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The innovative role of blockchain in agri-food systems: A literature analysis

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ABSTRACT

The agri-food sector has come under increasing pressure to increase safety standards. Both consumers and expert authorities are demanding that the agri-food chain implement higher levels of traceability and transparency to make the system less susceptible to fraud and to ensure higher quality. These needs have become even more pressing following food scandals that occurred in the 2000s.

Recent European policies have supported the growth of technological and digital innovations in firms, recognizing that digitization has a strategic role to play in modernizing the agri-food sector and moving toward ecological transition.

This paper aims to verify whether blockchain's cutting-edge technology can provide effective technical and strategic support to the agri-food system in achieving the aforementioned goals. A total of 123 articles underwent descriptive analysis and network analysis focusing on the topic of blockchain in the agri-food context. The methods used were the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) protocol and VOSviewer software. The results highlight the growing importance of (and increased interest in) blockchain and its functionality when applied to the agri-food sector.

1. Introduction

Blockchain is a shared database belonging to the category of distributed ledger technologies (Krzyzanowski Guerra & Boys, 2022; Rudman, 2021). It is a new technology that automatically stores (Pakseresht et al., 2023) and records information blocks from specific business networks in chronological order (Granillo-Macías et al., 2023). Data registered in the blockchain are protected by cryptographed codes (Cocco et al., 2021) and are verified by consensus. The inserted information cannot be removed, so it can be read at any time in the future. This creates a decentralized (Chan et al., 2019) ledger, in which every blockchain member has the same copy of the unit. Thus, the data do not flow to a central organization or entity and are not stored in a single server. In summary, blockchain comprises a distributed succession of time-stamped blocks linked by a cryptographic hash in which participants interact anonymously using encrypted identities.

These specific characteristics have led many to believe that blockchain could provide multiple benefits to the agri-food sector (Mazzù et al., 2021; Tanrıverdi, 2022). Several authors have stated that, as a new paradigm of distributed, decentralized, and immutable (Aldrighetti et al., 2021) public ledger databases (Antonucci et al., 2019), blockchain has the potential to revolutionize food supply chain management. This may be even more evident when its potential is examined in the context of the agribusiness sector.

The agri-food system embraces many different sectorial activities, such as greenhouse cultivation, field planting, crop cultivation, livestock breeding (Xie et al., 2022), and so on. Each activity embeds a differentiated system, which is composite. Throughout the agri-food chain, from production to consumption (Bhat et al., 2022) and marketing (González-Puetate et al., 2022), there are related activities inherent in the processing, distribution, and transportation stages (Georgescu et al., 2022) implying the interaction of many distinct economic subjects (actors and stakeholders). The agri-food system represents a highly distributed, cooperative, and heterogeneous sector. It involves a wide range of directions, products, production processes, and destinations (Chandan et al., 2023; Chu & Pham, 2022). Therefore, the flow of information along the chain is dispersed and data are generated across fragmented and widespread geographic areas. This makes it difficult to trace all the activities involved and coordinate them in a transparent and fair manner (Babu & Devarajan, 2023; Balasubramanian & Akila, 2022).

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Furthermore, a typical characteristic of food supply chain management systems is the centralization of information, which may create monopolistic conditions (Commandré et al., 2021). Conversely, when data flow management is outsourced to an intermediary (i.e., a third party external to supply chain members), there is a risk of creating a system that lacks reliability (Dos Santos et al., 2021; Menon & Jain, 2021). As the agri-food chain is a multifaceted system (Zhao et al., 2022), it is characterized by information asymmetry.

Against this backdrop, there has been increasing consumer demand for a system that is robust to fraud, corruption, and data falsification (Kamble et al., 2020; Verhaelen et al., 2018). A series of scandals in the early 2000s (Stranieri et al., 2021) resulted in food safety incidents that have severely undermined consumer trust (Liang et al., 2013). Such scandals included mad cow disease, toxic milk powder, and genetically modified food (Zhao et al., 2019), as well as incidents in which horse meat in processed food products was labelled as beef in 2013 (Echegaray et al., 2022). The fraudulent labelling of conventional production as organic is also an issue (Wünsche & Fernqvist, 2022). Such instances have altered consumer attitudes to food control and risk (Creydt & Fischer, 2019; Zhai et al., 2022), resulting in increased food safety and traceability requirements (Garaus & Treiblmaier, 2021). Along with this increased awareness and growing concern, consumers are demanding more information about quality in the broader sense (Corallo et al., 2020), including information about product origins (Patelli & Mandrioli, 2020; Tharatipyakul & Pongnumkul, 2021). All these factors mean that the agri-food sector needs to rebuild consumer trust.

Blockchain can support this specific aim (Motta et al., 2020; Shardeo et al., 2023; Syromyatnikov et al., 2020). Its capacity to store dispersed data that are simultaneously visible to all members creates a transparent and traceable data history (Mirabelli & Solina, 2021), and removes the asymmetry information problem inherent in the agri-food system (Mao et al., 2018). By enabling decentralized information management, it provides supply chain members with a secure alternative to entrusting the management of information traceability to a single entity (Chen et al., 2021; Kamble et al., 2020). Consequently, it has the potential to revolutionize interactions between different stakeholders in the supply chain (Anastasiadis et al., 2022; Kramer et al., 2022) including origin, process steps, environmental variations (Varavallo et al., 2022), microbial records, quantity, and even transaction operations and contracts (Kowalska & Bieniek, 2022). Once in the blockchain, data are immutable. If one member tries to modify existing data, all other participants are alerted to this change when they inspect the chain (Antonucci et al., 2019; Bhat et al., 2022).

The adoption of this type of technology, which ensures transparency and traceability (Krzyzanowski Guerra & Boys, 2022), certainty of data entry, integrity (Feng et al., 2020) and security, carries the potential to make agribusiness supply chain management more reliable and efficient (Compagnucci et al., 2022; Ramkumar et al., 2022). The tracking of commodity movement information from farm to fork may lead to the minimization of food fraud cases while enabling source identification of foodborne illness (Antonucci et al., 2019; Conti, 2022), thus improving both food safety and quality (Mehannaoui et al., 2023).

Against a backdrop of emerging potential benefits related to blockchain (Mavilia & Pisani, 2022), this study aims to highlight the importance that this technology may have within the agri-food sector (Morella et al., 2021). Specifically, the study seeks to examine whether and how blockchain technology is being valued across agri-food supply chain stages. It also seeks to establish the direction in which this perceived value is focused.

We posit three research questions to guide this study:

R1 What challenges, if any, constitute a barrier to the implementation of blockchain in the agri-food system?

R2 Can the agri-food business performance ameliorate when adopting blockchain?

R3 What are the practical requirements for applying blockchain to the agri-food system effectively?

To address these research questions, a meta-analysis was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) protocol (Moher et al., 2015) using the main worldwide databases (Web of Science [WOS] and the Elsevier Scopus core collection). This was followed by descriptive analysis and network analysis using VOSviewer software (Adegoriola et al., 2021; Agnusdei & Coluccia, 2022; Hassan et al., 2024; Marvin et al., 2022; Wang et al., 2023).

2. Research methodology

2.1. Database selection: PRISMA

The study followed the PRISMA procedure (Bakare et al., 2023; Page et al., 2021; Zarbà et al., 2022). The references used were drawn from the online core collection of Elsevier Scopus and WOS, since these are the main global scientific and economic online research databases. The databases were selected to provide a comprehensive worldwide overview of the specific literature and scientific studies in a given historical moment. The PRISMA procedure follows a detailed protocol (Cazazian, 2022) that is replicable, scientific, and transparent (Moresi et al., 2022), and includes several different stages. The PRISMA method is widely recognized and accepted in many fields. This makes it easier for reviewers to follow a standardized approach and for readers to understand and compare different reviews (Fig. 1).

The two research databases were searched for relevant material. Each included high-impact, peer-reviewed journal articles. The quality of results is improved and errors are reduced when peer-reviewed journal articles are used in systematic reviews (Uttley et al., 2023). The searches in our study focused on blockchain and the agri-food sector as thematic areas (identification) to establish the kinds of interactions that existed between them. Boolean operators (AND, OR), quotation marks (“ ”), and asterisks (*) were used to narrow the scope of the searches. After multiple tests with different strings, the final keywords selected to conduct the research were [“blockchain*” and (“agri-food*” OR “agro-food*” OR “agrifood*” OR “agrofood*”)]. The final search took place on March 15, 2023.

The data-cleaning approach (screening) led us to exclude duplicates and to include only articles and reviews written in English in order to focus on literature that had high visibility within the scientific community (Deglon et al., 2023).

The next PRISMA stage is usually eligibility checking (Golbabaei et al., 2020; González-Rubio et al., 2020; González-Sarrías et al., 2017). This generally leads to the exclusion of some studies according to select criteria chosen by the authors. However, this stage was omitted in the current study to avoid overly narrowing the scope of the research. In this study, the methodological structure involved using VOSviewer software (Esfahani et al., 2021; Norouzi et al., 2021), which processes and tapers data electronically.

At the end of the PRISMA process, 123 articles remained and were used for the study (included). Table 1 lists the inclusion and exclusion criteria followed throughout the process.

2.2. VOSviewer co-occurrence analysis procedure

After gathering articles following the PRISMA protocol, we imported the data, keywords, and titles of articles and abstracts (TITLE_ABS_KEY) into VOSviewer (Fig. 2). VOSviewer is a free Java-based software program that creates maps based on network data (Van Eck & Waltman, 2023). It was developed in 2009 by Van Eck and Waltman (2010) at the Centre for Science and Technology Studies at Leiden University in the Netherlands. The software processes bibliometric maps (Damar et al., 2018) and also displays a visualization of various network forms of scientific publication data by combining many factors through a quantitative method (Hirawan et al., 2022). It generates a so-called co-occurrence network map that shows the keyword, title, and abstract for all

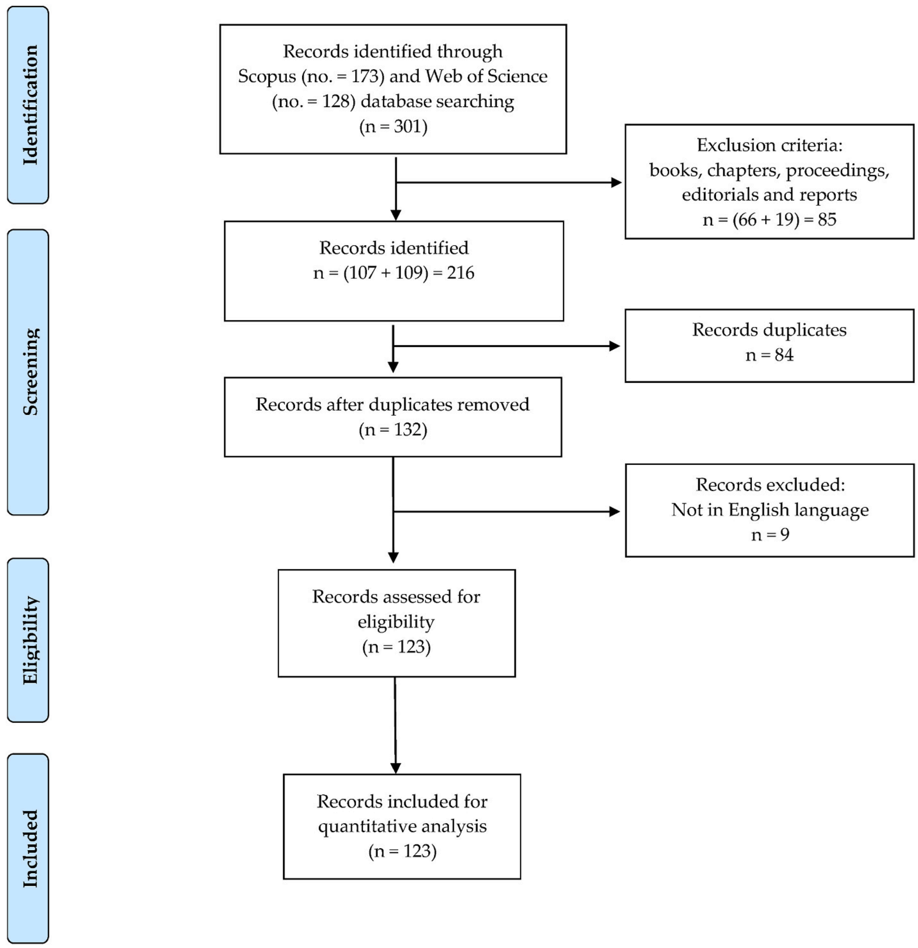

Fig. 1. PRISMA flow diagram.

Table 1
Inclusion and exclusion criteria.

Inclusion criteria
⇒ Full-text papers from Scopus and Web of Science
⇒ Full-text papers with a focus on blockchain and agri-food systems
⇒ Full-text papers (articles and reviews) published in a peer-reviewed journal
⇒ Full-text papers written in English
Exclusion criteria
⇒ Duplicates in Scopus and Web of Science
⇒ Paper books, chapters, proceedings, editorials, and reports

selected articles from the databases under review, and covers all available search periods (in the present case, 2018–2022). Once a map has been generated in VOSviewer, each node shown on it represents a word with a high level of occurrence. The size of the node depends on the frequency of occurrence. The links between the nodes show the co-occurrence relationships. Different colors characterize the keywords and distinguish them in different clusters.

The evaluation of these data leads to the development of network analysis (Barbosa, 2021).

The statistical analysis conducted with VOSviewer highlighted the most frequently used words in the 123 papers and the relationships between these words. This made it possible to identify trending topics in relation to the research themes relevant to this study (namely blockchain and the agri-food sector). Two co-occurrence analyses (Martínez-Vázquez et al., 2021) were developed following two different procedures, the first with the *keywords* function and the second with *title* and *abstract* functions.

This analysis showed the degree of occurrence of the keywords in relation to those of the cluster of belonging (Zhang, Y. et al., 2024). The *occurrences* attribute indicates the number of documents in which a keyword occurs. In the case of full counting (as used in this study) it also indicates the total number of occurrences of a term in all documents (Van Eck & Waltman, 2023).

To generate a co-occurrence network map, the data gathered from Scopus and WOS were imported into two RIS format files. These were eventually unified in order to upload the data to the VOSviewer software.

The development of the two network analyses based on the three aforementioned pieces of research data (TITLE_ABS_KEY) resulted in the two following separated flows (Arias et al., 2023):

a) for the keywords co-occurrence analysis

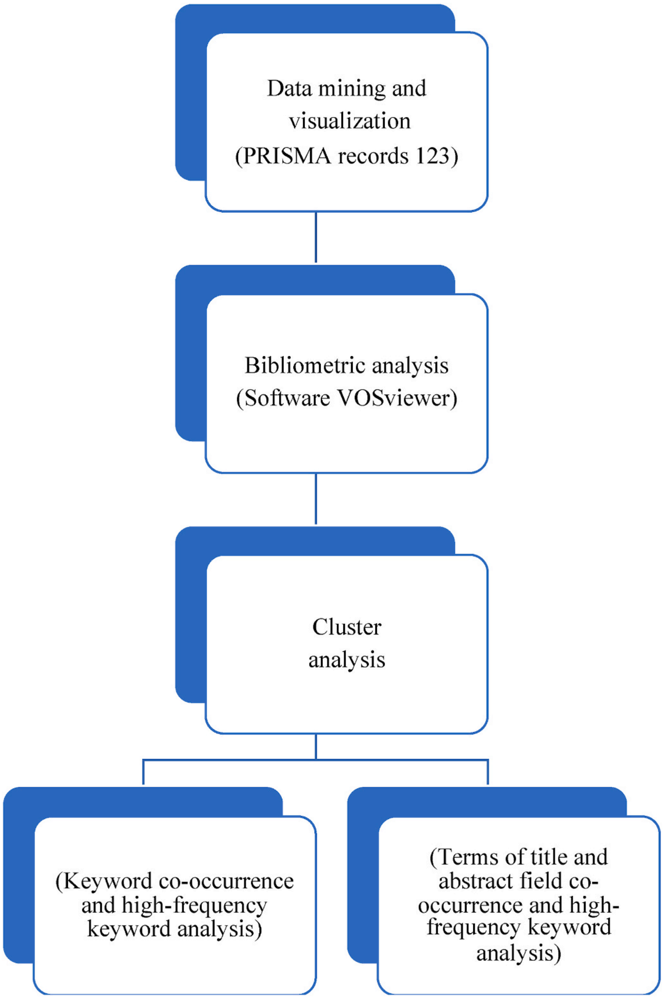

Fig. 2. VOSviewer procedure.

- map based on: bibliographic data;
- type of analysis: co-occurrence;
- unit of analysis: keywords;
- counting method: full counting;
- minimum number of occurrences of a keyword: five;
- number of keywords selected: 47;

b) for the title and abstract co-occurrence analysis
- map based on: text data;
- type of analysis: co-occurrence;
- fields from which terms are extracted: title and abstract;
- counting method: full counting;
- minimum number of occurrences of a term: 15;
- number of terms selected: 36.

In both cases, the full counting option was preferred over fractional counting. The difference between the two counting methods lies in the strength of the links created. There were several reasons for selecting full counting. First, VOSviewer gives the option of full counting by default. Second, after trying both tools for keyword aggregation, full counting gave results that were more appropriate for use in the current study (as verified by various attempts at aggregation) to highlight the total number of occurrences of the main keyword (Arias et al., 2023; Raboaca et al., 2021). Further, fractional counting reduces the influence of documents with many authors, whereas with full counting, all documents are considered (Van Eck & Waltman, 2023). Third, as the PRISMA protocol already uses selection criteria by choosing specific words of interest to focus the investigation, using the broadest and most inclusive approach was more consistent with the goals of the current study. Furthermore, the string "["blockchain*" AND ("agri-food*" OR "agro--food*" OR "agrifood*" OR "agrofood*")" had already narrowed the focus of the study to the selected 123 papers. A final consideration was that the fractional option operates an automatic 60% reduction in words driven by the software algorithm. This risked the exclusion of numerous keywords and related aggregations useful for the study. With these considerations in mind, no words were removed in the keyword co-occurrence analysis, including duplicates such as *Blockchain* and *Block-chain* or *Agri-food supply chain* and *Agri-food supply chains*.

A slightly different reduction approach was taken for the title and abstract co-occurrence analysis. However, this difference was minimal and was specifically driven by researcher preference. Ten terms (*article*, *case*, *case study*, *country*, *data*, *literature*, *problem*, *role*, *thing*, and *review*) were considered to be outside the scope of the study and were excluded. This approach resulted in a map with more clusters than were generated for keyword analysis. Therefore, in order to obtain the same number of clusters and to make it possible to compare the two network maps, the minimum number of occurrences of a term was increased from 10 (the default) to 15.

3. Results

3.1. *Overview of global scientific publications: descriptive analysis*

The PRISMA protocol provided data that enabled descriptive analyses based on the information extracted from Scopus and WOS. These data included geographical distribution, total annual distribution, total number of papers per year, and the major journals in the area of study.

3.2. *Distribution per year*

It resulted that scientific research on the topics selected ["blockchain*" and ("agri-food*" OR "agro-food*" OR "agrifood*" OR "agrofood*")] started very recently, in 2018. However, research interest has rapidly increased since this date (Fig. 3).

In 2018, a single article was published on the topic. In 2019, five more articles were published. The following year produced 18 articles, and by 2021 this had increased to 37. In 2022, the number of articles reached 52. Since the current study dates from the beginning of 2023, publications from that year were excluded. However, the trend that has characterized previous years suggests an increase in articles can be expected for the current year.

3.3. *Geographical area affiliation*

It is also interesting to analyze the distribution of author affiliations across different countries for the 123 selected scientific studies. Fig. 4

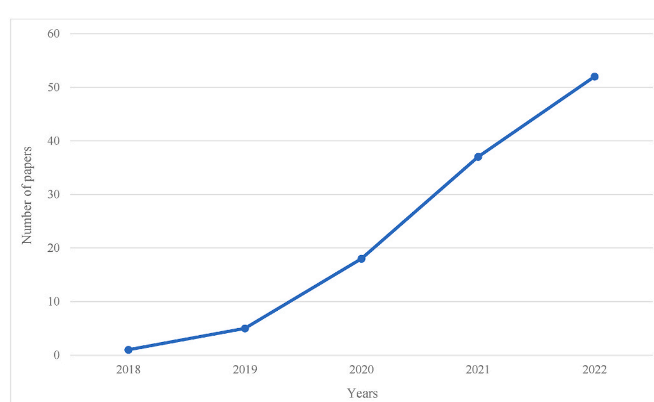

Fig. 3. Number of papers per year containing the selected keywords.

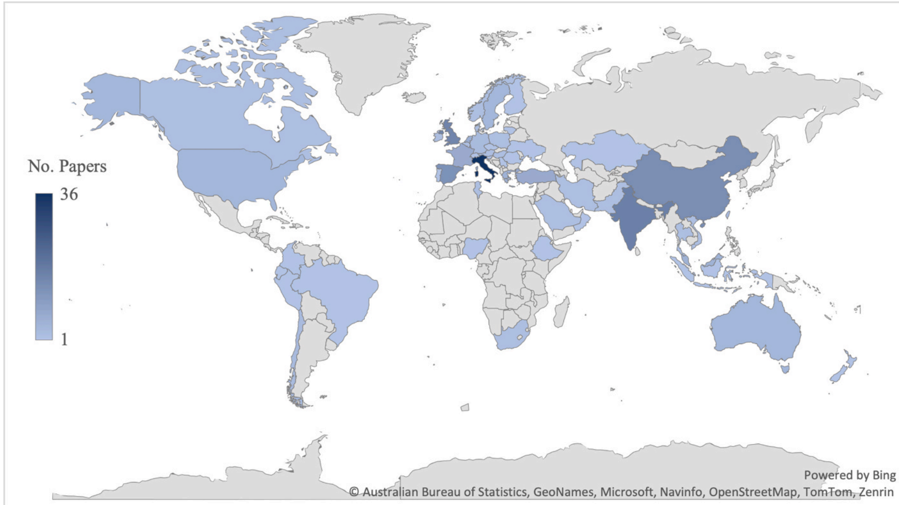

Fig. 4. Countries where the selected studies were conducted.

shows the global distribution of the 94 total author affiliations for the 123 selected publications (without reference to the date). The different colors show the number of studies from each country. In the gray areas, no studies were present. Light blue areas identify areas with a small number of studies. The darker the shade of blue, the greater the number of papers present in that area. The geographic distribution is not uniform because some areas had no or very few author affiliations. These areas include several Central American countries, Greenland, and the Russian Federation.

Globally, Italy produced the highest number of articles (36). This was followed by India (17), by the United Kingdom and China equally (14). Spain produced 13 articles, France and Turkey seven articles, followed by Holland with six and Greece and Malaysia with five. Australia, Sweden, and the United States of America produced four articles each, while Chile, Germany and Taiwan produced three articles each. Austria, Belgium, Canada, Denmark, Hungary, Iran, Ireland, Norway, Pakistan, Poland, Saudi Arabia, South Africa, Thailand, Tunisia, and Vietnam produced two articles each. The countries not listed here (included in Attachment 1) produced only one article each.

3.4. Top journals

Fig. 5 shows the top journals with the highest number of articles published from 2018 to 15 March 2023.

Sustainability ranks as the journal with the most articles published during the reporting period relating to the topic of the current study (17). *IEEE Access* published seven articles, while both *Foods, IEEE Transactions on Industrial Informatics and Frontiers in Blockchain published four articles. Agriculture, Applied Sciences, Journal of Cleaner Production published three articles. Agronomy, British Food Journal, Computers in Industry, Computers and Electronics in Agriculture, International Journal of Advanced Computer Science and Applications, Sensors, Technological Forecasting and Social Change, and Trends in Food Science and Technology all published two articles*. Finally, each of the journals not listed here (included in Attachment 1) published only one article.

The journals mainly belong to the fields of agribusiness and technology. This specific sectorial orientation is consistent with both the premise of the current study and its results.

3.5. Journal ranking

The 123 papers were published in 78 journals. Table 2 shows that one-third of the journals are high-ranking (i.e., between Quartile 1 and Quartile 2). Quartile 1 is the ranking with the highest percentage weight (42.3%), highlighting the merit of journals that have accepted and published work on the application of blockchain to the agri-food sector.

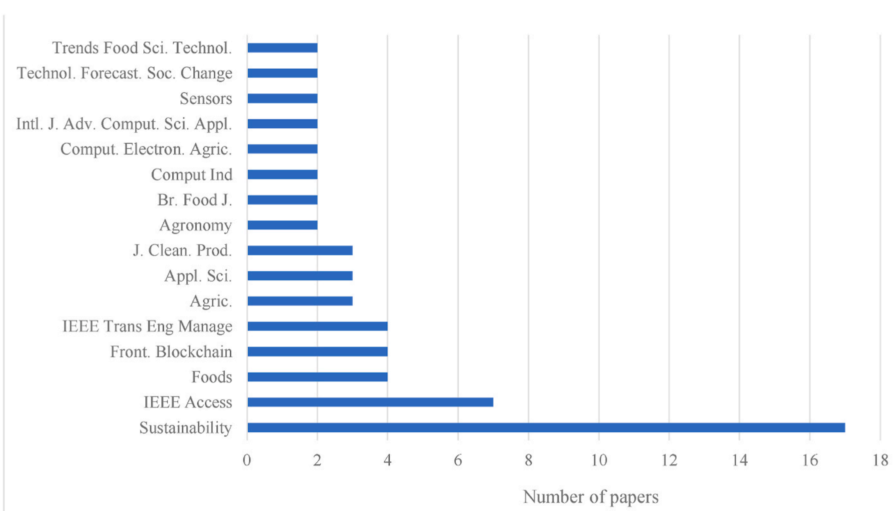

Fig. 5. Top journals in which the selected studies were published.

Table 2
Quartiles and H-Index ranking of journals containing the papers selected.

Quartiles (Q)	Journal		H-Index		
	No.	%	Min	Max	Means
1	33	*42.3*	19	317	127
2	10	*12.8*	10	74	35
3	9	*11.5*	7	101	36
4	5	*6.4*	6	30	18
1–2	9	*11.5*	18	219	102
2–3	2	*2.6*	13	73	43
1–3	1	*1.3*	10	10	10
3–4	4	*5.1*	8	22	15
N.A.	5	*6.4*	1	1	1
Total	**78**	*100*	**1**	**317**	**82**

Source: Adapted from Scimago journal ranking data.

The indication of multiple quartiles in some cases is related to the different scores given to the different subcategories within each journal.

4. VOSviewer results

4.1. VOSviewer co-occurrence analysis results

Fig. 6 shows that the keyword network map aggregated four clusters with a total number of 47 keywords. Fig. 7 shows that the title and abstract term diagram grouped 26 terms according to their co-occurrence relationship (Du et al., 2021), as shown in Fig. 8.

For both procedures, the co-occurrence analysis provided some important data (especially when conducted for the separate clusters).

1) Keyword network map:

Cluster 1 (red) was the most significant with 17 items. It combined the topics of *agriculture, architecture, benefits, blockchain technology, challenges, food, framework, future, impact, industry, information, management, performance, security, supply chain, system,* and *technology*.

Cluster 2 (green) grouped 14 keywords that focused specifically on the agri-food sector: *agri-food supply chain, agri-food supply chains, block-chain, blockchain, food safety, food supply, food supply chain, food traceability, IoT* (Internet of Things), *safety, smart contract, supply chain management, supply chains,* and *trust.*

Cluster 3 (blue color) displayed 12 key terms focused on *artificial intelligence, big data, COVID-19, digital transformation, innovation, internet, Internet of Things, precision agriculture, quality, sustainability, systems,* and *technologies*.

Cluster 4 (yellow color) had the smallest number of items and aggregated only four keywords: *agri-food, smart contracts, traceability,* and *transparency*.

2) Title and abstract map:

Cluster 1 (red color) grouped eight items: *agri-food sector, BCT (blockchain technology), circular economy, company, impact, stakeholder, sustainability,* and *transition.*

Cluster 2 (green color) grouped the following eight items: *consumer, framework, product, quality, smart contract, system, traceability system,* and *transparency*.

Cluster 3 (blue color) grouped seven items: *AFSC (agri-food supply chain), agri-food, big data, industry, innovation, internet,* and *IoT*.

Cluster 4 (yellow color) was the smallest, with three items: *agriculture, development,* and *digitalization*.

4.2. VOSviewer density map results

The density map uses varying color intensities to highlight the concentration or density of each data point. More intense colors indicate higher densities of the items being mapped. By default, the colors range

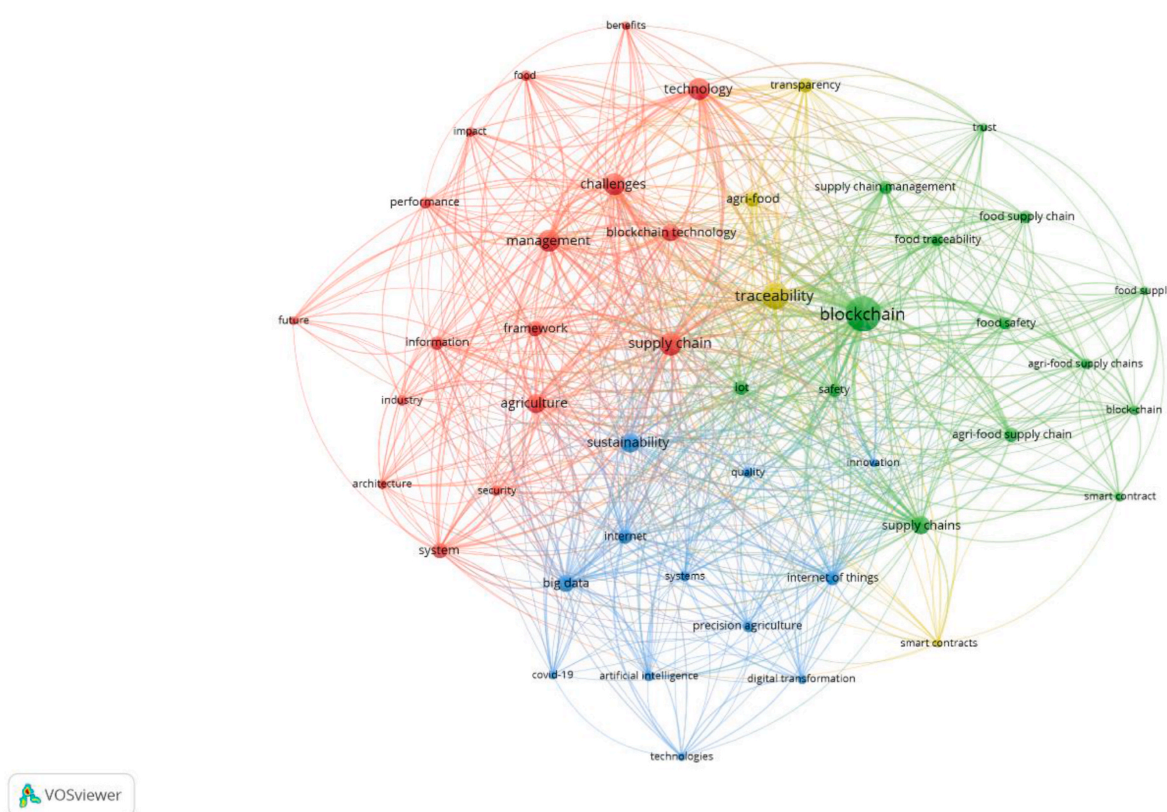

Fig. 6. Keyword co-occurrence map.

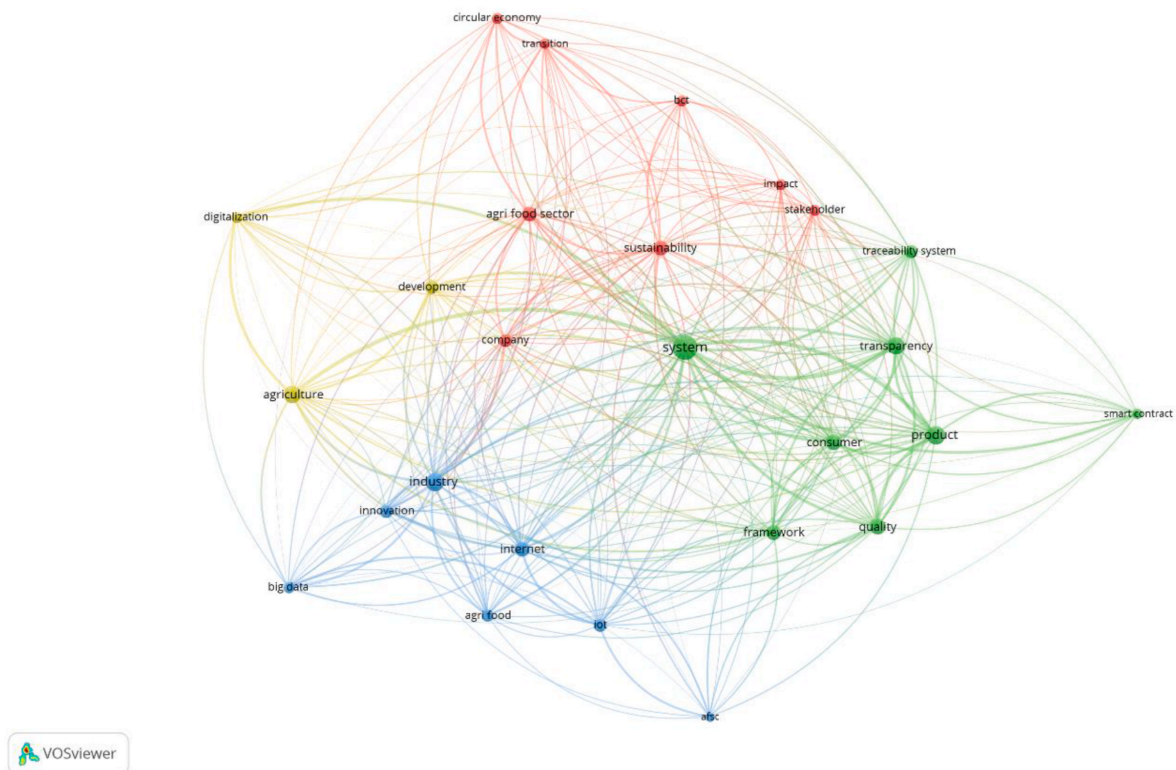

Fig. 7. Title and abstract term co-occurrence map.

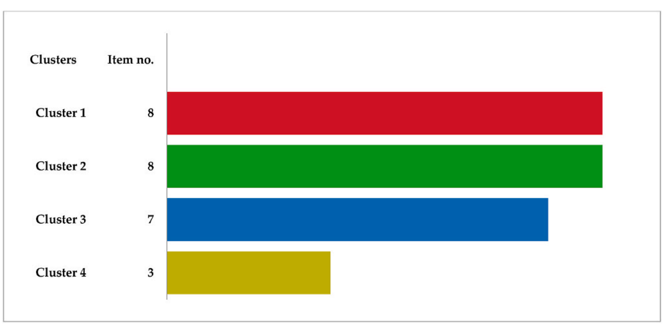

Fig. 8. Cluster analysis for title and abstract.

from blue to green to yellow (Van Eck & Waltman, 2023). Yellow represents a high density of items, blue indicates a small density, and green represents medium density. Using this density representation, it is possible to comment on the analysis at the node level. The density map did not reveal any surprising elements, but confirmed the co-occurrence results (Fig. 9).

4.3. VOSviewer high-frequency keywords analysis

While co-occurrence analysis examines distinct clusters, high-frequency keyword analysis considers all clusters (Liu et al., 2021). This analysis revealed the keywords with the highest frequency across all 47 items. Table 3 displays the most frequently occurring keywords for each cluster, showing each cluster's corresponding color (in accordance with the colors in Table 3) and their occurrence frequency.

Another difference between the two analyses lies in the respective objects they examine. The high-frequency keyword analysis considers the total link strength of the keywords of all clusters, while the co-occurrence analysis looks at links within each separate cluster. Having these two different perspectives and sets of findings enriches the current study.

4.4. VOSviewer total link strength attributes per keyword cluster

The total link strength attributes per keyword cluster required an analysis with a global approach that indicated the total strength of one item relative to that of another item (Fig. 10). When this analysis was compared with the high-frequency keywords analysis, some points of intersection and some differences emerged.

The keywords with the highest frequency and the greatest total link strength were *blockchain* (72 and 345, respectively) and *traceability* (44 and 224, respectively). This confirmed that the traceability of blockchain functionality is central to its use when applied to the agri-food sector. In line with this finding, both *supply chain* and *management* show similar levels of importance in both cases. These results suggest that there is an expectation of a higher level of traceability along the supply chain when applying blockchain to the agri-food sector. The aim is to achieve both a better management system and improved food safety and quality standards.

Challenges was another word with high relevance, highlighting that the scientific literature has tried to identify the potential challenges (Vlachopoulou et al., 2021) presented by the application of blockchain. These challenges could come from the agri-food system itself (e.g., food scandals) or from technical issues with blockchain.

5. Discussion of results from VOSviewer co-occurrence analysis

Many recurring topics emerged from the keyword network map. VOSviewer organized all topics into different clusters (Fig. 11) as follows:

The topics aggregated in Cluster 1 connected the term *agriculture*, in its all-encompassing sense, with *blockchain technology*. A general perspective emerged that addressed some of the research questions of the current study. Specifically, this cluster helped to answer whether the *architecture* of the *technology,* provided by *blockchain,* could constitute a

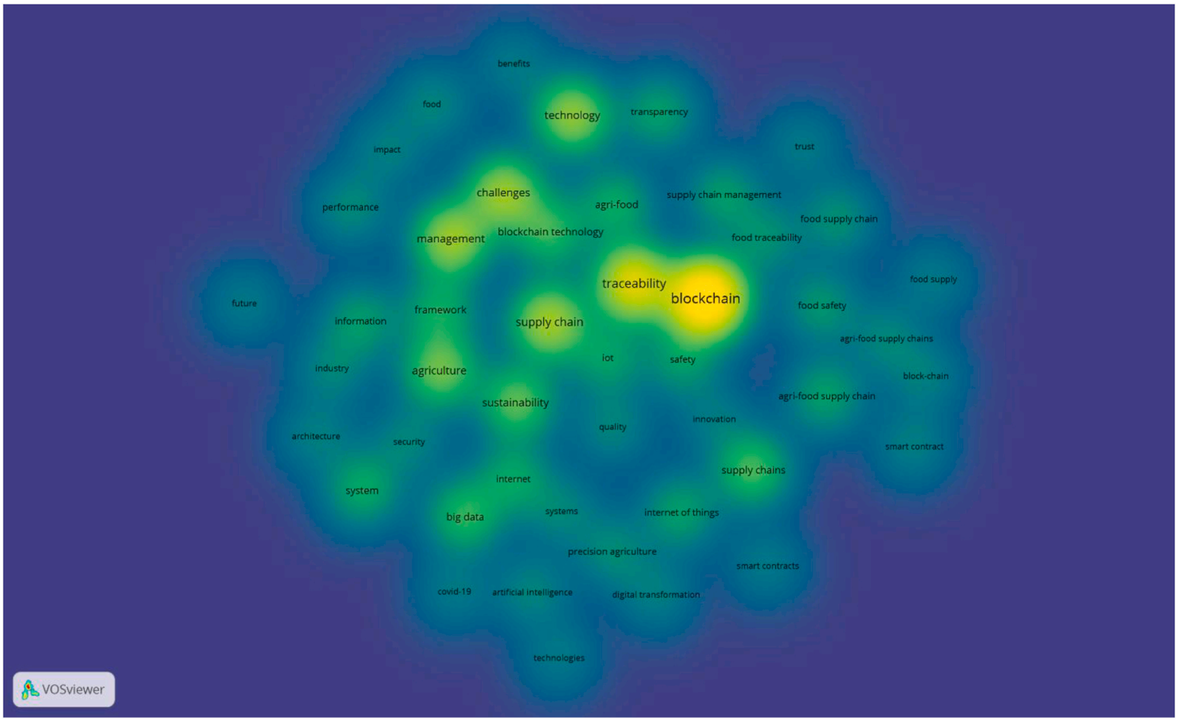

Fig. 9. Density map keywords.

Table 3
High-frequency keywords ["blockchain*" AND ("agri-food*" OR "agro-food*" OR "agrifood*" OR "agrofood*")] as shown via network visualization with VOSviewer.

Keyword	Cluster	Color (*)	Occurrences
Supply chain	1		31
Management	1		30
Blockchain	2		72
Sustainability	3		21
Big data	3		17
Traceability	4		44

Note: The colors in the table are in line with the colors from Fig. 8.

framework for the *management* of agricultural activities. It showed the potential *impact* of its implementation concerning the *performance* of the agri-food *supply-chain* (Adamashvili et al., 2021; Remondino & Zanin, 2022*),* specifically in relation to the words *food* and *security*. It also highlighted the *future benefits* and future *challenges* of blockchain (Bager et al., 2022; Roseiro & Parra-Dominguez, 2020; Shahid et al., 2020).

These results are in line with previous studies aimed at recognizing the drivers and barriers that affect the dynamic capabilities of the food industry (Kamble et al., 2020; Treiblmaier et al., 2021). Some authors have pointed out that although the potential of blockchain has been widely discussed, consideration of the practicalities required for it to function effectively is missing (Feng et al., 2020). Thus, some studies have criticized the emphasis on blockchain construction processes and tried to shift research attention toward a more practical direction by evaluating the effectiveness of the framework through the analysis of performance metrics (Qian, Dai, et al., 2022; Song et al., 2023).

The generic and general approach related to Cluster 1 is also evident in the relationship between the keywords *industry*, *information,* and *system*. blockchain has the specific function of storing diverse information within systems with the aim of creating a more functional and efficient food industry with interconnected management (Sgroi, 2022).

Cluster 2 correlated *agri-food supply chain* (both singular and plural versions) with *blockchain* and *supply-chain management*. Compared with the previous cluster, which provided a general overview, Cluster 2 highlighted more concrete aspects. It focused on the practical aspects of applying *blockchain* technology to the *agri-food supply chain*.

This result is particularly relevant since it supports the existence of current research seeking practical solutions for implementing blockchain into the agri-food system. However, although studies have emphasized the need to identify aspects that would concretely improve agri-food system management, there is still a lack of research reporting this in detail. This suggests that further research should be directed at verifying the effectiveness of agri-food performance improvement. Therefore, further research that incorporates concrete case studies could help to identify and measure specific beneficial aspects (Stranieri et al., 2021).

Other co-occurrences were *food traceability* and *food safety*. The close relationship that emerged between these two aspects expresses the interconnection between implementing actions in the agri-food sector to improve food traceability and the consequent expectation of food safety

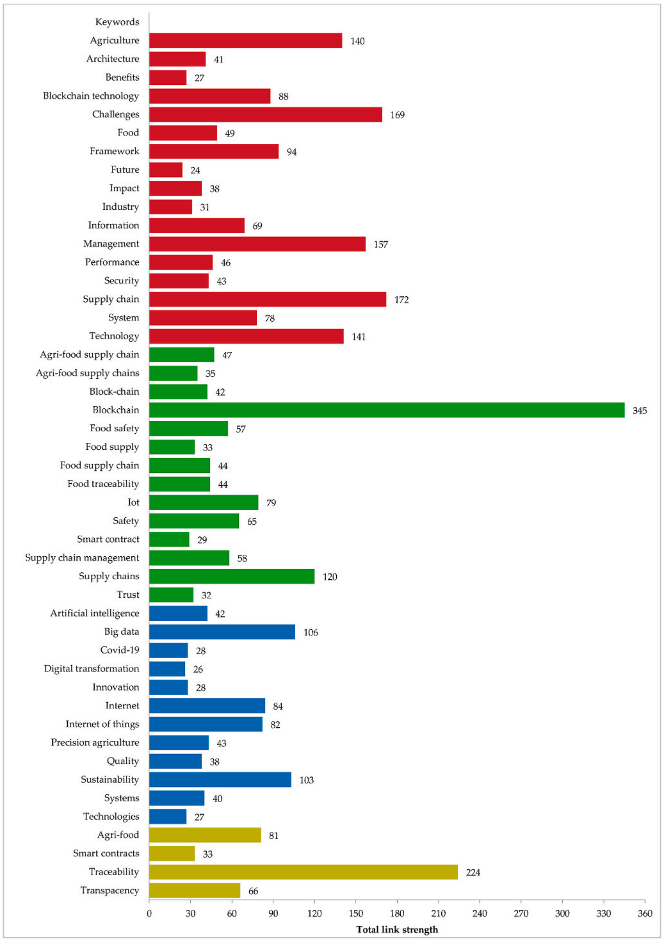

Fig. 10. Total link strength per keyword cluster keyword.

as an output (Demestichas et al., 2020). This is one of the key positive elements to be gained from the application of blockchain technology, as underlined in the introduction section, as it will improve traceability, increase transparency, and address future potential risks in the agri-food supply chain that may endanger food safety (Palocci et al., 2022; Patelli & Mandrioli, 2020).

Some authors have pointed out that, although food legislation is strict and some traceability systems are mandatory (Barge et al., 2020), consumers are not entirely protected against fraud (Marchesi et al., 2022). In recent years, various events have undermined consumer confidence (Kampan et al., 2022). These include food safety scandals regarding mad cow disease, horse meat, toxic milk powder, genetically modified food, and trench oil (Zhao et al., 2019). In line with previous studies, the current study suggests that better *supply chain management* can increase consumer trust (Feng et al., 2020) after outbreaks of food-borne illnesses (Dey et al., 2021). This result indicates that supply chain management systems require enhancements. It also suggests that besides the legal and political intervention, also food business operators need to take concrete actions.

Improving consumer trust through blockchain by clearly tracing production processes, distribution, and sales channels (Liu, Zhang, & Dong, 2022) could result in increased purchase willingness (Marchese & Tomarchio, 2022). In this sense, blockchain could make agribusiness more competitiveness (Ancín et al., 2022; Ye et al., 2022). Therefore, traceability and transparency may represent the differentiating elements between firms that do not offer these added values and those that meet consumer and market requirements (Ayed et al., 2022). This finding is particularly important since it addresses the research question concerning improvement in the performance of the agri-food system. By automatically storing and encrypting data in a decentralized way (Pakseresht et al., 2023), blockchain functionality ensures the authenticity of the information embedded in the system. By tracing the movements of food commodities, blockchain could raise the level of transparency of the agri-food system and eventually increase consumer confidence (Lezoche et al., 2020).

IoT also emerged in this group (Yadav et al., 2023). The combined use of blockchain with devices provided by IoT technology may enhance the functions of blockchain and may make its application to agri-food easier and more effective (Saurabh & Dey, 2021). Furthermore, IoT devices set the foundation for blockchain-based applications (Pincheira et al., 2022; van Hilten and Wolfert, 2022; Rana et al., 2021). As well as storing a lot of information, they can intercept factual data from agribusiness activities and transfer it into the blockchain (Haro-Olmo et al., 2021). Some authors have underlined that this is a centralized server–client paradigm and so the reliability is dubious (Feng et al., 2020). However, other studies have asserted that the way in which information is stored and transmitted within blockchain is very useful at all stages including production, processing, distribution, and consumption (Feng et al., 2020). The integration of IoT technology functionality with that of blockchain can help overcome the problem of information asymmetry. The centralized information model (managed by a third party with respect to members of the supply chain) could then shift toward a decentralized collection and storage model (Tagarakis et al., 2021). In other words, IoT enables decentralized applications (Pincheira et al., 2022) and could help solve the issue of monopolistic management of information in the agri-food sector. As emphasized in previous studies (Marchesi et al., 2022), decentralization can reduce operational costs, time, and errors. It can also improve the monitoring of information, leading to higher food quality and reduced food loss (Echegaray et al., 2022).

In Cluster 3, the word *innovation* (Calafat-Marzal et al., 2023) was linked to *digital transformation* (Dal Mas et al., 2023). The fact that *sustainability* also appeared is unsurprising (Köhler et al., 2022; Kumar et al., 2022) and is in line with recent European Union policies that push toward attaining greater sustainability (both environmental and otherwise) through innovative digital solutions (Firsova & Abrhám, 2021; Hassoun et al., 2022; Mercuri et al., 2021). This supports the idea that digitalization could provide concrete support the agri-food system in the ecological transition (Amentae & Gebresenbet, 2021; Luzzani et al., 2021).

It appears that introducing technological innovations such as blockchain into the agri-food system (Cricelli et al., 2024; Dadi et al., 2021) could bring about a digital transformation that would eventually create a competitive advantage and ensure greater sustainability. This is another concrete and positive performance output deriving from the application of blockchain to the agri-food system.

Furthermore, innovation and the development of advanced technologies may offer greater support in crisis events, as was demonstrated during the COVID-19 pandemic (Qian, Yu, et al., 2022). On the one hand, the pandemic increased the need for automated solutions (Oruma et al., 2021) due to worker shortages (Calafat-Marzal et al., 2023; Yadav et al., 2021); on the other hand (Ancín et al., 2022), it accelerated the move toward increased automation and digitalization options (Echegaray et al., 2022; Galanakis et al., 2021).

In the wake of this digital transformation came *artificial intelligence,* an innovation that is paving the way for a revolution in many economic systems (Calafat-Marzal et al., 2023). It shows enormous potential in supporting managers to make difficult and complex decisions, and much of its potential is yet to be explored. Within this framework, the possible applications of artificial intelligence in mitigating the risks inherent in agricultural activity are particularly interesting.

The term *precision agriculture* emerged together with the use of *internet* connection, data analysis and the *technologies* of the *IoT*. The practical interactions of the latter could bring about a big step forward in the management of a multitude of business data, whether strictly

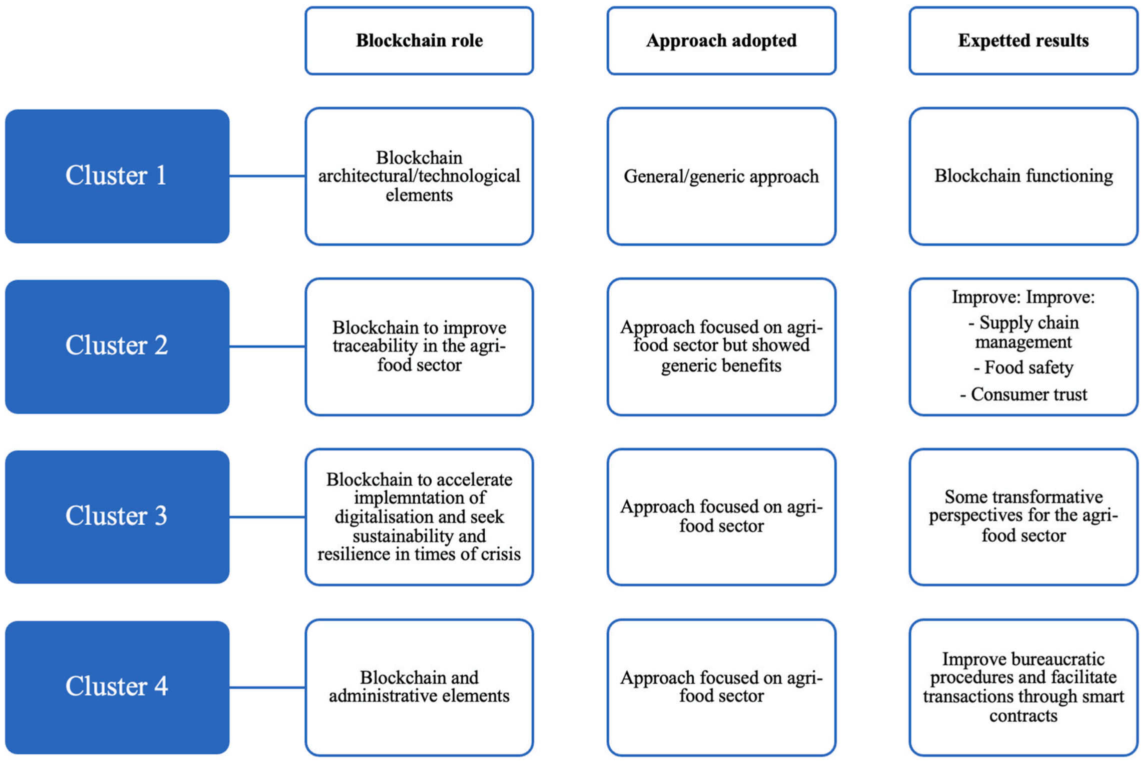

Fig. 11. Cluster perspectives.

technical, specific to agribusiness, or purely related to administration and accounting (Ayed et al., 2022).

Unsurprisingly, another item that appeared was *big data* (Liu et al., 2020, 2022), which refers to large, fast, and complex data. Such data are compatible with innovative technologies (specifically with blockchain), and traditional techniques cannot process and manage them (Ayed et al., 2022). The innovative transformation that these technologies may bring to the agri-food system could improve *quality* within this system (Boller et al., 2023; Feng et al., 2020), which was another word found in Cluster 3. In particular, blockchain can interact with the abovementioned technologies (Rejeb et al., 2022; Scuderi et al., 2022) and contribute to improving quality along the agri-food supply chain, providing traceability and transparency with respect to food origin and safety, production systems, supply chain, and the time a product takes to go from farm to fork (Feng et al., 2020; Scuderi et al., 2019; van Hilten, Ongena, & Ravesteijn, 2021). Easy and effective access to specific economic databases (e.g., historical price series and prices in different markets) can be extremely useful for both farmers and consumers.

Cluster 4 displayed one of the most recurrent word combinations in the 123 papers selected when discussing blockchain and agri-food topics: *traceability* (Pakseresht et al., 2022) and *transparency* (Krzyzanowski Guerra & Boys, 2022). These are two of the main motivations for agri-food operators to apply blockchain technology (Feng et al., 2020; Saurabh & Dey, 2021). Because transparency is an attribute that supports traceability, these concepts go hand in hand. Without the guarantee of transparency, traceability information loses its value. The attribute of transparency in turn reinforces consumer confidence. The demand for transparency along the agri-food chain comes from both customers and authorities (Liu et al., 2022; Marchesi et al., 2022) and covers a wide variety of information, such as provenance, suppliers, production, and transport conditions (Salehi Sarbijan and Behnamian, 2023).

Traceability, which is a feature of blockchain, could help rebuild consumer trust for several reasons. For example, it helps perform effective risk assessment along the production chain (Kampan et al., 2022); it also addresses counterfeiting concerns (Egwuonwu et al., 2022; Oguntegbe et al., 2022) and offers support in fraud prevention (Singh & Sharma, 2023). Consequently, it can create a higher perception of safety (Zhai et al., 2022).

Both consumers and governments require more guarantees in the face of food-safety and resource-scarcity challenges (Srivastava & Dashora, 2022; Zheng et al., 2023). The food scares of the early 2000s resulted in demands for more reliable and efficient management and processes in the agri-food supply chain (Kramer et al., 2021). Blockchain may allow a more prompt response to food scandals and accidents by guaranteeing a comprehensive overview (Pincheira et al., 2022) of each phase of product harvesting, processing, and distribution from farm to fork (Marchese & Tomarchio, 2022).

Where business systems lack traceability and transparency, blockchain technology may intervene to deliver key information (Ayed et al., 2022) about the origin, processing methods, quality, and sustainability of practices adopted across the entire life cycle of food products (Marchese & Tomarchio, 2022). This technology may also encourage operators in the sector to use voluntary certification procedures.

Traceability and transparency of data history may regard also aspects other than specifically related to food activities. The ability to trace business transactions, distribution channels, costs, and other relevant data points can have significant value (Marchese & Tomarchio, 2022). This explains the close relationship that emerged between the words *traceability* and *transparency* with *smart contracts*. While *traceability* was linked to the word *food* (hence *food traceability*) in Cluster 2, in Cluster 4 it was linked to concepts beyond the characteristics of the product and its provenance. Here, it referred to bureaucratic management systemic aspects, particularly those relating to the structures of firms. It also referred to the relationships and interactions that characterize different firms and enable the concrete performance of agri-food activities, such as the state of farms, inventories, and contracts (Samoggia & Beyhan, 2022).

In this context, smart contracts emerge, i.e. a predefined set of rules that automatically generates transactions, makes decisions, and stores data (Hisham et al., 2022). As “a set of promises, specified in digital form (that are immutable once entered), including protocols within which the parties perform on these promises" (Chandan et al., 2023), a smart contract can build trust among agri-food stakeholders by enabling tracking and control of long-term agreements (Song et al., 2023). The immutability of blockchain supports smart contracts (Fu et al., 2020; Shahid et al., 2020) as a trust-building tool for business partners that cannot be modified once executed (Antonucci et al., 2019).

The exploitation of the co-occurrence analysis of title and abstract showed similar results and novelty elements in comparison with the ABS co-occurrence analysis. Cluster 1 produced the following key terms: *agri-food sector*, *BCT*, *circular economy*, *company*, *impact*, *stakeholder*, *sustainability*, and *transition*. This cluster presented points of assonance with Cluster 3 of the keywords diagram. It shows that blockchain, along with other supporting technologies, could facilitate the transition toward a sustainable agri-food system. In particular, it suggests that blockchain could accelerate the implementation of a circular economy (Pakseresht et al., 2022). Blockchain's attributes of traceability, transparency, security, durability, and integrity can serve not only the stages of the supply chain but also those that occur after consumption (Yontar, 2023). The recycling food waste and scraps activities can enhance resource reuse productivity, which is the basis of the circular economy paradigm (Kowalska & Bieniek, 2022). The reduction of asymmetric information may help reduce food loss.

Cluster 2 presented some similarities with Clusters 2 and 4 of the keyword diagram, in which the move toward the creation of a traceable and transparent system was linked to both quality and smart contracts. Smart contract support is not only related to the output of the food supply chain (i.e., food) but also to systemic management aspects.

Cluster 3 of both the keywords diagram and the title and abstract diagram showed notable assonances with the same implications discussed. Indeed, there was a strong occurrence of the terms *AFSC, agri-food, big data, industry, innovation, internet,* and *IoT*, (Misra et al., 2022).

Cluster 4 contained similarities to both Cluster 1 and Cluster 3. The terms that recurred most frequently were *agriculture*, *development,* and *digitization*. The theme of digitization (Juan, 2020) and its development in the general context of agriculture (van Wassenaer et al., 2021) was also addressed. In particular, a move toward smart agriculture emerged (Alonso, Sittón-Candanedo, García, Prieto, & Rodríguez-González, 2020; Calafat-Marzal et al., 2023; Taş & Aylak, 2022).

6. Limitations and further research

This study is subject to several limitations. For example, the keywords ["blockchain*" and ("agri-food*" OR "agro-food*" OR "agri-food*" OR "agrofood*")] were selected on a subjective basis. The final extraction and selection (following the PRISMA protocol) resulted in 123 papers, which could be considered a large number given the sectorial themes addressed.

Furthermore, linking the research on blockchain to the entire agri-food supply chain management had the consequence of excluding other perspectives. Further investigation may address these limitations and explore several other specific aspects. For instance, it may be relevant to describe blockchain's functioning potential in relation to specific stages of the agri-food supply chain, elaborating potential new business models, decision support systems, and governance approaches to adapt blockchain technology to the agri-food system (Tiscini et al., 2020).

Future research could also aim to verify the effectiveness of agri-food system performance improvements. Although some existing studies have emphasized the need to identify aspects that would concretely improve agri-food system management, research verifying these aspects is lacking. Therefore, research that includes concrete case studies could be developed to identify and measure the specific beneficial aspects (Fig. 12).

7. Conclusion

Blockchain technology has emerged as a subject of scholarly attention within the last four years (Niknejad et al., 2021). During this time, there has been a steady increase in the number of articles on the topic. The present meta-analysis has confirmed this trend and found evidence of distributed (although not uniform) authors' affiliation across the world.

Blockchain is among new technologies that may bring countless benefits if implemented in the agri-food sector. This is due to its ability to implement traceability systems in an automatic, transparent, immutable, and visible way for all members without the need for third parties to manage the information in a centralized manner. Among the topics identified by the current study, the most frequently discussed to date has highlighted the expectations regarding the application of blockchain to the agri-food sector (and, in some cases, the way it has already been utilized).

The goal is to combine blockchain's functionality with the latest technological developments in order to enhance the management of agri-food activities along the supply chain. This development is likely to achieve greater food safety and quality through the functions of traceability and transparency. It may also increase consumer confidence, which was undermined in the wake of the food scandals of the early 2000s.

Alongside the potential offered by blockchain, some challenges for an effective implementation to the agri-food system emerged. However, agribusiness operators must address and overcome these in practice (Rocas-Royo, 2021). Further research might explore and provide a range of suggested steps that the operators might take, maybe conducting specific case studies.

Some previous studies have also highlighted misgivings about the real benefits that blockchain can bring, reporting that some firms and managers have expressed doubts about the benefits of implementing blockchain within supply chain management. This could be attributed to the complexity of the agri-food sector's lines of business, which involve many different actors and stakeholders. Such complexity may generate mistrust about the effective storage and management capacity of blockchain. It may also reflect a lack of inclination from actors and stakeholders toward use of the technology.

It is not surprising that the themes featuring prominently in the literature (together with blockchain) are those that address big data, artificial intelligence, and precision agriculture (Liu et al., 2021). All these themes relate to the aim of achieving a digital transformation of the various functions of the agri-food sector in order to improve service automation and create a new economic environment for smart firms (Klerkx et al., 2019; Villari et al., 2020).

In this context, there is a lack of in-depth research about the impact of blockchain on the business and corporate governance models of agribusiness (Dal Mas et al., 2023). Questions to be answered include:

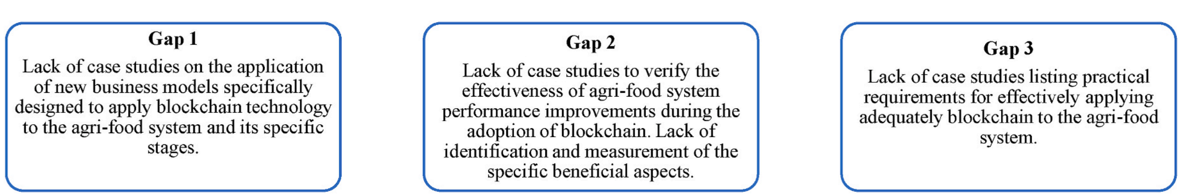

Fig. 12. Research gaps in the literature.

Which agri-food chain management practices and business models may favor the implementation of blockchain technology? What changes need to be made to existing business models? Is it necessary to develop new ones?

In conclusion, it would be worthwhile to develop more in-depth studies that could shape new governance approaches and new business model proposals. Direct interviews on this issue with operators in the agri-food sector would be valuable in gaining their point of view. Furthermore, such interviews could be used to obtain possible suggestions about best practices that could aid in setting up new theoretical frameworks for appropriate business and governance models.

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Data statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declaration of generative AI in scientific writing

None. The authors have nothing to declare for this manuscript.

Submission declaration and verification

This work has not been published previously, that it is not under consideration for publication elsewhere, that its publication is approved by all authors.

CRediT authorship contribution statement

Carla Zarbà: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation. **Gaetano Chinnici:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Agata Matarazzo:** Writing – original draft, Supervision, Conceptualization. **Donatella Privitera:** Writing – original draft, Supervision, Conceptualization. **Alessandro Scuderi:** Resources, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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