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Industry 4.0, circular economy and sustainability in the food industry: a literature review

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Abstract

Purpose – This paper aims to find the best tools to influence the improvement of sustainability in food supply chains (FSCs) by conducting a systematic review of articles. The reader will learn how the different industry 4.0 tools (I4.0T) benefit the FSC and the limitations of each tool.

Design/methodology/approach – A review of 436 articles published during the period 2019 to 2022 referenced in the Scopus and Web of Science databases was performed. The review was limited to articles published in English and directly related to Industry 4.0, circular economy and sustainability in the food supply chain.

Findings – The results show different contributions of I4.0, with some being more influential than others in improving sustainability in FSCs; for example, Internet of Things and Blockchain have been shown to contribute more toward transparency, traceability, process optimization and waste reduction.

Originality/value – The paper's contribution consisted of ranking according to their importance and the I4.0T that affect sustainability in FSCs by classifying the aspects of each tool and the sustainability factors through a categorization by the Analysis Hierarchy Process.

Keywords Industry 4.0, Food supply chain, Sustainability, Circular economy, Literature review, Bibliometric analysis

Paper type Literature review

1. Introduction

The problem of the accelerated growth in the demand for food is causing the food industries to look for ways to be more efficient (Mahroof *et al.*, 2021; Matsumoto *et al.*, 2020); this is because with the increase in their production, more significant waste is generated and an increase in the resources used throughout the entire food supply chain (FSC) (Govindan, 2018). The FSC is, at the industry level, one of the least efficient since it generates losses during processing, deposit, transfer and consumption (Ojha *et al.*, 2020). As a result, a large amount of resource use and also food waste (Jagtap *et al.*, 2021; Lin *et al.*, 2019; Mithun Ali *et al.*, 2019), this is due to the linear model of this industry, take, make and discard three products (Ada *et al.*, 2021; Moreno *et al.*, 2019); it is estimated that 40% of the food produced is lost during the supply chain (Kayikci *et al.*, 2022; Corrado *et al.*, 2019; Kiil *et al.*, 2018), food waste is expected to rise to 126 million tons per year by 2020 if no additional prevention policies are implemented (Principato *et al.*, 2019); in addition, the food industry represents a

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high percentage of the total electricity consumed in the industrial sector, approximately 12% (Clairand *et al.*, 2020); for this reason, it can be concluded that the FSC is very inefficient (Cannas *et al.*, 2020). Therefore, a way to solve this problem must be found urgently.

In this environment, the CE has become popular in addressing these problems. The CE provides an operational vision and an administrative structure for the reduction of resources and the reuse of these (Kumar *et al.*, 2021b; Bocken *et al.*, 2016); this is based on the reduction of inputs, reuse, recovery, recycling and reduction of emissions and waste (Laskurain-Iturbe *et al.*, 2021; Geueke *et al.*, 2018). From a supply chain perspective, CE has quickly become an influential driving force for supply chain sustainability in research and practice and offers a new and innovative frontier of sustainability in supply chain management (SCM) (Farooque *et al.*, *2019*).

The enabler of this type of company is the industry 4.0 tools (I4.0T) that are useful for their incredible technological capabilities and promote and speed up the transition toward a CE, maximizing the use of resources and minimizing waste (Kumar *et al.*, 2021b; Al-Sheyadi *et al.*, 2019). With these new tools, the integration and exchange of information in the supply chain have also been achieved (Yadav *et al.*, 2020). The I4.0 tools have stood out in different categories on how they can contribute to a CE. For example, Laskurain-Iturbe *et al.* (2021) pointed out that the additive manufacturing (AM) tool is characterized by a decrease in the use of raw materials, while tools such as Blockchain and Internet of Things (IoT) have managed to increase product traceability (Azzi *et al.*, 2019); Big Data, Artificial Intelligence and Robots have managed to improve energy use and waste reduction during the supply chain (Kumar *et al.*, 2021a; Gružauskas *et al.*, 2018).

The introduction of Industry 4.0 and smart factories have brought new opportunities for applying Industry 4.0 tools (Crnjac *et al.*, 2017). In addition, with the application of the IoT, intelligent process control, process optimization using Big Data, as well as production control and monitoring for sustainable purposes, a new era in technologies for the food industry is opening up (Režek Jambrak *et al.*, 2021).

It has been noted that there are studies on how Industry 4.0 tools have succeeded in demonstrating the positive influence of I4.0T on the CE and its sustainability in industries (Gunduz *et al.*, *2021*; Nascimento *et al.*, 2019; Pouriani *et al.*, 2019); but these mostly do not correspond to the field of the food industry; moreover, it is known that I4.0T is applied differently in each type of industry and with different implications (Bai *et al.*, 2020). Therefore, it is essential to know how these tools can positively impact sustainability in the food industry.

There are studies in which the use of Industry 4.0 tools (Baire *et al.*, 2019; Jæger and Mishra, 2020) has been implemented practically in the food sector, but these studies are more focused on a perspective of economic results and production optimizations (Bueno *et al.*, 2020). Although some authors explain how I4.0 increase traceability in FSCs in conjunction with other tools (Khan *et al.*, 2020), these studies show that complete traceability of food status can be obtained, this information is used by end users at the consumption stage (Casino *et al.*, 2021). However, these results do not emphasize the results of waste reduction and which of the tools generated a more significant impact on increasing sustainability in FSCs. Although there needs to be more research on implementing I4.0T in food industries focusing on sustainability; the last few years have seen an increase in the number of studies related to this area, both in theoretical and practical studies (Jæger and Mishra, 2020; Ali *et al.*, 2021a).

The purpose of this study is to find which Industry 4.0 tools are applicable in the food supply chain to implement sustainability practices positively (Wang *et al.*, 2020; León-Bravo *et al.*, 2019); since the applications of Industry 4.0 technologies for development seem to attract more and more attention from practitioners and academics (Beltrami and Orzes, 2021). In this context, an analytical approach is proposed to broadly understand the sustainable performance of I4.0 in the food sector (Bai *et al.*, 2020). Through a systematic review, the article seeks to obtain definitions of the concepts involved and their relationships and implementations to know the tools capable of generating sustainability in the food supply chain and be able to answer the following research questions:

RQ1. What are the Industry 4.0 tools that positively influence sustainability aspects in FSCs?

RQ2. Which tools are better than others for optimizing sustainability in FSC?

In order to be able to answer these research questions, the articles obtained in the search were analyzed using trend and bibliometric analysis. In addition, the study is in charge of defining and relating the concepts of industry 4.0, CE and sustainability in the FSC.

The article gives us a much broader view of the tools in terms of industry 4.0 and CE within the food sector, looking for the relationship that sustainability has with some other concepts such as traceability, process optimization and waste reduction, which complement the large field of compression that has the industry 4.0 (Safdar *et al.*, 2020). Thus, the bibliometric analysis generates different results for each evaluated tool to see which ones generate more sustainability within the food industry. Likewise, the results give different perspectives about the tools in the different fields in which they are evaluated to generate better or better adaptability according to what is sought.

The research generates a ranking of factors that give us an objective vision about which tools are the most compatible with the concepts of industry 4.0, CE and its environment, which in this case is the food sector. It is worth remembering the scarcity of articles on the food sector concerning these concepts; our article offers many aspects that have not been addressed in previous articles and the most prominent are the triple relationship between the tools, industry 4.0 and especially the food sector is critical for future research that wants to measure sustainability in this industry that does not stop growing and renewing itself. This is how it is intended to encourage the separate study of these tools to have different views on what they offer in this sector.

The structure of the article includes Section 2, research method, where the research methodology used for the collection of articles and explaining the methodologies that will be used in the research process will be explained; Section 3, statistics of the data, where the research trends of the topic during the years and the primary sources of research will be made known; Section 4, bibliometric analysis and results where analysis of clusters and tendencies within the research will be presented and the methodology of ranking of factors and Analysis Hierarchy Process (AHP) will be carried out (Van Eck and Waltman, 2010). In addition, the results of the research will also be presented. Finally, Section 5, discussion, presents the relationships between the literature and the results obtained from the analysis. Finally, Section 6, presents conclusions that culminate the research summarizing the results obtained and answering the questions posed, as well as recommendations for future work.

2. Research method

A systematic literature review makes it possible to identify the limits of existing knowledge and share the results of other studies closely related to the one being conducted (Corallo *et al.*, 2020). Likewise, a systematic literature review follows specific procedures that are reliable, repeatable and valid in different conditions and periods (Ada *et al.*, 2021). The objective is to have a structured methodology composed of the appropriate keyword search and a search and analysis of the literature to perform a good literature review (Corallo *et al.*, 2020). This systematic review has several schematic steps, such as the definition of the topic, identification of databases, keywords, search filters, preliminary review of articles, final review of articles and the final selection of articles to work.

In this research, a systematic review of the literature was carried out to know how the current situation of Industry 4.0 tools influences the sustainability of the supply chain in the food industry (Siems *et al.*, 2021).

A search was performed in the Scopus and Web of Science databases using keywords to obtain scientific articles related to the topic. These databases were chosen for their use and popularity at the academic and scientific levels.

For the search, the keywords “Industry 4.0” and “Food” were used to obtain articles in which Industry 4.0 (I4.0T) tools were implemented in the food sector; as a result of the search, 436 articles were obtained from which their metadata were extracted, using a CSV file format to perform the statistical analysis (trends in their publications) and bibliometric (cluster analysis) of the data, in order to know the environment and trends that exist on the I4.0T in the food sector. As well as the degree of influence that Industry 4.0 tools have on the topics in this research such as Sustainability, Supply Chains and Circular Economy (Stumpf *et al.*, 2021). Figure 1 summarizes the methodology of the research process, from the definition of the topic and keywords to the selection of the main articles used.

After the extraction of the metadata for the elaboration of the statistical and bibliometric analysis, the first step was to perform the search filters; first of all, the years from 2019 to 2022 were selected because it was sought to have the most updated information possible on the subject, then only articles in English were used, in addition, articles and journals in the subject area of engineering were selected, in the type of document conference papers, articles and review were used. With these filters, 196 papers were obtained, which were finally ordered according to the number of citations they had in descending order, to obtain the most relevant articles in the field.

The selection criteria of the articles used for the content analysis were:

(1) Review of titles and keywords (specific terms such as industry 4.0, sustainability and food or food supply chain were searched for).

(2) Articles indexed in journals within Q1 and Q2 in the level of relevance. To obtain this data, the web platform SCIMAGOJR (SJR) was used, which is a web in which the journals are hierarchized in a ranking according to their relevance and are placed within a ranking in which quartiles are used to classify them being Q1 and Q2 the ones with the highest scientific contribution.

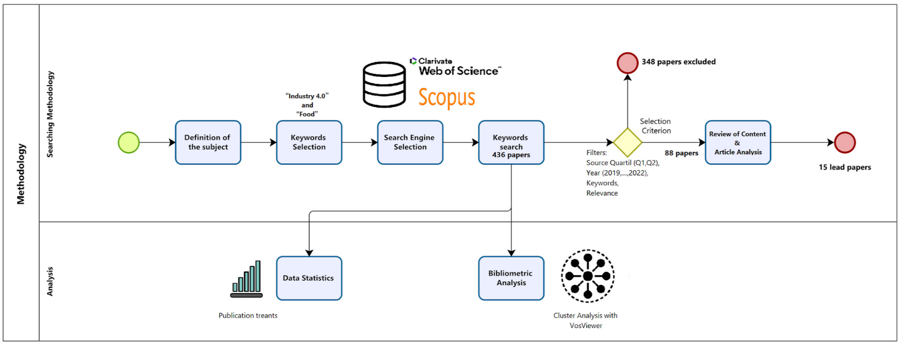

Figure 1.
Research methodology

Source(s): Authors own work

(3) A quick reading of the abstract to identify possible articles with potential for use in our research, preferably articles from practical studies.

Finally, with the 88 papers obtained through the different filters, a complete reading of the content was completed. After this process, 15 main papers were obtained to develop this article and the remaining articles were used as scientific support.

Table 1 shows the list of the articles selected as the primary sources of information in our research. These were ordered according to their year of publication and a brief description of their content and why they are essential for our research.

3. Data statistics

Through the analysis of metadata, the analysis of trends about the number and sources of the publications was initially carried out. Figure 2 shows the number of publications on industry 4.0 applications in the food sector. Although Industry 4.0 has been announced for about a decade (Xu *et al.*, 2018), it can be seen that this topic is relatively new and little explored in the food industry (Ada *et al.*, 2021); the benefits of it have begun to be explored (Laskurain-Iturbe *et al.*, 2021). Furthermore, these tools have been used in recent years and there has been a significant increase in exploratory and applied studies in this area (Režek Jambrak *et al.*, 2021). With this, it can be confirmed that there is a scientific interest in how to apply 4.0 tools in the food industry.

Figure 3 shows the prominent journals in which studies are being carried out, having as primary sources Procedia Computer Science with 12 articles, the IOP conference series with 21 articles published in its two editions, Sustainability (Switzerland) with 11 articles published, Computers in the industry with 8 published articles, having approximately 12% of publications made with content related to the topic.

4. Bibliometric analysis and results

For the elaboration of the bibliometric mapping, the VOSviewer program was used, which used the metadata extracted from the Scopus database.

The program was focused on the interrelation of keywords for the formation of clusters or groups with which to develop an analysis of trends in the field of industry 4.0 and its tools that seek sustainability in the food industry. Cluster analysis is based on classifying elements within the same category based on similarities (Rodriguez and Laio, 2014).

The first graph (Figure 4) shows the clusters for the 436 articles generated during the search process. In the VOSviewer configuration, a minimum of seven occurrences by keywords were used as a filter, thus generating six clusters differentiated by colors (red, green, light blue, blue, yellow and violet). It is observed that the most used keywords are industry 4.0 with 283 occurrences, IoT with 108 occurrences, food supply with 48 occurrences, food industry with 39 occurrences, supply chain with 50 occurrences and sustainability development with 37 occurrences.

From the analysis carried out, it can be concluded that there are industry 4.0 tools that are being used in food chains and industries; among them, the most common by far is the IoT. Other tools that are being used are Blockchain, Big Data, Artificial Intelligence and Cyber-Physical Systems. Furthermore, sustainability, SCM and decision-making are the most recurring topics in applying these tools.

Figure 5 shows the clusters over time. It was previously mentioned that this research topic is relatively new and this can be confirmed with the time display in VOSviewer. The graph shows us how, since approximately 2020, studies have begun to be carried out using I4.0 tools within the food industry. The variety of these tools could be much better in FSC and sustainability applications.

No	Author	Year	Title	Description or purpose
1	Rahul Kodan; Puneet Parmar; Shivani Pathania	2019	Internet of Things for Food Sector: Status Quo and Projected Potential	This article describes the current developments and prospects of the Internet of Things concept and aims to bring more conformity to the Internet of Things and its applications in food and agriculture
2	Chunguang Bai; Patrick Dallasega; Guido Orzes; Joseph Sarkis	2020	Industry 4.0 technologies assessment: A sustainability perspective	The article focuses on a multi-context analysis that helps us to understand broadly how Industry 4.0 is applied in different industries, with different implications. It introduces an approach that lets us know about the sustainable performance of I4.0T
3	Jean-Michel Clairand; Marco Briceño-León; Guillermo Escrivá-Escrivá; Antonio Marco Pantaleo	2020	Review of Energy Efficiency Technologies in the Food Industry: Trends, Barriers, and Opportunities	The article focuses on the food industry's different energy efficiency opportunities and delves into the trends and opportunities of Industry 4.0 and its demand response
4	Fran Casino; Venetis Kanakaris; Thomas K. Dasaklis; Socrates Moschuris; Spiros Stachtiaris	2020	Blockchain-based food supply chain traceability: a case study in the dairy sector	This paper presents a blockchain-based framework for Food Supply Chain traceability, detailing the different traceability functionalities in conjunction with other concepts such as Industry 4.0, Blockchain, and Smart contracts. A traceability test is also developed, focusing on the feasibility of the proposed approach
5	Angelo Corallo; Maria Elena Latino; Marta Menegoli; Pierpaolo Pontrandolfo	2020	A systematic literature review to explore traceability and lifecycle relationship	The article touches on a critical concept which is PLM (Product Lifecycle Management) which is a traceability tool whose primary benefits are cost and time reduction; it is also pointed out that it is a tool little used in the food industry and leads us to look for the relationship between this and the already established concepts of Industry 4.0
6	Prince Waqas Khan; Yung-Cheol Byun; Namje Park	2020	IoT-blockchain enabled optimized provenance system for food industry 4.0 using advanced deep learning	This article proposed an optimized supply chain provenance system for Industry 4.0 in the food sector, using cutting-edge technologies such as IoT, blockchain, and advanced deep learning. The article aims to help supply chain professionals to leverage cutting-edge technologies

(*continued*)

Table 1.
List of the 15 selected papers

No	Author	Year	Title	Description or purpose
7	Nachiappan Subramanian; Yasanur Kayikci; Manoj Dora; Manjot Singh Bhatia	2022	Food supply chain in the era of Industry 4.0: blockchain technology implementation opportunities and impediments from the perspective of people, process, performance, and technology	This article develops a blockchain-based food supply chain framework, including future opportunities and current impediments based on a systematic literature review and semi-structured case interviews from emerging economies' contexts. The study provides empirical evidence of the implementation of blockchain technology in the Industry 4.0 era, opens the debate for future researchers and lists potential threats
8	Shashank Kumar; Rakesh D. Raut; Kirti Nayal; Sascha Kraus; Vinay Surendra Yadav; Balkrishna E. Narkhede	2021	To identify industry 4.0 and circular economy adoption barriers in the agriculture supply chain by using ISM-ANP	The present study identifies the barriers to adopting Industry 4.0 (I4.0) and adopting a circular economy in the Indian agricultural supply chain. Its findings indicate that the lack of government support and incentives and the absence of policies and protocols are significant obstacles to implementing the I4.0-CE model
9	Theofilos Mastos; Alexandros Nizamis; Sofia Terzi; Dimitrios Gkortzis; Angelos Papadopoulos	2021	Introducing an application of an industry 4.0 solution for circular SCM	This article provides us with ideas of sustainability through circular SCM and illustrates different models and approaches to the topic, especially emphasizing the circular economy. It also focuses on the six dimensions of the circular economy and the automation offered by the proposed solutions
10	Iker Laskurain-Iturbea; Germán Arana-Landína; Beñat Landeta-Manzanob; Naiara Uriarte-Gallastegib	2021	Exploring the influence of industry 4.0 technologies on the circular economy	This article investigates the influence of the leading technologies in the main fields of action of the circular economy. Input reduction consumption, reuse, recovery, recycling and waste and emissions reduction. The results confirm the wide range of influences that Industry 4.0 technologies offer companies to improve circularity
11	Nesrin Ada; Yiğit Kazançoğlu; Deniz Sezer; Cigdem Ede-Senturk; Idil Ozer; Mangey Ram	2021	Analyzing Barriers of Circular Food Supply Chains and Proposing Industry 4.0 Solutions	This article analyzes the barriers that supply chains have about Industry 4.0, analyzes and also demonstrates through studies that some strategies could improve the design for a better application in the products, also touches on issues such as condition monitoring, preventive maintenance, and some more that play a crucial role as concepts within Industry 4.0

(*continued*)

Table 1.

No	Author	Year	Title	Description or purpose
12	Mohd Helmi Ali; Leanne Chung; Ajay Kumar; Suhaiza Zailani; Kim Hua Tan	2021	A sustainable Blockchain framework for the halal food supply chain: Lessons from Malaysia	This paper presents an IoT-based framework for monitoring food waste generation and energy and water use in the food sector. The framework supports the identification of improvements to optimize resource efficiency in food manufacturing by designing and implementing a series of IoT-based tools
13	Sandeep Jagtap; Shahin Rahimifard; Guillermo Garcia-Garcia	2021	Optimisation of the resource efficiency of food manufacturing via the Internet of Things	This paper presents an IoT-based framework for monitoring food waste generation and energy and water use in the food sector. The framework supports the identification of improvements to optimize resource efficiency in food manufacturing by designing and implementing a series of IoT-based tools
14	Režek Jambrak; Marinela Nutrizio; Ilija Djekic; Sanda Pleslić; Farid Chemat	2021	Internet of Nonthermal Food Processing Technologies (IoNTP): Food Industry 4.0 and Sustainability	The article explores the technologies of Industry 4.0 concerning the food industry through the various tools it offers to create intelligent and sustainable factories. The article concludes that this industry generates energy savings, less environmental damage, lower costs and better working conditions
15	Sandeep Mondal; Tripti Paul; Nazrul Islam; Sandip Rakshit	2021	The impact of blockchain technology on the tea supply chain and its sustainable performance	This article is an applied study that implements blockchain technology within the tea industry. The study provides positive results in the tea supply chain regarding its sustainability (transparency and trust). Furthermore, the study develops a framework and a conceptual model for applying blockchain technology to supply chains in the tea industry

Table 1.

Source(s): Authors own work

Figures 6 and 7 show which I4.0T have been used in the food industry and which have not, respectively. The main tools used are the IoT, this tool being the most outstanding in this field, in addition to its use in issues of sustainability and SCM (Manavalan and Jayakrishna, 2019). The second most used is Blockchain technology, which in this type of industry is closely related to IoT, traceability, security and sustainability (Bai and Sarkis, 2020); another tool used is Big Data which takes advantage of the previous tools and focuses more on decision-making (Kittipanya-ngam and Tan, 2020); finally, there are to a lesser extent the technologies of Cyber-Physical Systems (CPS), AM and Artificial Intelligence.

The I4.0T that have yet to be explored in this industry are cloud computing, digital twins and augmented reality—concluding that only some of the tools of the I4.0 are useful to apply in the food industry.

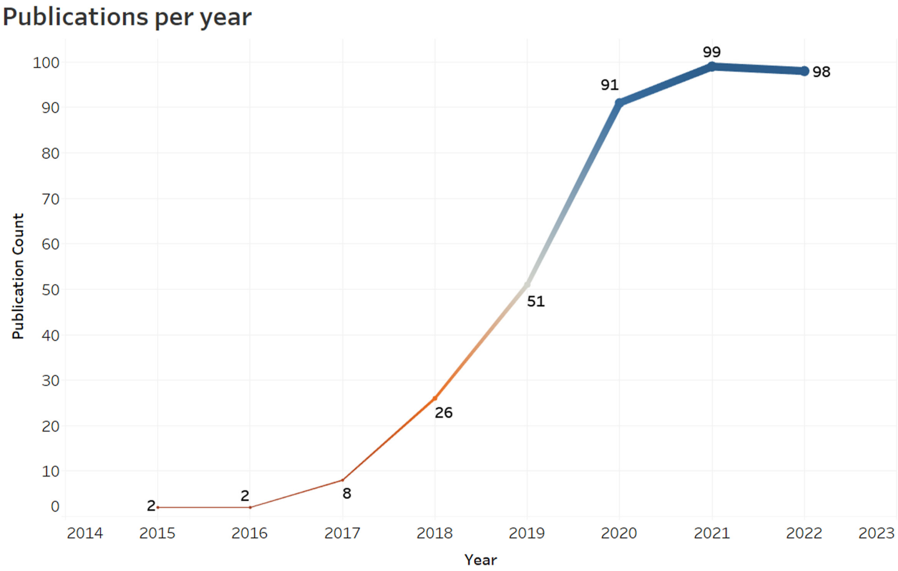

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Figure 2.
Publication count per year

4.1 Environment

Industry 4.0 is a way to improve production processes focusing on increasing productivity (Dalenogare *et al.*, 2018), individual demands and short-term management desires (Režek Jambrak *et al.*, 2021); likewise, it has different applications that generate sustainable development mostly with technologies that seek specific solutions and work in isolation mostly with some indirect effects (Ali *et al.*, 2021b), in this way its operation and different tools generate sustainability (Cañas *et al.*, 2020), this is based on results such as the reduction of delivery times and time to market (Režek Jambrak *et al.*, 2021), which turn out to be critical in any supply chain, especially in the food industry, these types of results increase the global influence of the developing industry 4.0 with its effect on the sustainability of the companies (Tufano *et al.*, 2018).

The concept of sustainability is present and is a part that Industry 4.0 has contributed by improving the use of available resources (Accorsi *et al.*, 2018, 2020) and minimizing waste and the emission of pollutants (Laskurain-Iturbe *et al.*, 2021). In industries such as food and many more, they have managed to reduce waste by up to 40%, as well as carbon emissions (Laskurain-Iturbe *et al.*, 2021), the applications of industry 4.0 technologies are increasingly increasing their global influence and these are presented in tools such as the Blockchain that increases the transparency, traceability and performance of companies (Ali *et al.*, 2021b; Barbosa, 2021), as well as the CPS system. Most of these are increasingly autonomous, transitioning from the traditional automation of the past to connected systems in the present (Režek Jambrak *et al.*, 2021).

In the food industry, the IoT can reduce food waste and loss (Ada *et al.*, 2021). Recent studies show that IoT strategies can improve product design and application. Likewise, in the IoT food industry, there is a tool with which solutions are generated, such as in the supply chain, which generates sustainability and can reduce the generation of costs, emissions and

Source title	
Procedia Computer Science	12
IOP Conference Series: Materials Science and Enginee..	11
Sustainability (Switzerland)	11
IOP Conference Series: Earth and Environmental Scie..	10
Computers in Industry	8
IFIP Advances in Information and Communication Tec..	8
Lecture Notes in Mechanical Engineering	8
Procedia Manufacturing	7
Proceedings of the International Conference on Indus..	7
Applied Sciences (Switzerland)	6
Lecture Notes in Networks and Systems	6
Processes	6
ACM International Conference Proceeding Series	5
Advances in Intelligent Systems and Computing	5
Technological Forecasting and Social Change	5
Advanced Series in Management	4
Critical Reviews in Food Science and Nutrition	4
IEEE Access	4
IEEE Transactions on Industrial Informatics	4
Lecture Notes in Computer Science (including subseri..	4
Materials Today: Proceedings	4
Production Planning and Control	4
Sensors (Switzerland)	4
Smart Innovation, Systems and Technologies	4
2019 International Conference on Sustainable Techno..	3
2020 IEEE International Workshop on Metrology for I..	3
Advances in Transdisciplinary Engineering	3
British Food Journal	3
IEEE Transactions on Engineering Management	3
International Journal of Production Economics	3
International Journal of Production Research	3
Journal of Cleaner Production	3

Source(s): Authors own work

Figure 3.
Main sources

social impacts (Mastos *et al.*, 2021). The food industry is closely related to the concept of traceability, which represents a strategic issue in the food industry due to the effect that a dangerous food product could have on consumer health (Corallo *et al.*, 2020; Mangla *et al.*, 2021).

4.2 Tool identification

After analyzing the tools according to the literature, recognizing their characteristics and perspectives on sustainability in the food industries are shown in Table 2. An analysis of the relevant factors of these tools was carried out to classify them and obtain the best tools that contribute to sustainability in the FSCs. For this, a ranking analysis of factors was used.

An AHP, a multi-criteria decision-making tool that uses pairwise comparison, was used to provide a methodology to calibrate qualitative and quantitative outcome measurement (Vaidya and Kumar., 2006).

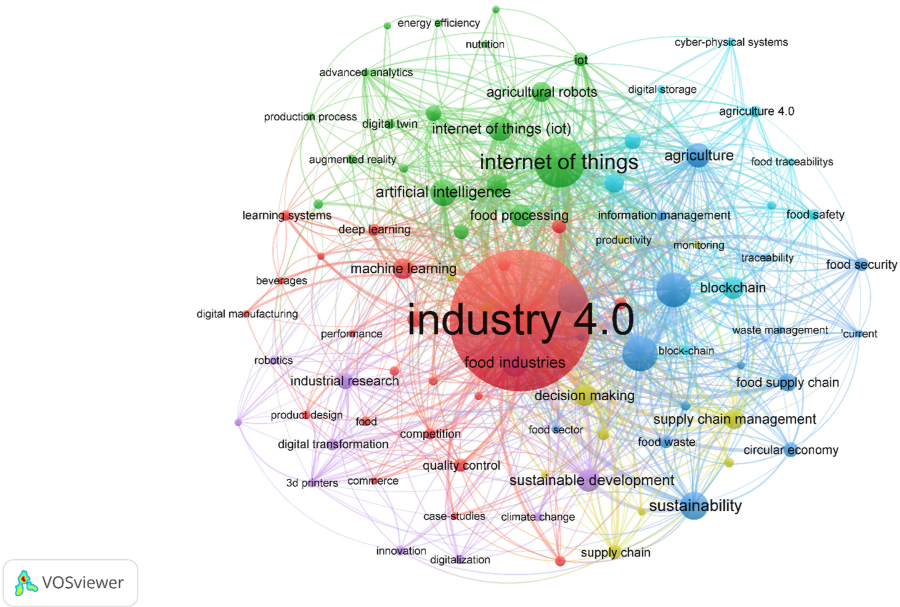

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Figure 4. Clusters food and industry 4.0

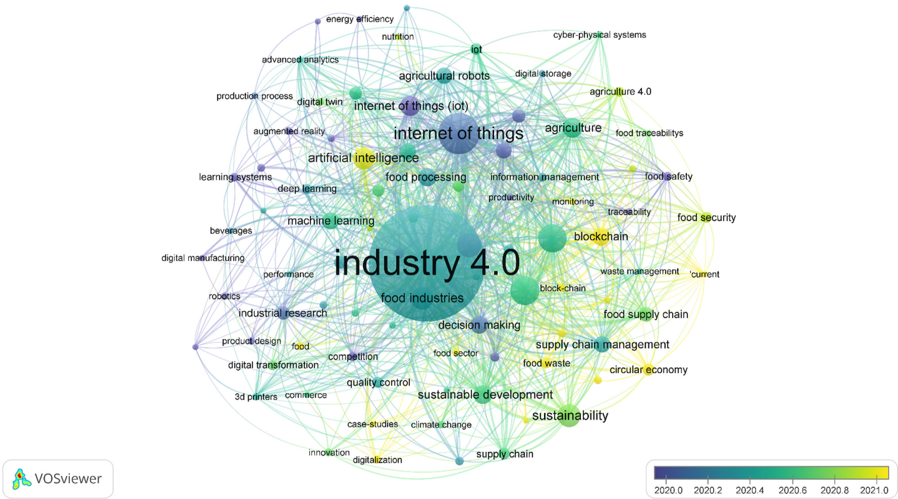

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Figure 5. Clusters Food and Industry 4.0 on time

The factors analyzed are the complexity of adoption of the I4.0T, which includes the difficulties or facilities to obtain the technology and implement it in the industry; process optimization, which refers to the ability to improve performance in processes within FSCs

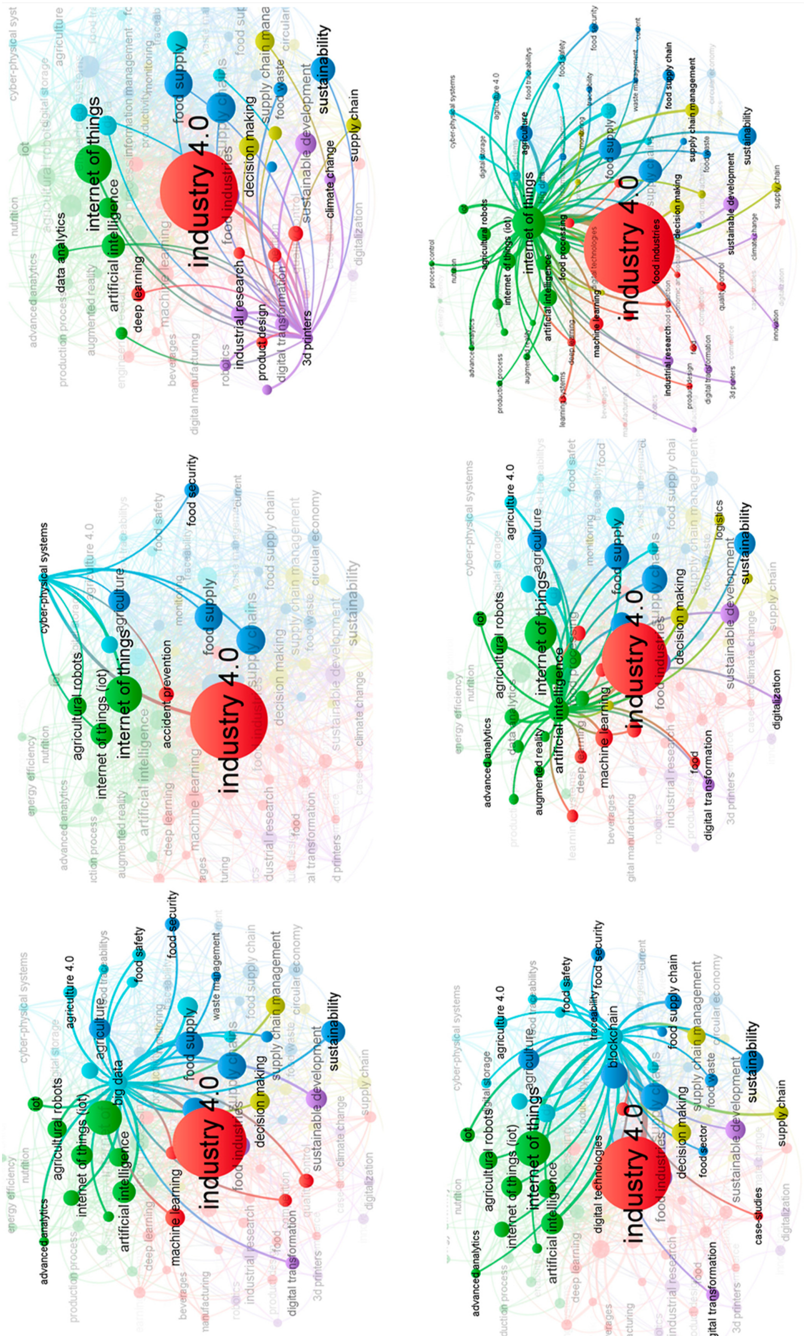
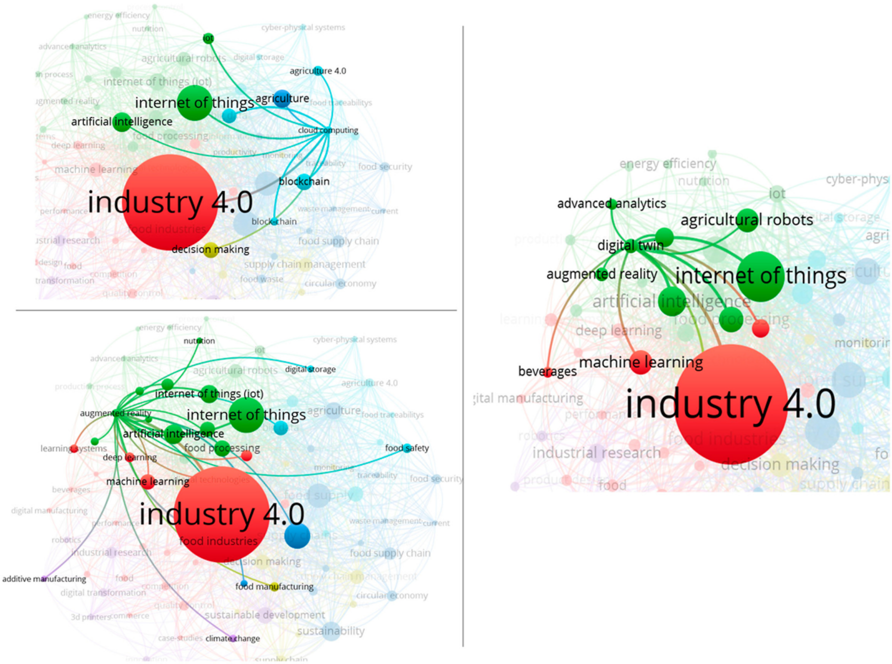


Figure 6.
I4.0T used in the food industry (Big Data, CPS, Additive Manufacturing, Blockchain, Artificial Intelligence and Internet of things)

Source(s): Authors own work



Source(s): Authors own work

Figure 7.
I4.0T not used in food industry or sustainability applications

(Zhu *et al.*, 2018); traceability is the ability to know the status of the products in each part of the FSC; the transparency that refers to being able to know clearly and truthfully (Astill *et al.*, 2019), both the quality and the authenticity of the products; its contribution to the reduction of waste and emissions and the economic impact on the profitability of the tool (Rhein and Sträter, 2021).

Table 3 shows the scale in which these factors will be ranked with values of 1, 3, 5 and 7, the highest values being the most favorable for the factor. Table 4 shows the weightings of each factor analyzed to be later classified by relevance.

Finally, Table 5 shows the hierarchy of factors, with process optimization and economic performance being the most important in the I4.0T and their influence on the FSC. With this hierarchy, it can be seen that for the implementation of these tools, there is primarily a need or concern to solve core problems of food companies, "if these tools solve their problems or not, if they are profitable and if they help in the sustainability of these."

Continuing with the analysis of the tools, each tool was evaluated in relation to the factors previously ranked by means of a ranking of factors to obtain the most relevant I4.0T in the FSCs on sustainability issues.

For this, a scale from 1 to 5 (Table 6) was made, within which the higher the number, the better the impact on the designated factor.

Finally, as shown in Table 7, the accumulated scores of each tool will be obtained and then ranked according to their relevance.

Table 8 shows the tools ordered by the score obtained. As can be seen, the IoT and Blockchain tools are the most relevant in FSCs in terms of sustainability; this result is related to the findings of the bibliometric review and these two tools are also the most used in this type of industry (Shashi *et al.*, 2018).

I4.0 tools	Benefit	Impact on sustainability and CE	Perception and limitations
Cyber-Physical System (CPS)	- Smart Manufacturing - Flexible Production - Digital products and services - Product data collection - Smart Packing	- Food loss and waste reduction - Improved food conditions and quality	- Difficult to implement in every process in the food industry
Blockchain	Blockchain -Optimization of procedures - Increased transparency and traceability - Increased intangible value (slaughter, contamination, purity) - Fraud avoidance Auditabilidad y resistencia a la manipulación	- Reduced food waste and losses	- Different cost-benefit depending on the size of the company - Complexity of adoption - Economic benefits
Internet of things (IoT)	- Traceability, visibility, efficiency - Identification of less efficient processes - Increased application in FSC - Cost reduction	- Emission reduction - Resource optimization - Reduction of light and wáter usage	- Important in I4.0T implementations - Low acceptance due to high installation costs Availability and accessibility - Concerns about data exchange and security - Unfeasible data collection for all due to the complexity and variety of ingredients
Big data	- Increased control and use of resources	- Decreased use of paper documents	- High implementation costs
Additive manufacturing	- High influence on other circular economy industries	- Reduction of raw material and input use	Scarce use in the food industry
Automation	- Process optimization - Adjustment of specifications	- Reduction of energy consumption - Reduction of environmental damage	- Worker resistance

Source(s): Authors own work

Table 2.
Matrix of I4.0 Tools and their characteristics in FSC

Numerical scale	Verbal scale	Comment
1	Equal importance	The two aspects contribute equally
3	Moderate importance	Small prevalence of one element over another
5	Strongly important	Evident prevalence of one element over another
7	Extreme importance	Extreme prevalence of one element over the other

Source(s): Authors own work

Table 3.
AHP assessment

Factors	Complexity of adoption	Traceability	Transparency	Optimization of processes	Reduction of waste and emissions	Economical	Standardization				
Complexity of adoption	1.00	5.00	5.00	0.20	0.33	3.00	0.103	0.216	0.167	0.042	0.042
Traceability	0.20	1.00	5.00	0.14	0.33	0.14	0.021	0.043	0.167	0.030	0.042
Transparency	0.20	0.20	1.00	0.14	0.20	0.14	0.021	0.009	0.033	0.030	0.025
Process optimization	5.00	7.00	7.00	1.00	3.00	0.33	0.514	0.302	0.233	0.208	0.381
Reduction of waste and emissions	3.00	3.00	5.00	0.33	1.00	0.33	0.308	0.129	0.167	0.069	0.127
Economical	0.33	7.00	7.00	3.00	3.00	1.00	0.034	0.302	0.233	0.623	0.381
Total	9.73	23.20	30.00	4.82	7.87	4.95					
Weighting	*0.11*	*0.06*	*0.02*	*0.33*	*0.16*	*0.31*					

Source(s): Authors own work

Table 4.
AHP evaluation matrix

Factors	Weighing
Optimization of processes	32.75%
Economic	31.46%
Waste and emissions reduction	16.01%
Adoption complexity	11.38%
Traceability	6.05%
Transparency	2.35%

Source(s): Authors own work

Table 5.
Hierarchy of factors

Value	Definition	Comment
1	Very low	No influence or counterproductivity with the factor
2	Low	Low influence or counterproductivity with the factor
3	Regular	Regular influence with the factor
4	High	High influence with the factor
5	Very High	Very high influence

Source(s): Authors own work

Table 6.
Factor ranking assessment

I4.0T	Factors Weighting	Optimization of processes 0.33	Economic 0.31	Waste and emissions reduction 0.16	Adoption complexity 0.11	Traceability 0.06	Transparency 0.02	
Cyber-Physical	Rating	4.00	2.00	4.00	3.00	3.00	1.00	
System (CPS)	Score	1.31	0.66	1.31	0.98	0.98	0.33	*5.57*
Blockchain	Rating	3.00	3.00	4.00	1.00	5.00	5.00	
	Score	0.98	0.98	1.31	0.33	1.64	1.64	*6.88*
Internet	Rating	5.00	2.00	5.00	3.00	4.00	4.00	
of things (IoT)	Score	1.64	0.66	1.64	0.98	1.31	1.31	*7.53*
Big data	Rating	4.00	1.00	4.00	3.00	3.00	3.00	
	Score	1.31	0.33	1.31	0.98	0.98	0.98	*5.90*
Additive	Rating	2.00	2.00	5.00	4.00	1.00	1.00	
manufacturing (MA)	Score	0.66	0.66	1.64	1.31	0.33	0.33	*4.91*
Automation	Rating	4.00	3.00	4.00	4.00	2.00	1.00	
	Score	1.31	0.98	1.31	1.31	0.66	0.33	*5.90*

Source(s): Authors own work

Table 7.
Ranking of factors

Although the I4.0 technologies work in isolation with spillover effects with the others (Ali *et al.*, 2021b), IoT technology has positioned itself as the most important due to its ability to enable most of the I4.0 tools. Moreover, with the Blockchain tool, they have a high capacity to contribute to issues of transparency, traceability, optimization process and waste reduction (Paul *et al.*, 2021).

The biggest drawback in the adoption of this type of tools have been the economic barriers and the complexity of their adoption due to lack of capital, the impossibility of obtaining technologies and the size of the companies; this has generated perceptions and limitations that, over time, have been decreasing due to results obtained in other similar industries (Ada *et al.*, 2021).

CPS has managed to enable intelligent and flexible manufacturing and improve food conditions by reducing food losses and waste (Dev *et al.*, 2020a, b), in addition to obtaining data from the procedures to optimize them with other technologies such as Big Data (Belaud *et al.*, 2019). For example, one of the implementations used a tool for smart packaging of the food that provided the conditions of the food to be able, through automated machines, to control the conditions of humidity and temperatures and to preserve the product in optimal conditions. In addition, he was able to indicate to the clients about the state of their food through changes in the color of the packaging, thus reducing their waste (Ali *et al.*, 2021b).

Big Data and automation technology have been used to improve processes within FSCs, generating greater control in the forecasting and analytics of companies and using this data to control the internal processes of the industry and generating predictive learning for the generation of intelligent machines in real-time and predictive models (Kakani *et al.*, 2020), in addition to achieving greater efficiency in resources and emissions in the food industries, managing lower energy and water consumption. However, the limitation of automation is the opposition of workers to its implementation and the costs of implementing this technology.

Data counts as limiting the high costs of implementing servers and programs to use information appropriately.

With automation and the Big Data tool, it has been possible to optimize production processes by autonomously controlling the machines and reducing energy consumption through self-regulation by adjusting specifications depending on the conditions in the process. This tool has decreased environmental impact with greater control of resources, optimizing processes and generating greater sustainability in the FSC. A limitation is that there is resistance by workers to this type of implementation because it has decreased the requirement of these (Accorsi *et al.*, 2019).

On AM, there are few investigations of implementations in the FSC. However, it has dramatically impacted the reduction of waste in other industries, so it is necessary to find a feasible place within the FSC to improve its sustainability due to its high potential to significantly (Yang and Chen, 2020).

I4.0T	Score
Internet of Things (IoT)	7.53
Blockchain	6.88
Big Data	5.90
Automation	5.90
Cyber Psycho System (CPS)	5.57
Additive manufacturing (AM)	4.91

Source(s): Authors own work

Table 8.
I4.0 tools hierarchy

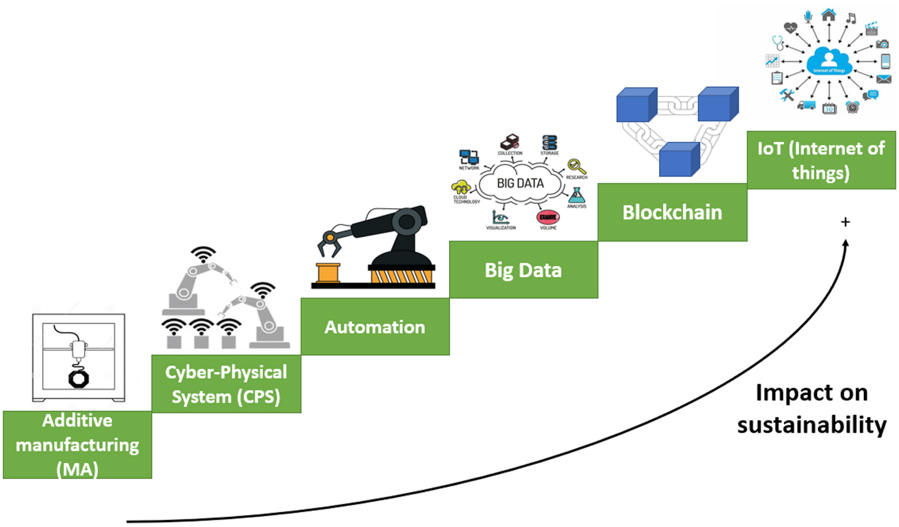
5. Discussion

The study and bibliometric analysis in search of trends and behaviors has found positive results concerning Industry 4.0 tools and their impact on the sustainability of FSCs by improving traceability, transparency, cost reduction and food waste. This finding is represented in Figure 8, in which it can be seen how there are some tools with a more significant influence on the sustainability of FSCs than others, such as IoT and Blockchain tools, that have managed to obtain higher scores according to the factor analysis, so it indicates a higher performance compared to the others in terms of benefits in perspective on sustainability, profitability, veracity and implementation capacity (Wamba and Queiroz, 2020; Köhler and Pizzol, 2020).

The I4.0T second results obtained support recent studies' trends in improving the FSC in the aspect of sustainability. For example, according to Kodan (2020), IoT tool has managed to help perform management and control of the FSC, optimizing the use of resources through the use of RFID tags, collecting environmental and status values inside the packaging in the transport of food, adjusting the variables of humidity, temperature, ethanol detection and amines preserving the conditions of food and locating the food throughout the FSC. Another study (Bai *et al.*, 2020) suggests that IoT tool 4.0 increased economic profitability and sustainability in the FSC, realizing better resource management in food production use of fertilizers, irrigations and food harvesting time; it manages to decrease repetitive tasks relieving labor burdens and decreasing the use of an unnecessary human resource.

Kayikci *et al.* (2022) talk about how the Blockchain 4.0 tool, in combination with IoT, has increased traceability, transparency and trust in FSCs achieving a decrease in food frauds due to food adulterations avoiding health disasters and generating greater customer confidence in the company; they also streamline payment operations, give more security to these and prevent frauds such as price cohesion achieving improved performance in the FSC.

The results of the exploratory analysis confirm that the I4.0 tools can improve the conditions in a sustainable approach of the companies in harmony with the economic factor by reducing and optimizing the consumption of raw materials and inputs and generating



Source(s): Authors own work

Figure 8.
Scale of the impact of I4.0 tools on the sustainability of FSCs

reductions in energy consumption (Frank *et al.*, 2019), in addition to impacting on the reduction of food waste and losses through the high degree of traceability and real-time controls that these tools offer (Rashid and Shahzad, 2021).

6. Conclusions

The exploratory study was conducted to identify the I4.0 tools that significantly impact the sustainability of FSCs (Ojo *et al.*, 2018), resulting in tools within this new industrial stage (Industry 4.0) that have a more significant and beneficial impact on sustainability (Rohmer *et al.*, 2019). Mainly the benefits obtained with these tools are a more significant control of their inputs, use of resources and in their outputs, emissions and waste generation. In addition, they also help to have greater control over the management and condition of food during the FSC, increasing food quality, traceability and transparency of these, preventing them from deteriorating quickly and preserving their optimal state for consumption, avoiding waste due to poor storage conditions, also protecting food from adulteration and promoting business sustainability, this has generated an added value for industries and also increasing the confidence that end consumers have in the company (Chen *et al.*, 2021). Industry 4.0 enables more sustainable and efficient processes along the FSC to meet the growing demand in food markets (Clairand *et al.*, 2020).

This study has managed to compile the benefits, impacts and limitations of I4.0T in FSC through the complete review of articles, hierarchical ranking of its factors using the hierarchical analysis method and the classification of the tools through a ranking of factors. As a result, comparing these tools to recognize which have a more significant impact on sustainable development has been possible. Furthermore, these tools manage to positively influence the sustainability (some more than others) of this type of companies, increasing their economic benefits and the sustainable perception of people toward the industry (Tsimiklis and Makatsoris., 2019).

The study shows us many tools that generate a high impact within the sustainability linked to industry 4.0 in the food industry. The tools of the most excellent nature among all are the IoT and Blockchain; thanks to the ranking of factors which has shown that these tools are currently the best positioned to generate sustainability about industry 4.0 and enable the other tools on issues of transparency, traceability, process optimization and waste reduction.

Likewise, tools were found that do not generate a high impact on the aspects evaluated, especially in the field of the food industry, such as CPS and AM came last in the ranking as the tools that generate the most negligible impact, but this does not mean that they are obsolete tools for not generating sufficient impact in the food industry, as they do have a high potential impact on sustainability in other industries, such as AM in another context works exceptionally well since it has managed to drastically reduce the use of materials in the manufacture of objects (Dev *et al.*, 2020a, b). Although it has not yet found a feasible place of use within the FSC, it would be advisable to seek the implementation of this tool in order to reduce the waste of resources within the FSC.

Among the main practical limitations is the economic investment, due to the high cost of investment for the acquisition and implementation of servers, systems, sensors and their cost-benefit ratio and the complexity of their implementation and adoption that is mainly related to the complicated technologies, systems, time and training that are necessary for these tools to have a correct functioning within the FSCs (Pietrzyck *et al.*, 2021). Also due to the very nature of this type of industry and its delicacy, it becomes more complicated and costly to implement these tools in each part of the processes due to the great variety of ingredients and processes during the FSC (Chen *et al.*, 2020).

Thus, it has limitations in guiding future research. First, the use of only two databases, Scopus and Web of Science, needs to be revised in the scope of the study. Although the qualitative nature of the study helps us understand the environment and trends of the studies, it is necessary to be able to quantitatively apply and verify this knowledge to have more objective results. Also, the low number of applied cases of I4.0T implementations in the food industry is due to the few feasibility studies of these tools in this sector and the fact that the studies generated in this sector have yet to cover all the tools offered by the Industry 4.0 (Rajput and Singh, 2020). In addition, there are sectoral gaps in the size of the companies among the studies, with different perceptions and implementation capabilities and benefits depending on whether they are small or large industries, which has generated a bias of results among the studies due to their economic capacity as well as their immediate and long-term objectives.

Finally, to overcome the economic limitations, investors interested in the implementation of the different tools must be identified and an economic projection is recommended to be able to see the cost-benefit of implementing the tools in order to be sure of being able to execute them since they entail many expenses and a significant investment. Thus, a projection of activities and objectives will be helpful to implement this type of tool, generating short, medium and long-term goals to recover the investment generated optimally. Likewise, it is recommended to use more databases for future research to enlarge the study's scope. It thus corroborates the qualitative nature of the study through its application and verification of this knowledge to generate results that provide more objectivity.

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