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Discovering the conceptual building blocks of blockchain technology applications in the agri-food supply chain: a review and research agenda

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Abstract

Purpose – This paper aims to provide an overview of the application of blockchain to agri-food supply chains, including key issues and trends. It examines the state of the art and conceptual structure of the field and proposes an agenda to guide future research.

Design/methodology/approach – This article performs a bibliometric analysis using VOSviewer software on a sample of 205 articles from the WoS database to identify research trend topics.

Findings – The number of publications in this area has increased since 2020, which shows a growing research interest. The research hotspots are related to the integration of blockchain technology in the agri-food supply chain for traceability, coordination between all actors involved, transparency of operations and improvement of food safety. Furthermore, this is linked to sustainability and the achievement of the sustainable development gtoals (SDGs), while addressing key challenges in the implementation of blockchain-based technologies in the agri-food supply chain.

Practical implications – The application of blockchain in the agri-food supply chain may consider four key aspects. Firstly, the implementation of blockchain can improve the traceability of food products. Secondly, this technology supports sustainability issues and could avoid disruptions in the agri-food supply chain. Third, blockchain improves food quality and safety control throughout the supply chain. Fourthly, the findings show that regulation is needed to improve trust between stakeholders.

Originality/value – The paper provides a comprehensive overview of the blockchain phenomenon in the agri-food supply chain by optimising the search criteria. Moreover, it serves to bridge to future research by identifying gaps in the field.

Keywords Blockchain, Smart contract, Agri-food supply chain, Traceability, Thematic organisation, Research agenda

Paper type Research paper

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1. Introduction

The agri-food supply chain encompasses all the stages of food processing "from farmer to fork -final consumption-", including production, manufacturing and distribution (Agnusdei and Coluccia, 2022). Industry 4.0 technologies, including blockchain, increase the efficiency and flexibility of this supply chain by improving food traceability and other essential aspects (Menon and Jain, 2024). Blockchain technology increases data transparency and streamlines food supply chain management, resulting in reduced food loss during production and waste during distribution and consumption (Pakseresht *et al.*, 2022; Alonso-Muñoz *et al.*, 2022). Through the use of decentralised systems and shared ledgers, blockchain addresses issues of information asymmetry while reducing transactional inefficiencies, making it applicable throughout the chain. Farmers can use blockchain technology to communicate information about farm conditions, harvest times and market prices to retailers. In turn, retailers can optimise storage temperatures and improve the accuracy of demand forecasts, helping to reduce food waste (Pakseresht *et al.*, 2022).

However, to fully understand the intricacy of contemporary traceability systems and mechanisms, comprehensive research is necessary (Casino *et al.*, 2021). In order to gain a holistic view, it is important to include two terms that are closely related to the use of blockchain in the food supply chain, as they have been recognised in previous works. According to Chang and Chen (2020), the use of blockchain applications in supply chains relies heavily on the ledger system and smart contracts, which support interactions.

Previous bibliometric articles have reviewed the implementation of blockchain in the agri-food supply chain. This is reflected in the terms used in search queries, with blockchain being the dominant term, as most analyses adopt a more restrictive perspective than this study. Niknejad *et al.* (2021) focused on papers in the food and agriculture industry up to 2019. Pandey *et al.* (2022) and Sharma *et al.* (2023) analysed the use of blockchain technology in the food supply chain up to June 2021. Some of these bibliometric analyses focus on even more specific topics within the application of blockchain technology in the food supply chain. Sinha *et al.* (2021) provides an overview of traceability for food safety. Mohapatra *et al.* (2023) identified the countries that have conducted extensive research on the intersection of agriculture and blockchain technology, and discussed the policy implications of their findings.

This article updates the conceptual framework on the application of blockchain in agri-food supply management. It reflects the state of the art in the field and considers the question with a broad approach by including the terms that have been identified in the literature as closely related to blockchain, such as smart contract and distributed ledger (Chang and Chen, 2020). This study presents a comprehensive and current overview of the use of blockchain in the agri-food supply chain. The paper addresses the following research questions (RQs):

RQ1. What is the historical development of the literature on blockchain technologies and agri-food supply chains?

RQ2. What are the leading journals in the field?

RQ3. What is the conceptual structure of blockchain and agri-food supply chains?

RQ4. What are the main gaps and future research agendas?

The paper is structured into the following sections. An introduction and theoretical background, a presentation of the methodological process and the bibliometric results. The descriptive analysis of the publications includes historical evolution, the most cited journals and the research fields. Additionally, the thematic organisation of the field was developed using co-occurrence analysis (VOSviewer) to detect research trends. Subsequently, key points are determined for the development of a research agenda including a discussion about the results obtained. It concludes by proposing future lines of research, as well as limitations and implications.

Therefore, this paper updates the current state of the literature by providing the conceptual structure of blockchain application to the agri-food supply chain. In comparison to previous studies, this article provides a broader approach by considering not only the concept of blockchain, but also other related terms such as distributed ledgers and smart contracts. Using bibliometric and content analysis, the inter- and intra-cluster relationships between the keywords are explored in depth to identify the more developed and emerging research topics. Based on the previous, we propose a research agenda to guide and strengthen relevant lines for future opportunities (Ramos Cordeiro *et al.*, 2023). This could be helpful for scholars, managers and practitioners in the field.

2. Theoretical background

The complexity and frequency of relationships that currently define modern agri-food supply chains require these technologies to facilitate the interconnection of multiple actors on a global scale by promoting transparency (Menon and Jain, 2024). Thus, blockchain is characterised by transparency, – as all members have access to the distributed database-; *immutability*, as the data that requires consensus cannot be changed; *decentralisation*, with many nodes of computers validating the data or transactions; *traceability*, as data blocks contain timestamps and hash codes; *security*, with validators using a mathematical function to obtain an encrypted hash code; and the ability to enforce smart contracts, which are computer codes that automatically execute user agreements when certain conditions are met (Sunmola and Apeji, 2020).

Blockchain technology has been proposed as a solution to ensure the traceability, safety and transparency of the global food supply chain, given the challenges posed by the increasing demand for food and its impact on the environment (Pandey *et al.*, 2022). Food traceability is crucial for monitoring food products to ensure their safety and quality control (Wang and Scrimgeour, 2022). It also helps to prevent mislabelling of products, provide guarantees to consumers and efficiently manage the food logistics system (Bosona and Gebresenbet, 2013). The use of blockchain and other technologies in certain types of food supply chains, such as agri-fresh food supply chains, can improve food safety guarantees and reduce the number of participants, two key aspects of supply chain management (Siddh *et al.*, 2017). However, the adoption of blockchain in the food supply chain is still at an early stage and requires a thematic framework to understand the implications of this technology (Tan *et al.*, 2018, p. 167). Certain aspects, such as the possibility of automated transactions, have not yet been sufficiently explored. The extent of their use is still under development (Caro *et al.*, 2018). Thus, this technology still faces the solution of negative aspects such as problems in scalability and connectivity, as well as the high economic or environmental cost in certain processes (Rana *et al.*, 2021). These adoption factors are fundamental to streamlining process design through a modular and scalable architecture and considering cost effectiveness from a broad economic and sustainability perspective (Zhao *et al.*, 2019; Saurabh and Dey, 2021). Recent work has highlighted the need to measure the impact of this technology on food supply chains from a broader perspective, taking into account different dimensions, rather than limiting it to a single indicator (Stranieri *et al.*, 2021).

As pointed out in the previous paragraph, beyond the “traditional” uses of blockchain technology in the operation of the food supply chain, recent research is opening up new avenues for more sustainable applications (Köhler and Pizzol, 2020; Rana *et al.*, 2021). Achieving smart agriculture means advancing food production with higher quality and safety, furthering the achievement of the 2030 Agenda (Musa and Basir, 2021). For example, blockchain-based traceability can contribute to sustainability communication (Cao *et al.*, 2023).

In the current environment of unprecedented levels of uncertainty caused by the onset of various types of crisis, organisations need to take on high-risk challenges such as eco-innovation, for which blockchain technology is a key driver (Chin *et al.*, 2022). But the focus on organisational sustainability needs to be expanded. The integration of blockchain in practices that contribute to enriching sustainability should look at different types of food chain considering its different dimensions – economic, social and environmental (Siddh *et al.*, 2021a, b). In addition, there are several areas that need to be further explored to find solutions to the problems posed by new technologies (David *et al.*, 2022). Consideration should be given to studying these difficulties, for example those related to the treatment of data or information in food chains and the implication of food legislation or regulation (Siddh *et al.*, 2018; Ali *et al.*, 2021). The loss of privacy, the problem of regulation and the lack of skills are challenges that need to be addressed (Zhao *et al.*, 2019).

This paper aims to contribute to the current state of research by examining the evolution of the subject's best-known applications and new trends related to sustainability or the resolution of implementation difficulties.

3. Methodological process

3.1 Data collection

The documents used to conduct this analysis were retrieved from Web of Science between 2018 and April 2023. The first article about the subject was published in the *British Food Journal* by Sander *et al.* (2018). This database is extensively used for scientific production analysis and to perform bibliometric analysis. It allows for the download of data, including cited references and bibliographic data (Yan and Zhiping, 2023), and provides keyword information for conducting co-occurrence analysis. Additionally, this database considers journals indexed in the *Journal Citation Report* (JCR) for their high quality (Birkle *et al.*, 2020; Singh *et al.*, 2021) to ensure the quality of the sample. The search stream was TS=("supply chain*" OR "value chain*" OR "supply network*") AND TS=("agr*" OR "food") AND TS=("blockchain" OR "distributed ledger*" OR "smart contract*") filtered by topic, including title, abstract and author keywords. Considering only English language articles, the search resulted in 738 documents. In terms of inclusion and exclusion criteria, we first sorted by the *Social Sciences Citation Index* (SSCI), resulting in a sample of 217 articles. We then filtered the sample to include only articles, review articles, and early access, excluding one proceedings article, which resulted in a sample of 216 articles. Thirdly, after double-checking by the authors to include only those articles that addressed the field as a main topic, we considered a total sample of 205 documents for this analysis. The selection process is illustrated in Figure 1.

3.2 Bibliometric analysis method

This paper uses a bibliometric analysis method, specifically a co-occurrence analysis, to provide a thematic analysis of the scientific literature in the field. The analysis includes papers with the highest number of co-occurrence keywords. Co-occurrence analysis uses links and keyword frequency to identify research topics and understand the conceptual structure of the field under study (Börner *et al.*, 2003; Martín-Navarro *et al.*, 2023). Bibliometric analysis is a quantitative technique that enables the visualisation of links between concepts (Schildt *et al.*, 2006; Lyu *et al.*, 2020). Co-occurrence analysis examines the links between keywords to track the evolution of a particular field of study (van Eck and Waltman, 2010). This technique is widely used in management, entrepreneurship or innovation (e.g. Fagerberg *et al.*, 2012; Nicolas and Geldres-Weiss, 2023). This method allows researchers to identify and explore the relationships between different articles or papers in

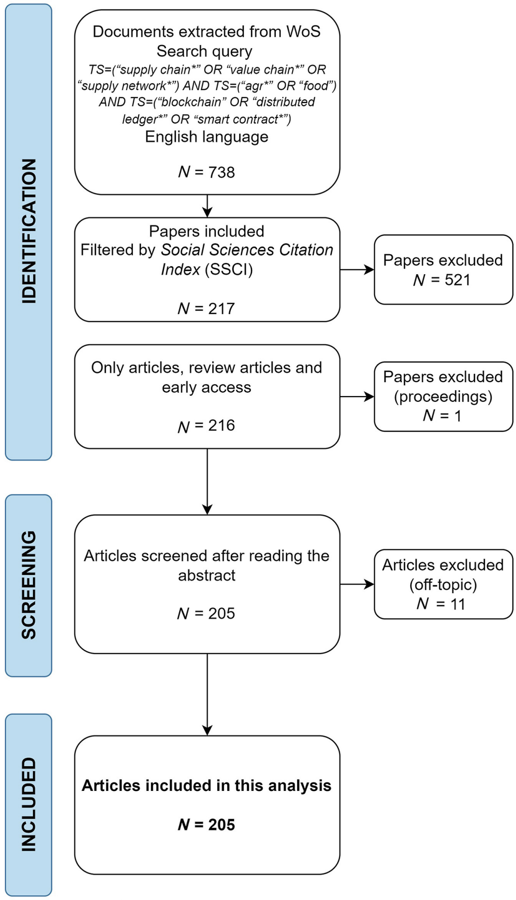

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Figure 1.
Inclusion and exclusion criteria

a particular field using data on shared references and citations (Zupic and Cater, 2014). Figure 2 displays the bibliometric analysis used in this study to address the formulated RQs.

4. Results

4.1 Descriptive analysis

From 2018 to 2023, research on the use of blockchain in supply chains is motivated by the demand to improve supply chain visibility and ensure sustainability in the agri-food system (Rana *et al.*, 2021). Organisations aim to meet regulatory requirements, including product quality improvement (Sahoo *et al.*, 2022). The Covid-19 pandemic exposed the vulnerability of the global food supply chain. The Covid-19 pandemic has compelled numerous food organisations to reconsider their strategies for the upcoming years (Rejeb *et al.*, 2022).

The implementation of traceability through blockchain enhances the integrity and safety of food products throughout the supply chain (Luo *et al.*, 2022). Blockchain applications in operations and supply chain management are still in their early stages, but this emerging

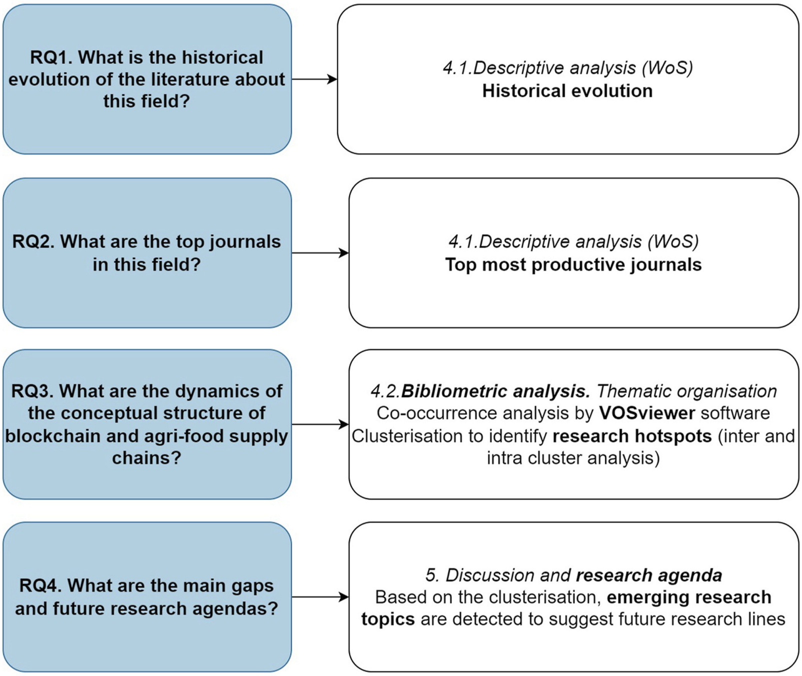

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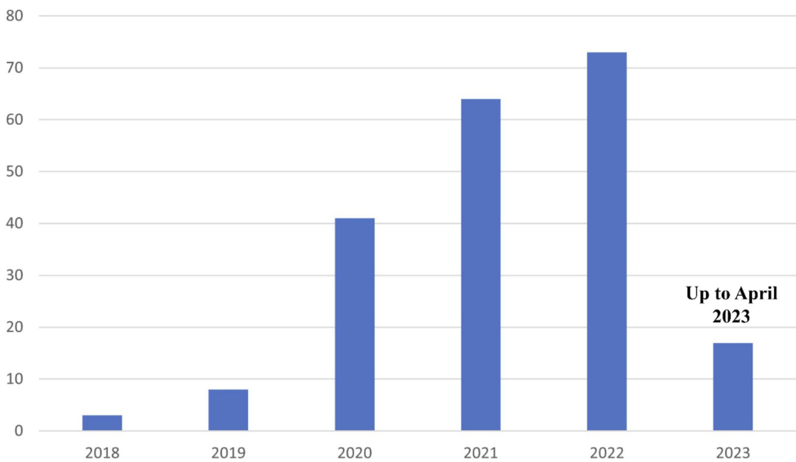
Figure 2.
Bibliometric analysis

technology has gained attention from academics, managers and practitioners and has made significant progress in recent years (Wamba and Queiroz, 2020). This is evident in the increasing number of published articles (see Figure 3).



Source(s): Own elaboration, information retrieved from Wos

Figure 3.
Historical evolution of publications (WoS)

Table 1 displays the journals with the highest productivity based on the number of published documents. *Sustainability* has the highest number of documents with 47, followed by the *International Journal of Cleaner Production* with 10. However, the most cited journal is the *International Journal of Information Management,* with a total of 177 citations per published document. The articles are related to environmental sciences, green sustainable science technology, and environmental studies, highlighting the influence of these areas on environmental sustainability.

4.2 Bibliometric analysis. Developing the thematic organisation

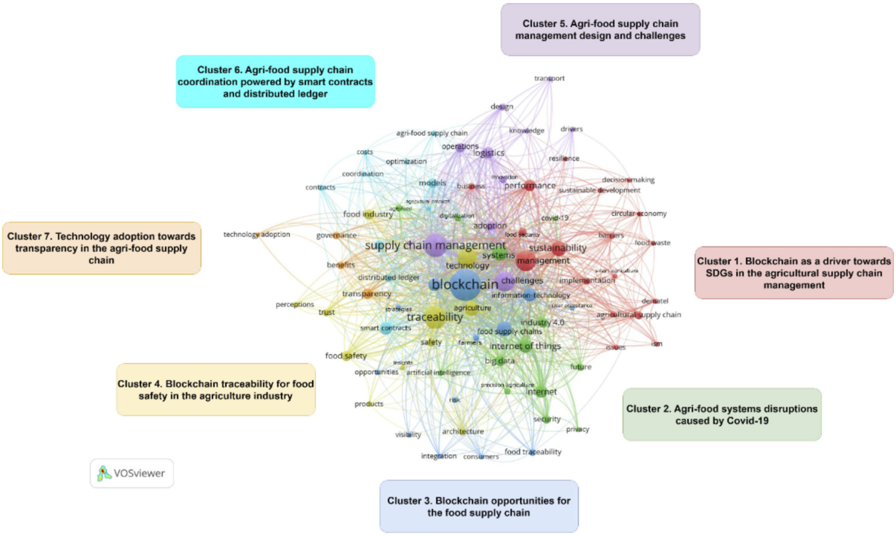
The thematic analysis is based on the results of a bibliometric analysis using the co-occurrence technique by VOSviewer software. To eliminate keyword duplication and inconsistencies, the authors created a thesaurus. A co-word analysis was carried out to identify the research hotspots in the field of blockchain technology and its application in the agri-food supply chain. The clusters were formed by assessing the strength of the links between the keywords, as identified by the VOSviewer software. The total link strength measures the strength of the relationships between the keywords (van Eck and Waltman, 2010). The analysis resulted in seven clusters of keywords, each represented by a different colour (see Figure 4).

Table II (Appendix) provides detailed information about the clustered keywords. This includes their frequency of occurrence, average publication year showing when the keyword appears, average citations, number of links showing the connections between the concepts and total link strength. The table is based on the documents in which the keywords appear together. Additionally, the five most co-occurring keywords are shown for each keyword, to help understand their connections. This information enhances comprehension of the structure and content of the identified clusters, offering insights into research trends in the

Table 1.
Topmost productive journals and research areas in the field

Journal	D	%	TC	C	Research area	D	%
Sustainability	47	22.93%	513	10.91	Environmental Sciences	65	31.71%
Journal of Cleaner Production	10	4.88%	542	54.2	Green Sustainable Science Technology	59	28.78%
IEEE Transactions on Engineering Management	9	4.39%	93	10.33	Environmental Studies	52	25.37%
Technological Forecasting and Social Change	6	2.93%	101	16.83	Management	47	22.93%
International Journal of Information Management	5	1.43%	885	177	Business	34	16.59%
Journal of Enterprise Information Management	5	1.43%	101	20.2	Engineering Industrial	22	10.73%
International Journal of Environmental Research and Public Health	4	1.95%	216	54	Food Sciences Technology	16	7.80%
International Journal of Logistics-Research and Applications	4	1.95%	43	10.75	Operations Research Management Science	16	7.80%
Transportation Research Part E-Logistics and Transportation Review	4	1.95%	299	74.75	Computer Science Interdisciplinary Applications	15	7.32%

Note(s): Abbreviation: D = number of documents; % = percentage considering the total sample (*N* = 205), C = citations per document; TC = total number of citations
Source(s): Own elaboration, information retrieved from WoS database



Source(s): Own elaboration VOSviewer software

Figure 4. Co-occurrence analysis by VOSviewer software

field. Furthermore, this study analyses the relationships, both inter- and intra-cluster, to establish the connections between the concepts in the literature.

4.2.1 Cluster 1 (red): blockchain as a driver towards SDGs in the agricultural supply chain management. The red cluster links “sustainability” issues to the “agricultural supply chain”, with a particular focus on its “management”, which is the most frequent keyword of this node. The agricultural supply chain – as part of the agri-food supply chain – focuses on the primary production of crops and agricultural products (Despoudi *et al.*, 2021). The “implementation” of blockchain technology in agricultural supply chain management provides traceability – yellow cluster – and transparency – orange cluster – (Nurgazina *et al.*, 2021). This technology improves the sustainability performance of the agricultural supply chain (Zkik *et al.*, 2022). Likewise, “smart agriculture” – which integrates digital technologies into all activities – can improve the sustainability of agriculture from an economic, social and environmental perspectives (Ciruela-Lorenzo *et al.*, 2020), according to the triple bottom line (TBL). Blockchain technology can enhance the “resilience” -the latest keyword in this cluster (see connections in Figure 5) – to agriculture and agri-food supply chain management (yellow cluster and cyan clusters) by increasing capabilities and reducing vulnerabilities in uncertain scenarios and disruptions (Mukherjee *et al.*, 2022). However, blockchain presents “barriers” in the supply chain, mainly due to the lack of regulation and standardisation, privacy concerns and a lack of trust among agricultural stakeholders.

In terms of “sustainable development”, the United Nations adopted the 2030 agenda for sustainable development goals (SDGs) in 2015 to provide a global strategy for minimising inequality, improving health and education, and boosting economic growth while respecting the environment (United Nations, 2015). The application of distributed ledger technologies (DLT) – linked to the cyan cluster-in agricultural supply chain management (blue cluster) can contribute to achieving the SDGs. By providing traceability and monitoring, blockchain technologies can improve food quality and safety, thereby promoting compliance with SDGs 2 “zero hunger”, 3 “good health and well-being”, 12 “sustainable consumption and production” and 13 “climate action” (Chandan *et al.*, 2023).

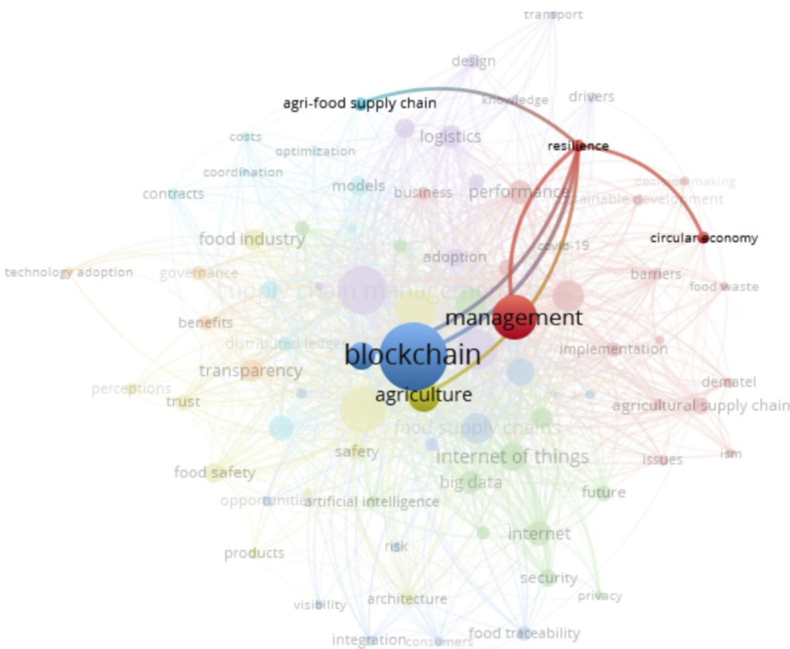


Figure 5.
Resilience connections

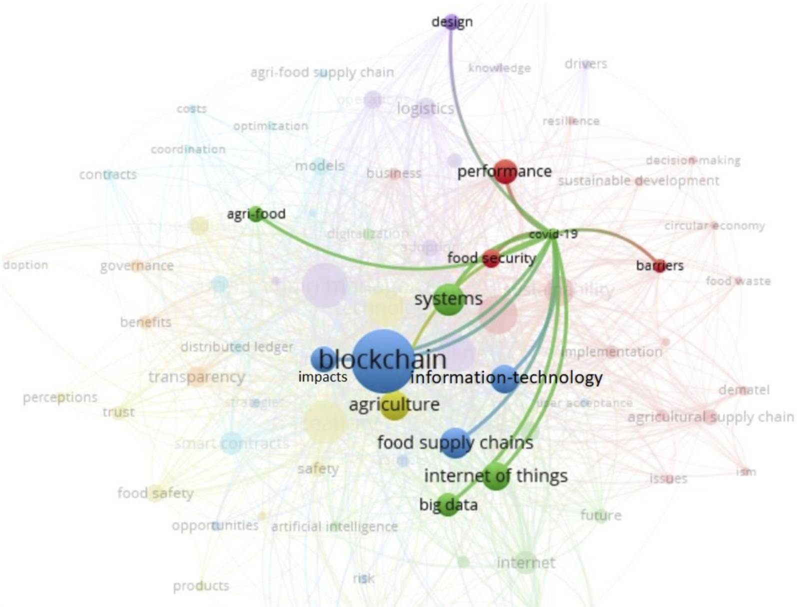
Source(s): Own elaboration using VOSviewer

In the same vein, blockchain enables the transition to a "circular economy", minimises "food waste", which is a significance issue in agricultural and food supply chains (cyan cluster). It also increases the efficiency of food supply chain management, its traceability and reduces environmental impacts (Pakseresht *et al.*, 2022), thereby supporting the achievement of the SDGs. In addition, blockchain technology has the potential to contribute to "food security" in agricultural supply chain management. For instance, through efficient water quality monitoring at the farm level (Lin *et al.*, 2017) can contribute to achieving SDGs (Tsolakis *et al.*, 2021), in particular SDG 3 "good health and well-being".

4.2.2 Cluster 2 (green): agri-food systems disruptions caused by Covid-19. The green node emphasises keywords focus on "agri-food systems" and the disruptions caused by the "Covid-19" pandemic, which is the most recent keyword in this cluster (see relationships in Figure 6). The pandemic has disrupted the global supply chain, affecting the resilience of food supply chains (red cluster). The main impacts (blue cluster) are on supply and demand disruptions, with a greater impact on consumption patterns in the food industry (Sharma *et al.*, 2022). Blockchain technologies can facilitate resilient strategies and "redesign" of supply chain (purple cluster), with a focus on flexibility, traceability (blue cluster), decentralisation, transparency (orange cluster), data "privacy" (Mukherjee *et al.*, 2022), and stakeholder coordination (Yang *et al.*, 2021).

The "digitalisation" along the agri-food supply chain allows to ensure food quality and safety, and to monitor all supply chain operations (Rejeb *et al.*, 2022). The integration of IoT, big data and AI (Artificial Intelligence) improves traceability and data monitoring along the supply chain through predictive analytics (Zhou *et al.*, 2022).

The "digitalisation" of the food supply chain also implies a relationship with sustainable and resilient supply chain performance (Yadav *et al.*, 2023), which is linked to the red cluster.



Source(s): Own elaboration using VOSviewer

Figure 6.
Covid-19 connections

In addition, digitalisation is crucial for "precision agriculture", which aims to improve management and production effectiveness, as well as real-time monitoring through innovation (Liu *et al.*, 2021). Blockchain and big data can improve precision agriculture by providing farmers (blue cluster) with better information and practices for the agri-food system.

4.2.3 Cluster 3 (blue): blockchain opportunities for the food supply chain. The blue node connects the implementation of "blockchain" in the "food supply chain" according to its main "opportunities" – the most recent keyword – (see connections in Figure 7). The food supply chain, which is a part of the agri-food supply chain, is more focused on the distribution and retail stages. Maintaining transparency (orange cluster) throughout the food supply chain, minimising costs in the agricultural sector, improving security (green cluster), ensuring "visibility" and tracking goods are the main "benefits" (orange cluster) of blockchain adoption in the food supply chain (Kayikci *et al.*, 2022). The "integration" of blockchain improves collaboration among stakeholders in the supply chain through the use of smart contracts (cyan cluster), digitisation (green cluster) and "information technologies", among others (Dutta *et al.*, 2020). This could play a key role for farmers (Quayson *et al.*, 2020). In addition, blockchain presents positive "impacts" on improving data management (Köhler and Pizzol, 2020) as well as achieving sustainability in food supply chains, as addressed in the red cluster.

Despite the previous opportunities that blockchain implementation offers to the food supply chain, one of the major application barrier (red cluster) is related to "user acceptance". "consumer acceptance" of blockchain is highly dependent on adequate information and education about the environmental impact of food products (Castellini *et al.*, 2022).

Improving the traceability (yellow cluster) of food supply chains using blockchain could be critical to reducing the "risks" and impacts associated with contamination and food waste (Lingxiu *et al.*, 2022). For instance, challenges related to supply chain disruptions, such as those caused by Covid-19 – green cluster – (Sharma *et al.*, 2022).

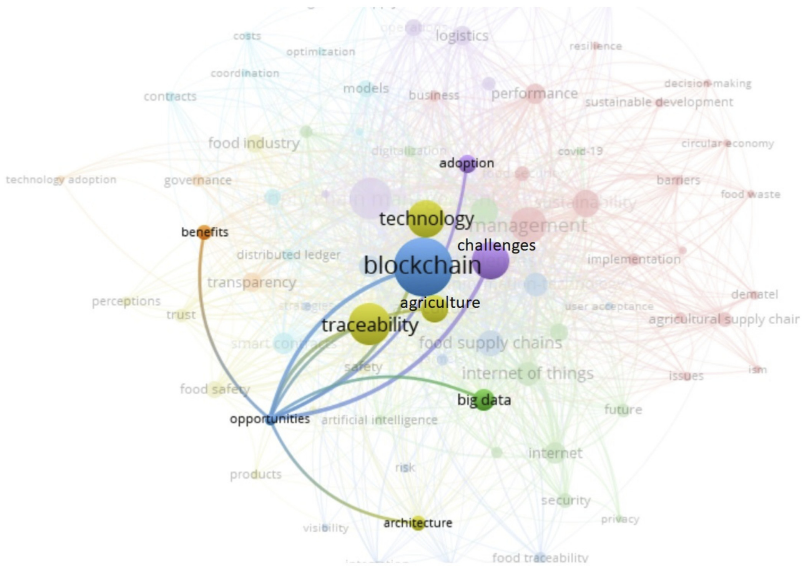


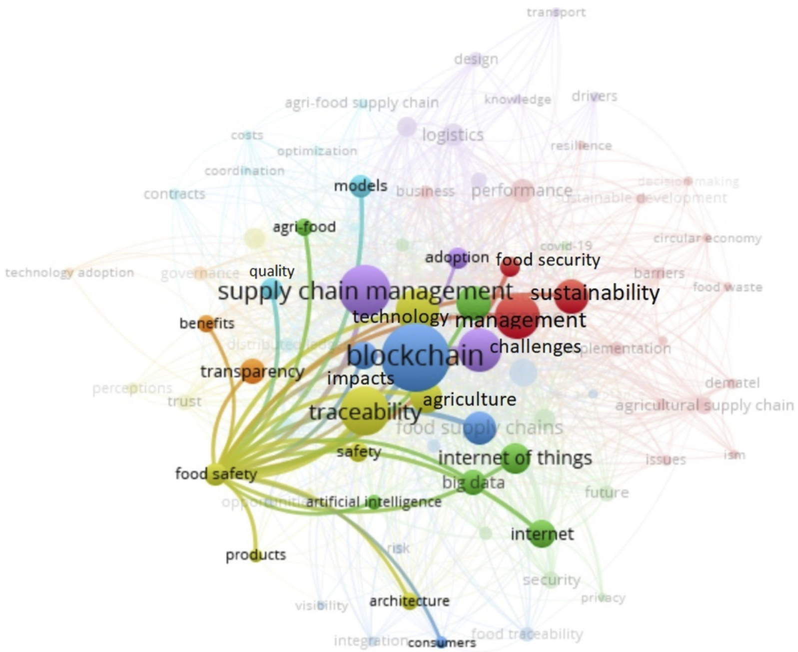
Figure 7.
Opportunities connections

Source(s): Own elaboration using VOSviewer

4.2.4 Cluster 4 (yellow): blockchain traceability for food safety in the agriculture industry. The yellow cluster presents the pivotal role of blockchain in achieving "traceability" for "food safety" in the "agriculture" sector. Food safety negatively affects the traceability of food along the supply chain, resulting in economic losses and a lack of consumer "trust" in food "products" (Yu *et al.*, 2020), as shown in the blue cluster. Food safety (see relationships in Figure 8) – appears as the latest keyword of this node- and encompasses the avoidance of foodborne diseases, detection of contaminants and pathogens, and adherence to personal, biological and chemical hygiene standards (Fung *et al.*, 2018). This is a relevant health issue that could be monitored by blockchain (Treiblmaier and Garaus, 2023) and DLT, which are linked to the cyan node (Lin, 2019).

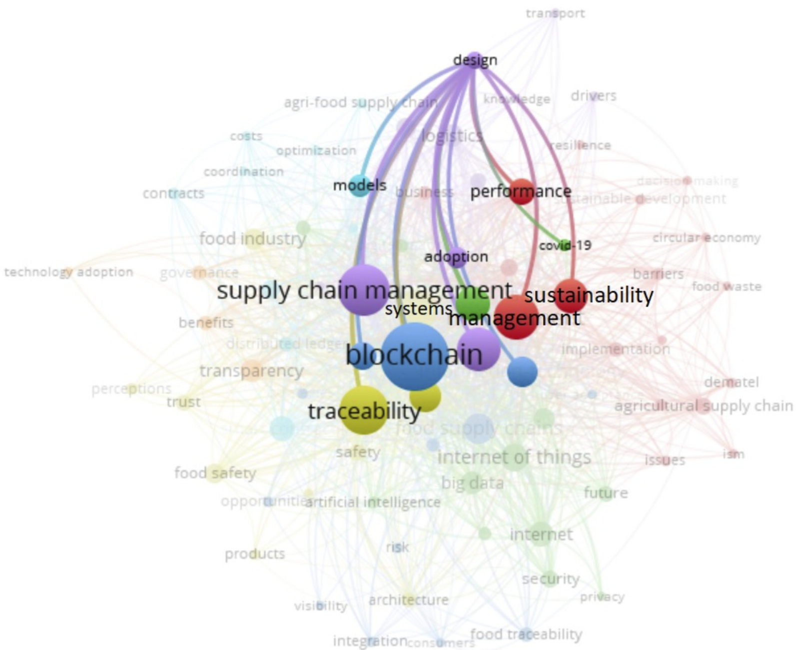
The use of blockchain technology for traceability, transparency and visibility in the food industry has been associated with increased safety by identifying risks in the supply chain (Prashar *et al.*, 2020). This technology is gaining attention in agriculture applications for increasing transparency and food quality control, improving contact exchange, transaction efficiency and traceability of origin (Lin *et al.*, 2020). Strongly connected to the red cluster, which presents blockchain as a driver for sustainability development (Mukherjee *et al.*, 2022) and achieving the SDGs. Related to the cluster in green, other technology applications, such as AI and big data, are also widely used for data processing to ensure food safety (Zhou *et al.*, 2022).

4.2.5 Cluster 5 (purple): agri-food supply chain management design and challenges. The purple cluster addresses blockchain as a "driver" for agri-food "supply chain management" in terms of its "design" "challenges". Blockchain is considered a driver for logistics management and supply chain transformation, as part of Logistics 4.0. Unlike traditional supply chains, blockchain enables "innovation" through an integrated structure that allows for the sharing, synchronisation and transfer of data among all involved actors (Granillo-Macías *et al.*, 2023). In terms of the design of the agri-food supply chain –the most recent keyword (see links in Figure 9) – using blockchain, it is important to consider social, environmental and economic sustainability aspects – linked to the red cluster- (Kamble *et al.*, 2020).



Source(s): Own elaboration using VOSviewer

Figure 8.
Food safety
connections



Source(s): Own elaboration using VOSviewer

Figure 9.
Design connections

The “operations” of the food supply chain were affected by the Covid-19 pandemic (green cluster) with the subsequent logistics disruptions – from food production to its “transport” (Kumar and Singh, 2022). Blockchain and Information Technology (IT) (blue cluster) could address the challenges and impacts on the food supply chain through traceability of operations (yellow cluster) and decentralisation of operations.

4.2.6 Cluster 6 (cyan): agri-food supply chain coordination powered by smart contracts and distributed ledger. This cluster investigates the application of blockchain-related technologies, specifically “smart contracts” and “distributed ledger”, to the “agri-food supply chain”. The latest concept in this cluster is “coordination” in terms of supply chain management, which is related to all clusters (see Figure 10). Decentralised “models” such as smart contracts could enable coordination between the actors involved, including farmers and stakeholders, and their transactions in the supply chain. The implementation of smart contracts within ICT can increase the efficiency and transparency of operations along the agri-food supply chain-linked to the blue, orange and purple clusters respectively (Lin *et al.*, 2022).

Blockchain-based technologies can “optimise” agri-food supply chain management by improving food safety, traceability and sustainability management. According to Lin (2019), the distributed ledger can enhance traceability, leading to increased efficiency and quality in the agri-food supply chain, ultimately resulting in cost savings. Furthermore, these technologies enhance the quality of food products, which in turn increases customers’ willingness to buy them (Treiblmaier and Garaus, 2023).

4.2.7 Cluster 7 (orange): technology adoption towards transparency in the agri-food supply chain. In this analysis, the smallest node is the orange one, which contains terms related to the benefits that the adoption of technology provides to the agri-food supply chain. The most recent keyword in this cluster is “technology adoption” (see relationships in Figure 11), which is related to blockchain implementation and supply chain traceability (yellow cluster), in line with the benefits and challenges explored in this study. “Transparency”, monitoring,

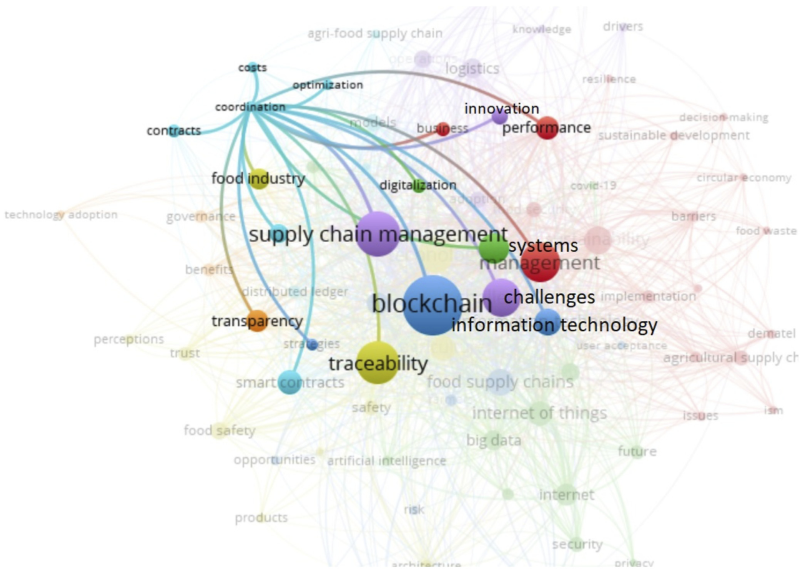
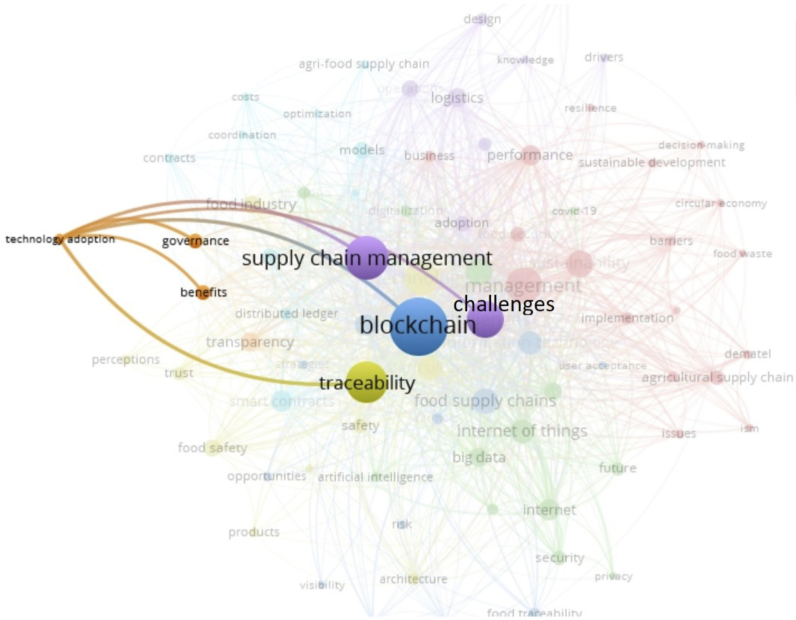


Figure 10.
Coordination connections

Source(s): Own elaboration using VOSviewer



Source(s): Own elaboration using VOSviewer

Figure 11. Technology adoption connections

coordination and trust were identified as the primary benefits (Saurabh and Dey, 2021). Furthermore, blockchain adoption, linked to the red cluster, could support sustainable supply chain "governance" (Köhler *et al.*, 2022).

5. Discussion and research agenda

Based on the clusterisation results, it is highlighted that further research and exploration into the application of blockchain in the agri-food supply chain is necessary. Additionally, greater attention should be given to the social aspects that impact the agri-food supply chain (Saha *et al.*, 2022). Previous bibliometric overviews of this field, such as Pandey *et al.* (2022) and Niknejad *et al.* (2021), have also highlighted this point. However, their results did not specifically focus on the social aspects either. The co-occurrence analysis shows that keywords such as "standardisation" and "regulation", – although related to the main barriers and challenges, do not appear as keywords in this analysis. This is also the case in previous co-occurrence studies (e.g. Niknejad *et al.*, 2021; Pandey *et al.*, 2022). Furthermore, there is a lack of knowledge and information regarding acceptance, education and training. These factors are assumed to be the main challenges related to the implementation of blockchain technology in the agri-food supply chain – particularly highlighted in the red, blue and purple clusters. It is noteworthy that "user acceptance" is a concept that did not appear in previous analyses (e.g. Niknejad *et al.*, 2021; Pandey *et al.*, 2022; Sharma *et al.*, 2023). Likewise, concepts related to "education" or "training" still do not appear (Sharma *et al.*, 2023). With regard to blockchain digital currencies and platforms, previous thematic studies have mentioned "ethereum" (Niknejad *et al.*, 2021; Pandey *et al.*, 2022). However, our co-occurrence analysis shows that "bitcoin" has recently received more attention.

In terms of sustainability issues, related terms such as circular economy or sustainable development does not appear in Niknejad *et al.* (2021) or Sinha *et al.* (2021). Nevertheless, in

Pandey *et al.* (2022), a more recent paper, the term "sustainable development" emerged in the mapping due to the increasing attention on sustainable impacts. Regarding journals, management and business research areas have improved their position compared to previous bibliometrics. Additionally, logistics-related journals that were not previously present (e.g. Niknejad *et al.*, 2021) have emerged. Accordingly, the term "logistics", -which did not appear in Niknejad *et al.* (2021)-, is currently presented as a key issue for agri-food supply chains in the current literature.

Therefore, based on the evaluation of the thematic organisation, research trends and gaps identified through bibliometric analysis, this section proposes the following research agenda.

The first proposal is connected to the red cluster, and aims to apply blockchain to the sustainability reporting framework to increase transparency in the agri-food supply chain. Sustainability reports, also referred to as environmental, social and governance (ESG) – environmental, social, governance are gaining attention due to standardisation efforts to harmonise ESG information and data. Blockchain technologies can enhance the credibility of reported information, thereby avoiding "third party trust" issues (Sulkowski, 2021) and thus achieving stronger agri-food supply chain management. Although some papers have explored the use of blockchain to standardise sustainability reporting -for instance, in the banking sector (Pizzi *et al.*, 2022) there is a lack of published articles focussing on the food system.

Regarding the green cluster, the use of blockchain with other technologies based on AI and big data could support decision-making and traceability in the agri-food supply chain (Romanello and Veglio, 2022). Robotics and automated control operations could be employed to manage data extraction and reduce the workload in the agri-food industry. In addition, the implementation of AI and blockchain-based technologies could improve the efficiency of resource use and yield forecasting, improving processes towards smart agriculture – red cluster – (De Baerdemaeker *et al.*, 2023).

The blue, purple and orange clusters illustrate the opportunities and challenges of blockchain implementation in the agri-food supply chain. While the blue cluster highlights the potential benefits of blockchain, it is important to address user acceptance, which could be improved through information and education campaigns. For instance, providing IT and blockchain training to farmers (Renda, 2019; Quayson *et al.*, 2020) can improve their usability and enable them to take advantage of the opportunities presented by these technologies. This addresses one of the main challenges: the need for training and education throughout the agri-food supply chain, which is the fourth proposal. Familiarise employees and managers with blockchain technologies through programmes and initiatives such as the European Union's "Blockchain for Agri-Food Educators" (Blockchain for Agri-Food Edu, 2023). It is important to not only develop precise blockchain applications but also to provide educational programmes and campaigns on food safety.

Lack of government regulation is one of the most significant barriers to blockchain adoption in the agricultural supply chain (Yadav *et al.*, 2020). Improving regulation on data and protocols could achieve supply chain transparency and traceability – linked to the blue and orange clusters, respectively- (Montecchi *et al.*, 2021), while preventing fraud and ensuring product safety and quality (Lin *et al.*, 2020) -addressed by the yellow and cyan clusters. Thus, the third proposal emphasises the importance of standardising blockchain to ensure food quality and safety throughout agri-food supply chains. In addition, blockchain facilitates transparency that provides more accurate and detailed information on ingredients, nutritional composition and source of origin. This could have a positive impact on customer trust, leading to greater adoption of blockchain technology and user acceptance – associated with the blue cluster- (Castellini *et al.*, 2022).

Cluster	Topic	Research gaps	Potential research questions
Red cluster	SDGs and circular economy in the agri-food supply chain	1. More emphasis on the key role of blockchain for sustainability reporting standarisation 2. More empirical research about SDGs achievement and circularity practices related to the key role of blockchain in the agri-food supply chain is required	RQ1. How can the use of blockchain-related technologies standardise sustainability reporting on food systems? RQ2. How can be applied the blockchain technology for ESG standarisation along the agri-food supply chain? RQ1. What is the impact of blockchain in the achievement of SDGs in the agri-food supply chain? RQ2. How can enable blockchain the implementation of circular practices in the agri-food supply chain?
	Blockchain implementation barriers in the agri-food supply chain	1. The need to improve privacy and trust between agro-stakeholders	RQ1. How can enhance agro-stakeholders privacy throughout the supply chain by means of blockchain technologies? RQ2. What is needed to improve stakeholders' trust in blockchain?
Green cluster	AI and blockchain for the agri-food supply chain management	1. More case studies and empirical research about AI, Big Data and blockchain technologies in the agri-food supply chain 2. The role of AI and blockchain to support efficiency in the agri-food supply chain is needed	RQ1. How can AI, Big Data and blockchain technologies be analysed to support the agri-food supply chain? RQ1. What measures can be implemented to improve the efficiency of the agri-food supply chain through AI, Big Data and blockchain technology?
	Dealing with agri-food supply chain disruptions	1. Greater emphasis on building a resilient agri-food supply chain thanks to AI and blockchain technologies 2. The role of AI and blockchain to face future disruptions	RQ1. How can blockchain together with AI technologies provide resilience in the agri-food supply chain? RQ1. What could blockchain and AI technologies deal with future disruptions in the agri-food supply chain?
Blue, purple and orange clusters	User acceptance and challenges throughout the agri-food supply chain	1. Addressing the main challenges about ease of use and acceptability across the agri-food supply chain	RQ1. What information and education initiatives could be implemented throughout the agri-food supply chain? RQ1. What training and programmes related to blockchain could be adopted for employees and managers?

(*continued*)

Table 2. Research gaps and future guides

Cluster	Topic	Research gaps	Potential research questions
Yellow and cyan clusters	Blockchain standarisation for food quality and safety	1. Greater emphasis needs to be given to standardising blockchain technology in order to ensure the quality and safety of food	RQ1. How can blockchain standarisation benefit the food quality throughout the agri-food supply chain? RQ2. How can blockchain standarisation benefit the food safety throughout the agri-food supply chain?

Table 2.

Source(s): Own elaboration

Based on the identified research gaps in clusterisation, and following the structure of previous articles such as Hina *et al.* (2022), Table 2 provides future avenues of research in this field.

6. Conclusions

Blockchain technology has the potential to improve transparency, traceability, and efficiency in the food supply chain, increase trust between stakeholders and reduce risk. This bibliometric analysis provides insights into the use of blockchain in agri-food supply management. The number of publications related to the application of blockchain in the agri-food supply chain has increased between 2018 and 2023. The Covid-19 pandemic has exposed the vulnerability of the food supply chain, prompting organisations to reconsider their strategies (RQ1). The findings indicate that journals in environmental sciences, green sustainable science technology and environmental studies are the most prevalent (RQ2). Research trends are currently focused on achieving the SDGs, analysing the disruptions caused by Covid-19, exploring the opportunities presented by blockchain technology, such as improving transparency of operations and traceability for food safety and enhancing coordination along the agri-food supply chain through the use of smart contracts and distributed ledgers (RQ3). The research agenda focuses on the transparency that blockchain technology provides for sustainability reporting. It also explores how AI could support traceability within blockchain and aid in decision-making. Additionally, the agenda highlights the necessity for standardisation of blockchain technology to ensure food quality and safety. Finally, it emphasises the importance of education and training throughout the agri-food supply chain (RQ4).

6.1 Theoretical implications

In terms of theoretical implications, this paper provides valuable insights into the field of blockchain application in the agri-food supply chain. This bibliometric overview provides a broader perspective than previous analysis, since other blockchain-related technologies concepts – such as *distributed ledger*–have been considered. Attention to blockchain to improve supply chain visibility and sustainability – in relation to blue and red clusters, respectively –has emerged to improve product safety and quality – yellow and cyan nodes (Lin *et al.*, 2020; Sahoo *et al.*, 2022)-. The mapping visualisation, performed by the VOSviewer software, provides an overview inter- and intra-cluster of the research trend topics, enriching as well as understanding the agri-food supply chain and blockchain literature and tracking its evolution. In addition, by identifying the most productive journals and the most influential areas of research, it can help researchers know where to publish in order to contribute to this field. The findings could be helpful for scholars in the further development of research on blockchain-based technologies. It is highlighted that the results show that there is a lack of regulation and knowledge among the actors involved in the operations, which are assumed to be the main barriers linked to the red cluster for the application of blockchain in the agri-food supply chain. Which, given its urgency, requires action by governments and organisations. In the same line, the need of improving privacy and trust between stakeholders (red cluster) and their acceptance of the use of blockchain (blue, purple and orange clusters) is highlighted in the literature. In terms of standardisation, this could be linked to sustainability and food quality and safety (red, yellow and cyan clusters, respectively), while building resilient agri-food supply chains (green clusters). Moreover, it is emphasised in the scientific literature that further development is needed at the empirical level. Advanced technologies such as blockchain can promote both economic profitability and sustainability linked to the fulfilment of the SDGs and represented by the red cluster (Tsolakis *et al.*, 2021; Altarturi *et al.*, 2023). It is identified that further research is needed, along with blockchain technologies, to be used as a driver for circular practices and the achievement of SDGs. The research agenda and future avenues of investigation provided with RQs according to the research gaps detected could be used as a guide in this field.

6.2 Practical implications

In practical terms, this article provides timely information on implementing blockchain in the agri-food supply chain for academics, agri-food supply chain stakeholders, practitioners, managers and governments. It offers a research agenda with suggestions based on analysis and findings that could inspire academics for future research, according to current scientific literature. Privacy and trust throughout the agri-food supply chain (red cluster) require more attention from practitioners and managers across this supply chain. Accordingly, this would enhance the acceptance of the use of blockchain-related technologies presented in the blue cluster (Sander *et al.*, 2018). The identified emerging trends in blockchain technology have the potential to assist practitioners and managers in implementing and managing it in the agri-food supply chain, which is directly linked to the red node. By implementing innovative designs and enhancing transparency, traceability and food safety objectives as analysed in the yellow, purple and orange clusters, significant progress can be made. As highlighted in the red cluster, blockchain technology has the potential to improve sustainability and standardise sustainability reporting. It is also important to focus on SDGs and circular practices in blockchain-based solutions to prevent future disruptions in agri-food supply chains (Sharma *et al.*, 2022). Accordingly, it is necessary to learn how to handle food disruptions beyond the Covid-19 pandemic. This requires public-private collaboration, as well as support from governments and organisations to build more resilient agri-food supply chains, referred to as the green cluster. Regarding governments, a policy framework in this regard is required to guide the agri-food supply chain stakeholders in the application of blockchain-related technologies (Mohapatra *et al.*, 2023). Implementing education and information initiatives throughout the agri-food supply chain is crucial in addressing ease of use and acceptability. Highlighting the necessity of training programmes for stakeholders, as presented in the blue and orange clusters, should be a key factor for practitioners and managers. In order to enhance collaboration on blockchain implementation within the agri-food supply chain identified on the cyan cluster, stakeholders should focus on coordinating their efforts (Yang *et al.*, 2021). This can lead to various benefits in agri-food supply chain management, including improved supply chain efficiency, traceability, transparency and consumer trust, as highlighted in the orange and yellow clusters (Lin *et al.*, 2020). Regulations must be established to ensure the quality and safety of food. According to Pandey *et al.* (2022), blockchain technologies are crucial in meeting these requirements. Standardisation of this issue will benefit all stakeholders, practitioners and managers involved in the agri-food supply chain, as indicated by the yellow and cyan clusters.

6.3 Limitations and future research lines

Firstly, this paper only includes articles retrieved from WoS, which potentially excluding interesting articles from other databases. Secondly, only papers written in English are considered, despite the fact that although most scientific literature is in English, papers in Chinese or Spanish, based on their scientific production average, may also be relevant. Thirdly, the software employed for analysing and visualising of scientific mapping allows for the presentation of the examination with other tools such as Bibliometrix or SciMat. Additionally, other techniques, for example, bibliographic coupling and co-citation analysis, could be used to explore the intellectual structure of blockchain applications in the agri-food supply chain.

Future research could focus on establishing regulations for food labelling, quality, and safety using blockchain-based technologies. Additionally, exploring the potential advantages of integrating blockchain with AI tools, such as ChatGPT, in agri-food supply chain management, could optimise crop forecasting and management connected to the green cluster (Biswas, 2023). Further investigations could explore the technical and technological implementation of blockchain technology in food systems, as well as practical case studies. This would extend beyond the benefits and barriers of blockchain technology.

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Appendix

The supplementary material for this article can be found online

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