in the future as an adoption barrier.

3.6.4. Financial Theme

The financial theme has only one challenge regarding general financial concerns in terms of novel technologies as follow:

- High implementation and operating costs:

Implementing I 4.0 requires new technologies and always emerging technologies have been pricy. Furthermore, the maintenance cost will be a challenge for organizations [23]. In a study by [41], active packaging is suggested as a new solution for sustainability in the post-harvest food supply chain. Although active packaging increases the quality, safety, and shelf life of packaged food, the high-cost implementation is a barrier to adopting this beneficial tech. On the other hand, the other paper proposes that although the implementation of I 4.0 technologies and digitalization is expensive, in the long term, these technologies are beneficial [58].

3.6.5. Social Theme

We name this theme social because it is about social challenges pertaining to humans. The issues show the lack of human skills and educational issues, which is explained as follow:

- Lack of human skills and educational issues:

It is essential to address the issues related to farmers and I 4.0. Farmers should be aware of the benefits of industry 4.0 context to participate in the supply chain. However, there is a lack of human skills in the agri-food supply chain as most data analysts and data scientists are not at agricultural universities or agri-food-related companies [39]. Likewise, universities have not yet prepared industry 4.0 courses or programs to provide sufficient human skills in this field. Furthermore, the lack of skilled labor is apparent, and it is essential to speed up preparing highly skilled experts and laborers in the agri-food supply chain [58]. In research by [48], education and training were found as the fifth most important enabler of the agri-food 4.0 supply chain among 14 enablers, proving the significance of this challenge.

4. Discussion and Conclusions

This systematic literature review aimed to address challenges regarding industry 4.0 application in the agri-food supply chain. In the first step, we defined industry 4.0 and its main technology components, including IoT, IOS, CPS, and smart factory. Then we described the agri-food supply chain containing four types of supply chain; "agriculture supply chain", "agriculture value chain", "food supply chain", and "food value chain". Afterward, we devised six research questions. We defined the search terms based on our definition of industry 4.0 and agri-food supply chain. In the final step of the systematic review, we applied a quality assessment. The result of SLR was 24 selected Publications. Although a few articles were selected in the final process (24), the quality assessment showed the selected publications are quite well matched to the scope of this study, which could be due to the novelty of the field and the preciseness of the scope of this SLR. We contribute to the literate by applying a systematic literature review into industry 4.0 application in the agri-food supply chain. A systematic review that concentrates on I 4.0 is scarce. Similar publications mainly discuss specific technologies such as IoT, CPS, or blockchain, and not the I 4.0 as a general concept. Hence, the findings in this study are worth reading, and it helps both scholars and practitioners in the agri-food supply chain.

We found 15 challenges regarding the agri-food 4.0 supply chain that each one is defined separately. Then, we classified them into five main themes. The principal findings of this review are summarized as follows:

- (RQ1) There are five categories in terms of agri-food products in the agri-food 4.0 supply chain. Three specific products and two general ones. The particular products contain fresh fruits and vegetables, cold chain, and packaging. On the other hand, in some studies, almost 40% of this SLR generally addresses food and agricultural products due to their concentration on frameworks or reviews. Since there have not been similar articles that classify products, our findings contribute to the agri-food supply chain by demonstrating the importance of the I 4.0 application for perishable products such as fresh fruits, vegetables, and cold chains.
- (RQ2) This research question aimed to find the most applicable technology in this field: IoT with its wide application. IoT has gotten considerable attention compared to other technologies. In this section, we found some other technologies in addition to the four leading mentioned ones; IoT, CPS, IoS, and smart agriculture. Other technologies are big data, robotics and automation, cloud computing, AI, 3D printing, blockchain, augmented reality (AR), cybersecurity, simulation, and VR. These technologies also play a role in the agri-food 4.0 supply chain. The results of this question are shown in Figure 5, another contribution of this study. We displayed which technology has been used on which type of products. For example, IoT and its application in fresh fruits and vegetables, agriculture, and food products have the highest number of articles, respectively.
- (RQ3) The answer to this research question identified a vast gap in sustainability in the agri-food 4.0 supply chain. When new technologies come up, sustainability should be considered. Nevertheless, some new technologies, such as a single AI, not only do not reduce carbon emissions but also can emit carbon as much as five cars through its lifetime [62]. The selected articles that addressed sustainability were 37.5% of selected studies. In this era, the importance of sustainability is inevitable in various contexts from climate change to the social terms. This gap is an opportunity for future research.
- (RQ4) The answer to this research question determined that waste management has gotten more attention due to the perishability of products in the agri-food supply chain. Then water resource management is another area that industry 4.0 contributes to the sustainable agri-food supply chain. Climate change has caused new challenges in the agri-food supply chain, such as water shortages and droughts. Scholars in this area should address how new technologies in I 4.0 would affect sustainability from different aspects. There is a necessity for the hard work of scholars and researchers to analyze I 4.0 impacts on sustainable development goals.
- (RQ5) In answer to this question, we found 15 challenges, including security and privacy, wireless power transfer and ambient energy harvesting, big data management, reliability, availability, and robustness, developing IoT-based cloud system, technological architecture, IoT-based infrastructure (Internet), lack of governmental regulations, standardization, high energy consumption, scalability, interoperability, congestion and overload issues of IoT, high implementing and operating costs, and lack of human skills and educational issues. The challenges are shown in Table A1 in which a column represents the number of articles discussing each challenge. With these numbers, we found the most notable barriers ahead of I 4.0 in the agri-food supply chains. Here we name the four most discussed challenges: technological architecture, security and privacy, big data management, and IoT-based infrastructure, respectively. Designing a professional framework or model in which technologies perform properly is the biggest challenge in the selected articles. Before doing any action, it is essential to have a map or an architecture that demonstrates how I 4.0 technologies should function. The second most discussed issue is security and privacy, which is a barrier for enterprises, farmers, and all layers of the agri-food supply chain to trust the new technologies. Security and privacy have always been a striking challenge for new technologies. Lastly, big data management and IoT-based infrastructure have the third important position in the list of challenges. It is vital to address this issue because data is the main component of this supply chain that facilitates procedures and speeds up functions.

Therefore, managing an immense of data is recognized as an issue. Furthermore, all efforts towards I 4.0 are useless without proper infrastructure like the internet.

- (RQ6) Finally, after reading the challenges, we classified them into five main classifications: technical, operational, social, infrastructural, and financial.

The findings of this study showed a considerable gap in the sustainability of agri-food 4.0 supply chain. Meanwhile, most of articles addressed I 4.0 application in the agri-food supply chain without addressing sustainability which draws attention and shows a considerable gap for future research in the agri-food 4.0 supply chain. On the other hand, among articles that addressed sustainability, waste management, and water management were found two sub-sections of sustainability that are more discussed and need to be further addressed. The two issues of water and waste management are the most notable challenges in the sustainable agri-food supply chain. More research is needed to study how I 4.0 is able to address water and waste management. Furthermore, I 4.0 is still emerging with the development of disruptive technologies and is in its early decade.

Moreover, based on agri-food product classification in this study we suggest further research on challenges regarding each product's category because first, this study considered challenges overall on agri-food supply chain and second, the character of each category could make define other challenges or more specific sub-challenges.

Furthermore, this study pictures a comprehensive classification of challenge themes which help practitioners and scholars to narrow the concentration on addressing the problem and to have a better understanding of the whole challenges in one frame. The presented themes outline the main barriers that need to be addressed by the agri-food industry in adopting industry 4.0 into their supply chain.

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Appendix A

Table A1. Quality assessment complete result of the selected studies.

ID	QA1	QA2	QA3	QA4	QA5	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	SCORE	Ref
1	1	0	1	1	0.67	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	79.36	[56]
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	97	[51]
3	1	0	0	0	0.67	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	0	1	54.36	[27]
4	1	1	1	0	0.67	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	0	1	79.36	[47]
5	1	0	0	1	0.67	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	0	1	66.36	[52]
6	1	0	1	0	0.67	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	0	1	66.36	[23]
7	1	1	1	0	0.67	1	1	1	1	1	1	1	1	0	0	1	0	1	1	1	0	1	74.36	[46]
8	1	1	1	1	0.67	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	0	1	86.36	[63]
9	1	1	0	1	0.33	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	1	63.64	[48]
10	1	1	1	0	0.67	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	75.36	[49]
11	1	1	1	1	0.67	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	84	[39]
12	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	87	[50]
13	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	1	0	1	0	1	0	1	81.36	[41]
14	1	1	1	1	0.67	1	1	1	1	1	1	1	1	1	0	1	1	1	0	1	1	1	84	[42]
15	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	0	1	69.36	[40]
16	1	1	1	0	0.67	1	1	1	1	1	1	0	1	1	0	1	1	0	0	1	1	1	71.36	[43]
17	1	1	1	0	0.67	1	0	1	1	1	1	0	1	1	1	1	1	0	0	0	0	1	56.36	[53]
18	1	0	0	1	0.67	1	1	1	1	1	1	0	1	0	0	1	1	0	0	1	0	1	53.36	[54]
19	1	1	1	0	0.67	1	1	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	72	[20]
20	1	1	1	0	1	1	1	1	1	1	1	0	1	1	1	1	1	0	0	1	0	1	61.36	[44]
21	1	1	1	1	0.67	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	84	[45]
22	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	0	1	92	[58]
23	1	1	1	0	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	68.36	[58]
24	1	1	1	1	0.67	1	1	1	1	1	1	1	1	0	1	1	1	0	0	1	0	1	78.36	[55]

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