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Exploring the role of blockchain technology in modern high-value food supply chains: global trends and future research directions

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Abstract

Trust, safety, and quality are among the most important factors in the agri-food supply chains. Traceability is a powerful tool to ensure them, but implementing a transparent and effective system is a complex operation. As a result, innovative systems, like blockchain, could be introduced. Although research on its impacts in the agri-food is recent, the literature appears fragmented. The objective is to investigate the studied aspects of the blockchain adoption in agri-food, with the purpose of retrieving meaningful considerations about the current state of the art about strategic high-value supply chains, such as wine and olive oil, particularly subjected to fraudulent behaviors. A productivity measurement was applied to retrieve the evolution of the number of documents through the years, the most productive countries, the sources, the research areas, and the most significant papers in terms of number of citations received. To understand the research trends, a co-occurrence analysis was employed. Results show that most of the existing studies focus on the role of blockchain in the resolution of some critical issues as food safety and frauds. While wine is currently an emerging sector in which this approach can be implemented, olive oil still needs more attention. In both cases, blockchain could potentially help to support the profitability and sustainability of the production. The research underlines the importance of focusing on the environmental and social dimension of the blockchain phenomenon and the use of technology to improve the efficiency of agri-food chains and reduce waste and resource use.

Keywords: Traceability, Transparency, Agri-food, Bibliometric review, Wine and olive oil, Digitalization

Introduction

Transparency is a prerequisite in today's modern food supply chain (FSC). Transparency helps reduce information asymmetry among stakeholders and allows a relationship of trust to be established between the company and consumers, consequently strengthening brand reputation and organizational legitimacy in the social system (Fiore 2016; Carter and Rogers 2008). As a result of a succession of scandals (the Irish pork crisis, BSE, and dioxins to name a few) and food frauds, it is necessary to redefine effective

traceability systems capable of satisfying the growing consumer demand for safe and quality products (Stranieri et al. 2021; Saberi et al. 2019; Van Rijswijk and Frewer 2012). However, defining and implementing a transparent and effective traceability system for the FSC is a complex operation, mainly due to its many operatives and to the lack of two-way information flows between them (Astill et al. 2019). In addition, various existing traceability systems that guarantee information operate only regarding some aspects or are accessible only to some members of the supply chain (Galati et al. 2021; Stranieri et al. 2021). These barriers have led the food producers and various FSC operators to develop new skills and solutions to guarantee effective information flow and a completely transparent process. In this context, the adoption of innovative technological solutions, including blockchain technology (BCT), has the potential to ensure the transparency and verifiability of the entire process by providing final consumers with additional guarantees regarding the quality and safety of the purchased products (Konfo et al. 2023; Bastian and Zentes 2013). BCT can be understood as a digital ledger that uses the internet to release a distributed and secure database model along the supply chain; each participant in BCT verifies and confirms the data records entered by other members through an established consensus protocol (Raikwar et al. 2019; Smith et al. 2016). The decentralized and distributed ledger logs transactions in chronological order to create permanent and tamper-proof records (Gligor et al. 2022), ensuring a high level of transparency for all transactions (Nakamoto 2008). The adoption of BCT in the food chain, in line with the operating principles of technology, makes it possible for all operators to obtain permission to access the block database; thus, they have reliable data on the origin and state of foods in carrying out their transactions.

Over recent years, some studies have explored the potential of BCT in the FSC. These have emphasized how implementing technology enhances transparency, ensuring better accessibility, availability, and sharing information relating to different phases of the supply chain (Dal Mas et al. 2023; Marchesi et al. 2022; Gligor et al. 2022; Stranieri et al. 2021). The transparency and verifiability of information on various processes eliminate the risk of opportunistic behavior among supply chain operators, bearing the possibility of reducing food counterfeit and adulteration (Tiscini et al. 2020; Astill et al. 2019). By its intrinsic characteristics, blockchain has the potentiality to increase confidence in the information provided to consumer, in terms of food safety, traceability, and transparency (Martínez-Castañeda and Feijoo 2023). Furthermore, the success of BCT implementation is linked to a better understanding of the appropriate technological solution, the opportunities to integrate other IoT technologies, and the type of data to be shared (Compagnucci et al. 2022; Saurabh and Dey 2021). In addition, as several authors as emphasized, BCT could help improve the sustainability of the production by operating on tracking food waste production, one of the main issues in reaching a circular economy (Li et al. 2023; Pakseresht et al. 2023, 2022; Yontar 2023; Hassoun et al. 2022). Notwithstanding the increasing interest, the literature about this phenomenon is not consistent, focusing only on certain potentialities of this technology, and not clarifying the categories of research area that are studied. Therefore, the potential advantage for agribusiness requires further conceptual and holistic investigations. In this regard, it is essential for innovation-oriented practitioners to clarify the role that BCT can play in food chains, especially those with high added value, and whether this emerging

technology can contribute to sustainability. Indeed, nowadays, comprehensive studies about high-value chains are missing. Given the growing interest in the adoption of BCT in the food supply chain and considering the above-mentioned gaps, the present study aims to answer the following research questions: "Which aspects of the adoption of BCT in the agri-food chain have been studied? Which implications of BCT have been the focus of the economic literature? To what extent does the literature focus on strategic supply chains, such as wine and olive oil, which are more exposed to food fraud? What are the possible implications of the adoption of BCT for the operators of these two supply chains?" For the scope of the study, a productivity measurement was applied. To understand the research themes in BCT applications in the food sector, a bibliometric tool, namely co-occurrence analysis, was employed. The reminder of the paper is organized as follows. "Methodology" Section introduces the adopted methodology, based on a productivity measurement and a bibliometric analysis. "Results and discussion" Section shows and discusses the main results of the two methodological approaches. Finally, Sect. "Conclusions and future research directions" draws the conclusions about BCT adoption in the agri-food sector and high-value chains and presents the conclusions and the future research directions.

Methodology

The research was carried out in two different databases, Scopus and Web of Science (WoS), to expand the range of eligible documents. The two platforms were chosen as they are recognized as covering a notable range of high-ranking journals and peer-reviewed articles of high quality (Barbosa 2021; Niknejad et al. 2021; Rejeb et al. 2021a). First, an appropriate sequence of keywords, based on the research objectives, was carefully selected. As the research topic is new, the search string was kept as generic as possible, to try to include all the published works. One group of words used referred to the technology, while the other concerned the agri-food sector. For this purpose, the search string using Boolean operators ((blockchain OR "block chain") AND (agr* OR food)) was applied for title, abstract, and keywords to examine the structure and substance of BCT in food and agriculture literature. Data collection was performed for each database separately, using the same methodological criteria, on November 2, 2022. The initial number of documents was 4,653, to which a series of filters was applied. Papers were screened and kept according to the type of publication (article, review, and book chapter), the language (English), the availability of the full text, and the consistency with the objectives of the study (eligible documents). Finally, overlaps between the two databases were checked and maintained only once. To avoid subjective decisions, four authors performed the screening, keeping 79 documents from Scopus and 400 from WoS. Since this moment, the two databases have been considered as one (November 11, 2022) (Fig. 1) (Agnusdei and Coluccia 2022; Chiaraluce et al. 2021).

For the scope of the study, a productivity measurement was applied to retrieve the evolution of the number of documents through the years, the most productive countries, the publishing sources, the research areas, and the most significant papers in terms of number of citations received (according to the two chosen databases). A productivity measure is a meaningful tool to assess the current position of a specific theme in literature, as well as its research trends and evolution over time, to

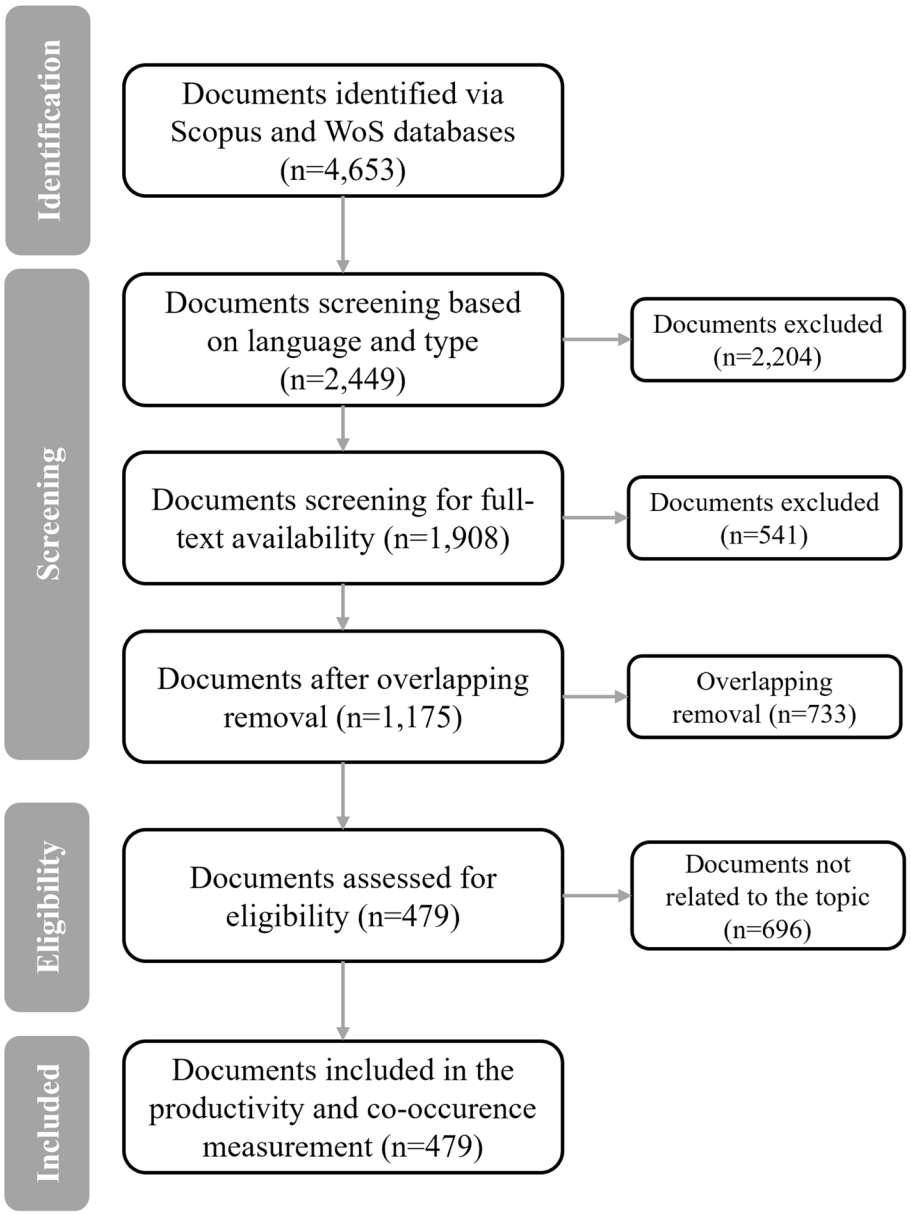

Fig. 1 Document selection explanation based on the PRISMA methodology

contextualize a specific topic. To understand the research themes in BCT applications in the food sector, a bibliometric tool, namely co-occurrence analysis, was employed. Bibliometric reviews are not new instruments for exploring BCT adoption in the agri-food sector (Mohapatra et al. 2023; Abideen et al. 2021; Lwesya and Achanta 2022; Wamba and Queiroz 2020). Co-occurrence was studied through VOSviewer software (1.6.18). VOSviewer is an open-access tool that can be used to create, visualize, and explore maps based on any type of data. The map is a visual depiction of the subject showing the relation among the items in the field. In the network visualization, circles represent the items, grouped in clusters. Clusters are non-overlapping; thus, an item may belong to only one cluster (Van Eck and Waltman 2022). Maps normally guide

the analysis, but field expertise is still required for proper interpretation (Heersmink et al. 2011).

Results and discussion

Publication years

Figure 2 presents the evolution of the number of published papers about BCT applications in FSC over the years, from 2017 to 2022. A growing trend, with an exponential increase, is recognized, revealing a consistent raise in interest of scholars in this field.

Blockchain was introduced in 2008 for the bitcoin system; however, it is currently under study for the implications in different contexts like finance and banking, industry 4.0, health system, and tourism (Ozdemir et al. 2020; Alladi et al. 2019; McGhin et al. 2019; Guo and Liang 2016). In recent years, the attention moved also toward the agricultural and food sector, with several authors starting to investigate how this innovative group of technologies could solve some problems of the supply chain, namely food safety, traceability issues, and frauds (Singh and Sharma 2023; Galati et al. 2021; Demestichas et al. 2020; Casado-Vara et al. 2018). When it started in 2017, the publications focused on ICT-applications for smart agriculture (Gu et al. 2017; Lin et al. 2017) and for supporting cooperatives for a global commonwealth (Manski 2017). An increase of more than 300% of the available documents took place between 2019 and 2022. The most recent papers focus on the specific application of BCT for traceability. Such papers demonstrate its potential for providing more transparency, veracity, and trust in food information (Feng et al. 2020; Galvez et al. 2018; Kamath 2018; Lin et al. 2018). There is a continuous process of implementation of traceability systems. Indeed, since it became mandatory for the food supply chain by EU Regulation 178/2002 ("General Food Law"), companies are motivated to improve the process of track and trace not only to comply with compulsory regulations, international standards, and certifications requirements, but also to implement marketing strategies and programs. The latter aims to guarantee

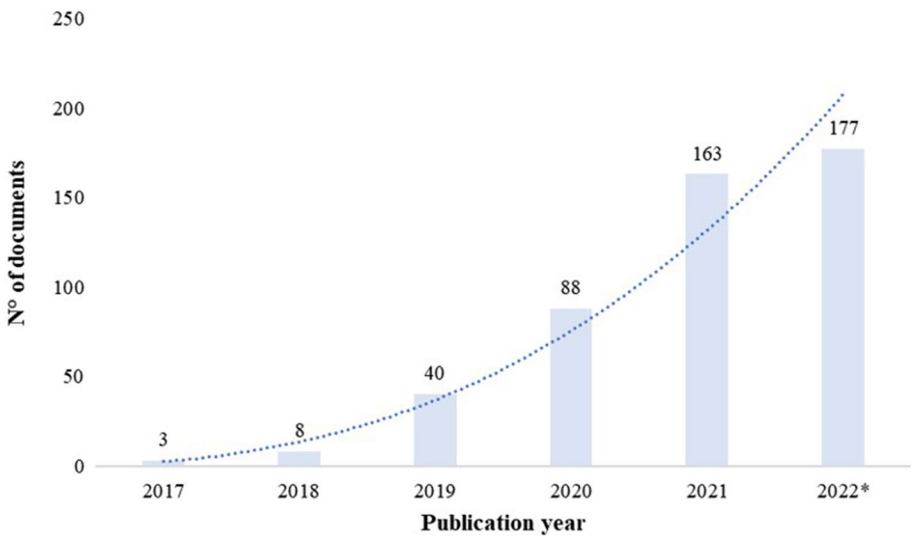

Fig. 2 Evolution of the number of published papers about BCT applications in agri-food indexed in Scopus and WoS. *Papers published as of December 2022

the origin, identity, and quality of a product, and necessarily to react against the diffusion of sanitary outbreaks with efficient methods (Dabbene et al. 2014). Its intrinsic characteristics (immutability, transparency, distribution, decentralization) put the BCT in a privileged position as the future standard for a safe traceability system. Nonetheless, to become the common paradigm, global agreement on data standards and governance should be realized, as well as key technical issues, like scalability and privacy mechanism, to protect the users' data (Yang et al. 2023; Pearson et al. 2019).

Publications categorized by geography

Considering the number of publications per country, China gains the top position in the list, with 150 documents, followed by a substantial gap from India (80) and the UK (57). Even if countries like Italy and Spain devote a particular attention to the protection of their agricultural system and food production, the developing countries are the ones focusing more on innovation and research in agri-food, as reported by Niknejad and colleagues (2021). This can be explained by the fact that in those countries, where it is often difficult to implement efficient public policies, the use of the blockchain in agricultural supply chain, land registries and financial services can help the sector to achieve food security and rural development goals and promote sustainability (Rana et al. 2021). Moreover, to be competitive on a well-established global food market, developing economies need to upgrade their food supply chain using digital technologies to guarantee high-quality production and the compliance with business partners' legislation, to ensure a fair and competitive trade (Hasan et al. 2023).

Publishing sources

Considering the top ten journals with the highest number of published documents in BCT applications in the FSC, altogether these sources published 156 articles, representing 33% of the 479 papers in the database. In the top spots, sustainability is the most present with 36 publications, followed by IEEE Access (33), Journal of Cleaner Production (25), and Foods (10). The distribution of articles indicates that BCT research has been published in a wide range of top-tier journals, whose diversity reflects its interdisciplinary nature and the versatility of its applications in the FSC. It should be observed that, if we search in literature a topic that, by its nature, is predominantly engineering as BCT, the first source of information is a miscellaneous journal like Sustainability. IEEE Access, a high-tier journal dedicated to advancing technology, is in the second position only. This can be explained by the fact that, due to the choice of the authors, papers of a purely engineering nature, focused on the characteristics and technical specs of blockchain and not on its application in agri-food, were deliberately removed during the filtering process, as they were not considered relevant for the analysis.

Main research areas

In this aspect, the engineering nature of the topic emerged: Computer Science (160 papers), Engineering (159), and Telecommunications (64) are among the most exploited fields of study according to Scopus and WoS classification. Nevertheless, the multidisciplinary approach to this topic is further underlined by the fact that Business, Management and Accounting (90), and Environmental Sciences (87) are also among the research

areas that are dealt with in the papers. The environmental issue is quite controversial: even if blockchain is mostly considered a potential positive contribution to sustainable development goals (Parmentola et al. 2022), the mechanism of proof of work is generally judged to be high-energy demanding, thus being not environmentally sustainable. The current opinion optimistically praises the potential societal, environmental, and economic benefits behind this technology; however, the background is not necessarily positive, and in-depth study is still required to cope with this problem (Schinckus 2020). In addition, the implementation of a BCT system for different purposes (smart farming and traceability above all) requires investments, in which the costs depend on the type of chosen blockchain (public or private, permissioned or permissionless, consortium blockchain), the number of nodes, the amount of data stored. The contribution of the economics studies is essential to guarantee the economic sustainability of the technology in the long term and to attract potentially interested stakeholders. Entrepreneurs need to assess the increase in the costs of their production, as well as the compliance with the current policies about data treatment and food production; consumers require more information about this technology, if it affects the products they purchase in terms of quality and safety, and if it implies a defensible increased cost.

Methods and most cited papers

Dealing with a substantial database allowed to investigate the methodologies mostly employed in literature when referring to BCT applications in the FSC. Of the 479 documents, 79 are reviews. Conceptual articles represent the most common studies of the 400 other documents, and they are used to create new knowledge not derived from data in the traditional sense, but rather build on theories and concepts that are developed and tested through empirical research (Jaakkola 2020), proposing theoretical implementation of BCT in different supply chains. These studies are followed by empirical research based on the case study method, to explore the adoption's barriers and drivers, as well as advantages and disadvantages, of the technology in the FSC. Among the quantitative methods, it is notable that also consumer analysis is exploited to understand the behavior toward the technology and the willingness to pay for products embedded with the BCT characteristics. As business and management are among the most investigated research areas, several management tools are present in the considered literature, such as Multi-Criteria Analysis, ISM-DEMATEL models, structural equation and finance modeling, SWOT analysis, Delphi methodology, Stackelberg, and other kinds of business games. Beyond the methods, to address the research, it is essential to identify the papers considered as milestones for the topic. This can be done by searching for the most cited articles in the database. Table 1 presents the ten most cited papers according to the number of citations considered by both Scopus and WoS. The table also reports the methodology employed in the studies.

Among the most cited papers, five of them are reviews discussing BCT applications in the FSC. This is linked to the fact that a literature review is a relevant instrument for tracking the state of the art on specific subjects, helping to provide an overview of areas in which the research is disparate and interdisciplinary, synthesizing research findings to show evidence and to uncover areas in which more research is required (Snyder 2019). In particular, these reviews are focused mainly

Table 1 Top 10 cited papers

Title	Author(s)	Publication year	Citations*		Methodology
			Scopus	WoS	
The rise of blockchain technology in agriculture and food supply chains	Kamilaris et al	2019	347	270	Review
Future challenges on the use of blockchain for food traceability analysis	Galvez et al	2018	339	262	Review
Modeling the blockchain enabled traceability in agriculture supply chain	Kamble et al	2020b	290	247	ISM—DEMATEL decision-making techniques
Achieving sustainable performance in a data-driven agriculture supply chain: A review for research and applications	Kamble et al	2020a	269	237	Systematic Literature Review
Blockchain technology and the sustainable supply chain: Theoretically exploring adoption barriers	Kouhizadeh et al	2021	246	219	DEMATEL
Blockchain-Based Soybean Traceability in Agricultural Supply Chain	Salah et al	2019	250	190	Ethereum blockchain and smart contracts proposal
Blockchain in Logistics and Supply Chain: A Lean Approach for Designing Real-World Use Cases	Perboli et al	2018	244	188	GUEST methodology
Boundary conditions for traceability in food supply chains using blockchain technology	Behnke & Janssen	2020	239	184	Multiple case study (interview protocol)
Blockchain technology in agri-food value chain management: A synthesis of applications, challenges and future research directions	Zhao et al	2019	224	191	Systematic Literature Network Analysis
Blockchain technology in supply chain operations: Applications, challenges and research opportunities	Dutta et al	2020	217	189	Systematic Literature Review

*November 2022

on the potentialities offered by the BCT adoption both generally and with specific reference to the traceability, transparency, and data security in the FSC. Kamilaris and colleagues (2019) examine and present the impact of BCT in the agri-food sector, projects, and initiatives in progress (powered by Walmart, IBM, Nestlè), and debate about implications, challenges, and potentialities of this emerging technology. The reluctance of small and medium enterprises toward the application of innovative technologies, the absence of ad hoc policies, privacy issues, and costs of implementation are among the identified barriers. By looking at the potentialities of the application, Kamble et al. (2020a) investigate the state of the art on the linkage between a data-driven FSC and sustainable performances, to develop an application framework useful for the practitioners to plan their investments and to innovate the sector. Their findings reveal that the managers, to accomplish sustainable objectives,

to improve transparency, and to track food products in the supply chain, may use blockchain thus achieving a high level of integration. In the work of Zhao and co-authors (2019), the systematic literature network analysis revealed that hurdles like storage capacity and scalability, privacy leakage, high cost and regulation problem, and lack of skills still need to be faced. Nonetheless, BCT could be adopted to improve traceability, information security, manufacturing, and sustainable water management in the agri-food value chain. These findings were reiterated by Dutta and co-authors (2020) which reveal that Distributed Ledger Technologies, as blockchain, could be used to securely link all the actors of the entire food chain, from farm to fork, contributing to the elimination of food adulteration, ensuring high resolution of food safety issues, improving the management of quality issues, and increasing the sustainability. Galvez et al. (2018) discuss the possibility to implement an efficient traceability system against food frauds using blockchain. Even though this technology seems promising, some limits need to be considered in this case as well, like the assurance that the data uploaded are correct, the overall costs, and what kind of data should be publicized.

By relying on data coming from literature review analysis, the authors adopt the DEMATEL methodology in two cases. Combining DEMATEL with ISM, Kamble et al. (2020b) identify thirteen enablers for the application of BCT in the FSC, studying the complex causal relationships between them. Their outcomes suggest that traceability was the most significant reason for BCT implementation in the FSC, followed by auditability, immutability, and origin. Kouhizadeh et al. (2021), on the contrary, exploit DEMATEL to investigate the barriers for adopting BCT for a sustainable supply chain, their interrelationships, and predominance. They conclude that technological barriers are the most critical and need specific measurements to be overcome.

The definition of a BCT system is the scope of the work by Perboli et al. (2018) and Salah et al. (2019). In the first study, the authors apply the GUEST methodology to design the use-case related to an e-commerce food retailer located in Europe, to show the critical aspects of implementing a BCT system. Their findings point out that this technology involves a significant amount of implementation costs, particularly for small- and medium-sized enterprises, but the benefits could result in increased sales, primarily driven by reduced counterfeiting and improved customer confidence. The second work proposes a blockchain-based solution and framework for traceability and visibility in the soybean supply chain, using Ethereum and smart contracts. The authors provide details, aspects, and interactions about the system architecture and design, including the participation entities, sequence diagrams, and implementation algorithms. This study is one of the first examples of BCT implementation in a specific FSC, as the literature on food and agriculture is scant and just started to gain popularity. Lastly, using a multiple case study approach, Behnke and Janssen (2020) identify eighteen boundary conditions, categorized in business, regulation, quality, and traceability classes, for sharing assurance information to improve traceability, investigating four cases in the FSC. Before the employment of blockchain, organizational changes are needed, and traceability processes and interfaces, having a joint platform and independent governance, should be standardized.

Co-occurrences network

A co-occurrence network analyzes the most frequent keywords and the relationships between them, providing a deeper insight into the main research topics to understand the transition and trend of research in a specific scientific field (Rejeb et al. 2021b). In Fig. 3, the terms occurring at least three times were considered. A total of 210 words were identified and 9 clusters were formed. The results shown in the figure represent only the networked items.

Apart from "blockchain" (occurred 1642 times), the most commonly occurring items are "traceability" (925), "management" (810), "technology" (678), "supply chain" (625), "agriculture" (493) "sustainability" (364) and "food safety" (239). From the network, it is notable that the concept of BCT applied to the FSC is predominantly linked to the implementation of the technology as an innovative track and trace system. Looking at different colored clusters, it is possible to identify some well-defined research fields:

i. "Consumer cluster": characterized by the red color, this group of words determine the benefits that a consumer is searching for when hearing about BCT for food products. Trust, authenticity, safety, transparency, and quality are the most important aspects that a blockchain should bring if used. For this reason, "fraud" is also present. However, even if consumers are searching more and more for food quality and guarantee of origin, the price of products is still a crucial factor (European Commission, 2012). In this sense, "willingness to pay" is also included in the cluster, as it is important to understand if the consumer is willing to pay a premium price for the embedded characteristics of a BCT. The final price is determined by the cost of implementation of the technology, and Longo et al. (2020) report that the benefits of a blockchain-based supply chain can be realized with a minimal impact on the product's consumer price. Among the most investigated products,

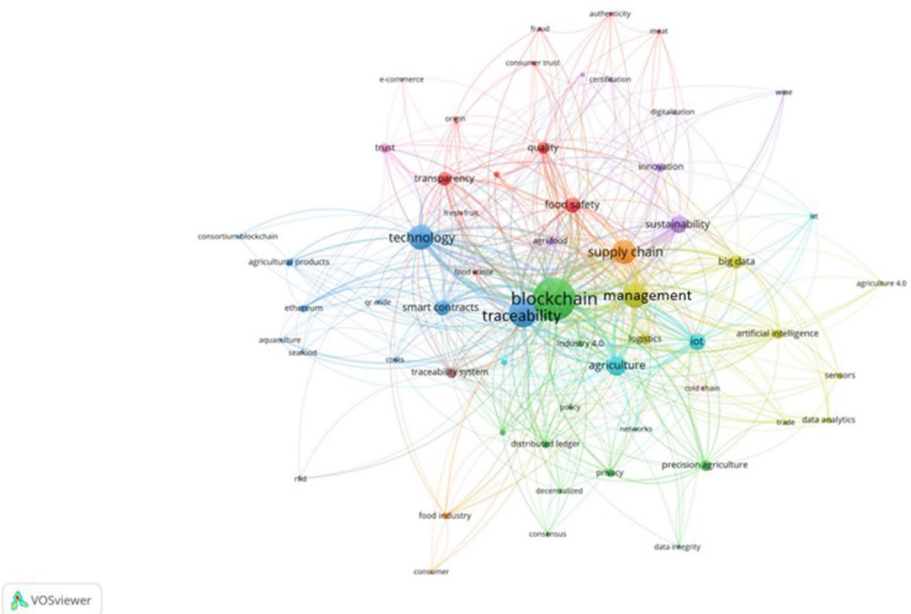

Fig. 3 Network visualization of the co-occurrence items (Minimum number of occurrences of a keyword: 3)

meat and fresh fruit stand out, the former because of the increasing attention to foodborne pathogens and safety (Ren et al. 2022). On the other hand, the current fresh fruit supply cycle is considered lengthy and inefficient, leading to continuous deterioration of quality and the rise of safety hazards (Zhang et al. 2022). Blockchain could be used to upgrade different supply chains through a high level of integration of information and communication technologies, improving production and operational processes in the agri-food sector, streamlining decision-making, production cycles, and transport times (González-Puetate et al. 2022).

ii. "Blue cluster": named so for the presence of "aquaculture" and "seafood." Fish is among the most consumed food products globally (FAO 2022), but the worldwide trade is facing challenges of invasion of fraudulent and substandard products in the entire supply chain (Korneyko et al. 2019). Moreover, the aquaculture sector is constantly increasing, because of the continued depletion of wild fish stocks, requiring continuing innovation to enable sustainability (Rowan 2022). In this framework, BCT can be used for transportation, handling and storage, tamper-proof checks, and product history among others, to ensure safety and traceability of such susceptible agricultural products (Callinan et al. 2022). Implementing a BCT system in the fish sector entails the necessity of digitizing and automatizing the supply chain; in this sense, the use of "smart contract" is necessary to automate the data processing and reduce the risk of errors during the transactions (Hang et al. 2020). Smart contracts can be defined as protocols confirming that an agreement between the transacting parties is traceable, automatically, and irreversibly executed by a pre-written code in a blockchain without the verification and intervention of a third party. In this way, the execution is resilient to any intervention, making it easier, more effective, and less expensive to accomplish (Said et al. 2022). In the fish supply chain, this tool could be exploited to increase the transparency of the value chain, record data from IoT sensors to continuously monitor the storage temperature, improve the communication and the coordination between the parties involved. The permanent registration of the product will thereby provide its history of traceability information, from fishing or production until consumption, improving the safety and quality of the seafood using a trusted mechanism (Patro et al. 2022; Tsolakis et al. 2021; Cruz and da Cruz, 2020). Inside this cluster, there is also "consortium blockchain." Differently from the public and private environment, in consortium blockchains the consensus process is controlled by a preselected set of nodes, and the right to read the blockchain may be public or restricted to the participants. To serve such a purpose, consortium blockchains are usually deployed in environments that consist of multiple organization networks often interconnected by the internet. These blockchains may be considered partially decentralized, emerging as an interesting architecture concept that benefits from the transactions' efficiency and privacy of private blockchains, while leveraging the decentralized governance of public blockchains (Dib et al. 2018). They could be successfully implemented in the food system to improve the security and privacy of the transaction, while maximizing profit at low computational cost (Mao et al. 2019).

iii. "Smart farming cluster": inside the cluster, marked by the green color, the concept of precision agriculture is linked to "data integrity," "industry 4.0," "machine learning," "policy," and "privacy." BCT could be a useful resource to foster precision agriculture techniques. This innovative system utilizes satellite technology, geographical information system, and remote sensing to enhance all functions and services of the agriculture sector, relying upon apps, smart sensors, drones, cloud computing, artificial intelligence, and internet of things. Based on these technologies, it becomes possible to process and access real-time data about the soil, water, crops, animals, and weather conditions (Anand 2021). Blockchain could bring a variety of benefits and support in several applications in precision agriculture, like supply chain monitoring and tracking, finance management, data storage, assurance, and security (Chatterjee and Singh 2023; Torky and Hassanein 2020). A smart farming BCT-based technology provides farmers with instant agricultural data, stores the data only after a thorough check on its integrity, and prevents data from being tampered once stored. Usage of blockchain in precision agriculture can reduce the uncertainty of the output by increasing its predictability and the profit, while also reducing resource wastage (Bodkhe et al. 2022; Krasteva et al. 2021; Vangala et al. 2021). However, concerns about the implementation of BCT in smart farming involve the privacy of users and data, the scalability, the cost of investment, lack of knowledge, and the absence of dedicated policies and regulations (Liu et al. 2021).

Blockchain applications in the wine supply chain

One of the objectives of producing a bibliometric map was to highlight if high-value products are explored as possible fields of adoption of BCT. The co-occurrence analysis included "wine" in the list of relevant keywords. It belongs to the purple cluster with "certification," "coffee," "digitalization," "innovation," and "sustainability." The presence of wine highlights the fact that is currently a hot topic in the research about BCT in agri-food. The word is also connected to other clusters marked by green, blue, yellow, and orange (Fig. 4).

Digitalization, and therefore, blockchain, is an important parameter that, together with sustainability, must be part of the modern strategic management approaches of wine producers (Richter and Hanf 2021). To date, research has focused on the identification of both barriers and challenges (Cordeiro and Olsen 2021), as well as the enabling factors (Galati et al. 2021) affecting the motivation behind the adoption of blockchain-based systems in the wine supply chain. BCT could be seen as an innovative instrument to let forward-thinking wine producers distinguish themselves from the others by renewing their business strategies to integrate the digital transformation concept. It could be seen as an effective system to consolidate trust between supply chain players, such as buyers and suppliers. Within the current non-digital supply chain, trust relationships are kept through personal interactions, reputation, integrity, and cooperation, with commonly shared values. Blockchain offers structural assurance through data immutability and supply chain visibility (Brookbanks and Parry 2022). BCT could exploit positive effects in the winemaking, such as trust establishment, food safety and quality guarantee, supply chain disintermediation, and anti-corruption, enhancing the sustainability of the

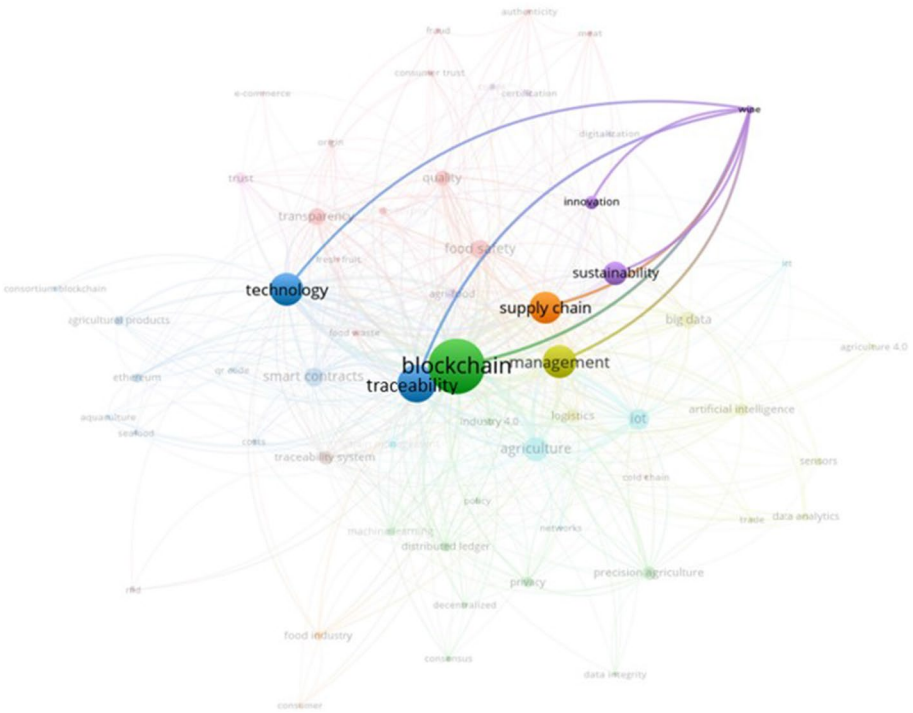

Fig. 4 Detail of the wine cluster

business model of a company (Tiscini et al. 2020). Considering this, the technology can be implemented to reduce food and wine fraud. In 2021, the Italian wine sector received the highest number of controls, almost 1 out of 3 companies, with irregularities detected in 18% of operators and 11% of products, and seizures for 7.3 billion euros (over 70% of the total). Counterfeit was one of the most common fraudulent activities, consisting in copying the brand name, packaging concept, recipe, and processing method of food products for economic gain, consciously deceiving the consumer behavior (ICQRF 2021). A blockchain system could be implemented to prevent and dishearten this phenomenon, improving the current traceability methods through data management to see all the transactions and clearly track the final product to detect where the wine bottle is coming from, authenticate its origin and originality from vineyard cultivation to wine consumption and packaging disposal (Popović et al. 2022; Tokkozhina et al., 2022; Danese et al. 2021). Such a system will ensure transparency and security of all processes involved within the wine production, as a quality info management tool. Since the blockchain stream is immutable, counterfeiting and relabeling would not be successful, thus ensuring transparency and security in the overall process. The information collected along the supply chain is typed into the management system and made accessible by farmers, winemakers, and bottlers; distributors, logistic operators, and consumers can only consult all the information stored on the blockchain to know the origin, the quality, the processing, and the authenticity of wines. As this is one of the most important features when BCT is adopted in the wine supply chain, any customer can check the origin and authenticity of the purchased wine at any time (Agnusdei et al. 2022; Biswas et al. 2017). This is the example of MyStory™, a permissioned BCT that, with the application

of QR codes on the bottles, supports the differentiation of the products, reducing the costs of transactions and counterfeiting, validating the provenance of the goods in a supply chain for customers and the public, offering transparency, and engendering the public's trust in their products (Helliar et al. 2020). In addition to this, blockchain, with its intrinsic characteristics, could bring several benefits to the agri-food and, therefore, to the wine supply chain. It simplifies sharing information between actors and digitizes the track and trace processes, reducing time and cost. Its transparency allows the identification of contaminated products in time, with the consequent recall from the market, thus reducing food waste (Adamashvili et al. 2021). Lastly, the adoption of a blockchain system can contribute to improving the sustainability of wine companies. The relatively low time-consuming and effective traceability system offered by BCT can be adopted by wine companies and sustainability certifications, programs, or standards as a tool to monitor greenhouse gas emission and water management. The reliability of the system also shows future promises in detecting unethical suppliers, unfair labor practices, and counterfeit products (Luzzani et al. 2021). The adoption of BCT can contribute to the building and development of new digital competencies. However, its adoption is influenced by the entrepreneurs' propensity for innovation, a not-secondary aspect in the Italian wine panorama, characterized by small and medium enterprises (Silvestri et al. 2023). It is worth bearing in mind that some peculiarities of the wine supply chain may make it difficult to implement blockchain-based systems. This is the example of cooperatives, where the grape used in wine making comes from different producers. Blending and mixing grapes may slow down the collection of information, making it more difficult to provide univocal and precise information about the origin of that specific wine.

Blockchain applications in the olive oil supply chain

Differently from wine, olive oil was not included in the visualized items of the co-occurrence network. This result opens new research horizons, as the application in such a specific supply chain may have not been fully exploited yet. A critical aspect in BCT adoption in the olive oil production is the origin of the raw material. Besides small traditional productions, focused on bearing a well-defined sensory profile, olive oils from larger and more industrialized producers are more standardized and often stem from mixing up oils from different countries (Carbone et al. 2018). The high price and quality of extra virgin olive oil make it a target for frauds, and traceability is an essential part of the strategy to reduce this risk. In light of this, BCT could be used to enforce the certification of the entire supply chain of extra virgin olive oil (Conti 2022). For instance, technology can be adopted to verify the authenticity of the extra virgin olive oil through the traceability of the geographical origin of the olives by considering the content of particular elements, ensuring an effective implementation of the EU Commission Delegated Regulation (EU) 2022/2104 of 29 July 2022. In addition, the integration of new processes of production and data management is a mandatory step to meet consumer's and market's requirements (Ben Ayed et al. 2022). In the literature, studies about the creation of a BCT system to track and trace the entire supply chain are already available, from seeding to the customer, while empowering olive oil traceability, extra virgin quality certification, and providing final consumers with quality and safety (Bistarelli et al. 2022; Frikha et al. 2022; Ktari et al. 2022; Guido et al. 2020; Arena et al. 2019). As olive oil is

particularly vulnerable to adulteration and frauds, ensuring its authentication is a critical step and a priority for producers, as consumers are willing to pay a premium price if the quality is guaranteed. Blockchain could help to keep track of the visibility of all processes throughout the chain and facilitate the detection of possible adulterations (Alkhudary et al. 2022). If traceability is performed correctly, it facilitates the transparency of each stage of olive oil production, increasing the final consumer's trust when they buy or consume the product (Fernandes et al. 2022; Masmoudi and Gargouri 2021). Consumers are interested in the application of different kinds of technology in the FSC, and they are even willing to pay a premium price if reliability, transparency, and security are ensured (Violino et al. 2019). Finally, the possibility to monitor an olive field by using the internet of things and BCT, coupled with wireless sensors to obtain data for temperature, humidity, wind, and light, allows to have secure data and increase tracking to avoid any attempt to steal or hack data related to products or agriculture (Ghorbel et al. 2022).

Conclusions and future research directions

The present study reviewed the literature on the potential application of BCT to the FSC and those supply chains with high added value. This investigation provided a clear outline of the main applications of BCT that could be of interest to scholars. As a result, it has investigated research areas that remain relatively or completely unexplored. Regardless of their methodological approach, scholars agree on the benefits of BCT. The intrinsic characteristics of this digital innovation make it a tool capable of ensuring greater transparency and trust in food information for various supply chain actors, including consumers (Bosona and Gebresenbet 2023; Agnusdei et al. 2022; Bastian and Zentes 2013).

The adoption of the technology allows the continuous and real-time monitoring of data of various FSC links, thereby ensuring the quality and freshness of the products and eliminating the problem of food fraud. The latter damages the image of companies and the quality of products and it also causes economic damage to consumers (Vern et al. 2023; Demestichas et al. 2020; Casado-Vara et al. 2018). The wine supply chain has attracted the greatest interest among those scholars who wish to understand what drives the adoption of BCT and what hinders its implementation. The results show that the adoption of BCT is mainly driven by the need to combat fraudulent behaviors and by the fact that it is a tool that support marketing strategies. However, this requires a change in organizational structures and, specifically, the need for highly qualified human resources able to implement, manage, and maintain the new technology (Galati et al. 2021; Tiscini et al. 2020). On the other hand, few studies have explored other strategic supply chains subject to frequent fraud, such as the supply chain for olive oil, in which BCT could play an important role. Today more than ever, consumers are increasingly attentive to quality but, above all, to the origin of the product. BCT could guarantee product authenticity, origin, and quality, starting from the raw materials and moving along the supply chain, to detect alterations of oil during transport (Bistarelli et al. 2022).

Conversely, studies focusing on environmental and social dimensions of BCT are limited. The support of the monitoring, recording, and reporting of the movement of goods from "farm to fork" ensures more efficient coordination of processes thus reducing food and resource waste (Krstić et al. 2023). Future studies in this area could explore how

the adoption of BCT can affect the sustainability of supply chain practices and thereby improve organizational performance.

An in-depth analysis of the implementation costs incurred by the agribusiness in the agri-food chain by adopting this emerging technology, along with an analysis of consumer preferences, is essential to provide useful information to innovation-oriented companies in the sector. It is necessary to shift the company's organizational model, to train internal human resources, or to contract out to a technology management service (Galati et al. 2021; Tiscini et al. 2020). This has an inevitable significant impact on management costs, which is reflected in the price of consumer goods. Understanding how consumers positively react to the decision of companies to implement BCT and how many of them are willing to pay a premium for a transparent system could reduce the concerns of FSC operators and encourage them to invest in this area.

Furthermore, our study underlines how one of the main barriers to the adoption of BCT is the fact that companies are not always open to innovation and the difficulty in integrating BCT with artificial intelligence tools (Kamble et al. 2020a). By systematizing different technologies with the introduction of information from artificial intelligence tools into the BCT digital ledger could help to support increasingly innovative suitable business models. As sustainability is becoming the common paradigm, entrepreneurs must consider its aspects when they do business and, therefore, when they develop sustainable business models. Therefore, future studies should focus on the opportunities to integrate different data sources and how they should be implemented according to the structural and organizational characteristics of companies operating along the FSC.

Our work has several theoretical and practical implications in the managerial field. On a theoretical level, it is, to the best of our knowledge, the first contribution to acknowledge the role and implications of BCT not only in the agri-food chain but, more specifically, in high-value chains, as wine and olive oil. The results also have implications for various operators in the agri-food chain, from the production to the distribution stage. For high value-added products, the implementation of BCT can make it possible to guarantee authenticity, origin, quality, and safety, responding to the growing demand for food information from consumers. In this regard, food operators should try to integrate various technologies and databases to make the supply chain increasingly transparent and sustainable. This means investing in personnel training and organizational change, which are now both more necessary than ever to remain competitive in the market.

This paper can surely open huge implications for theory and practice. Certainly, they might become useful for agri-food policy strategies and entrepreneurs. Research on BCT can highlight that this technology optimizes the processes in the supply chain by, on the one hand, improving traceability, enhancing food safety, reducing times of transaction, food fraud, and inefficient processes; on the other hand, this can result in improving farmers' profits (Devi et al. 2023; Fernandez et al. 2020; Lin et al. 2020). From the social and inclusive perspective, the adoption of BCT in the whole agri-food system can have repercussions thanks to the creation of new business models, the reorganization of existing models, the introduction of new systems and new skills. In addition, the research on the topic can give evidence that the BCT adoption presupposes the involvement of various stakeholders operating along the supply chain. They will operate according to a virtuous cycle engaging them in peer-to-peer transactions,

reducing corruption, increasing accountability, and creating value for the firms and the local communities as a whole. Additionally, BCT adoption can promote ethical issues, like fair-trade and animal welfare thanks to an inclusive development ensuring the access of small owners in a better market and ensuring safe payments or financial possibilities.

The novelty of the system and its gray areas may concern several stakeholders, among which policymakers, various players of the FSC, and consumers alike. A lack of consistent and clear regulation and standards, accessibility gaps, data security and ownership, privacy issues, required technological infrastructure, consumer knowledge and safety, and human error are all potential challenges associated with the use of BCT in agri-food. Agri-food companies should undertake efforts to demonstrate concrete benefits to balance the risks of data sharing. Policies and rules pertaining to BCT application have to be defined and framed not to exploit any stakeholder, or deprive them of any rights, but to favor their engagement and participation. Blockchain traceability is really effective if technology becomes a tool adopted by the majority of actors in the supply chain, consolidating trust between operators and creating synergies. BCT should be implemented so as to be used unconditionally by all, and not to be just the privileged tool for market domination by larger players in the agri-food industry (Krstić et al. 2023; Mohapatra et al. 2023; Krzyzanowski Guerra and Boys 2022; Bianchini and Kwon 2020).

Study limitations can exist due to the research areas selected by the software that can appear fewer than the possible areas, thus decreasing the quantity of the delivered works. Indeed, if on the one hand VOSviewer presents interesting new tools for zooming/scrolling/searching maps with details', on the other hand, the viewing capabilities seem above all good for a moderate number of items. However, a wider number of articles from several fields could also make the software analysis more difficult. Another limitation that at the same time can become a further path of research could be not having adopted different data mining techniques to compare the methodologies used and so select the most effective classifiers (i.e., multi-layer perceptron, support vector machines, linear discriminant analysis, and random forest). In addition, the inclusion of the Shannon entropy indicator can make the investigation more insightful.

Abbreviations

FSC Food supply chain
BCT Blockchain technology
WoS Web of Science

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Author contributions

GC involved in conceptualization, writing—original draft, writing—review & editing, methodology, data curation, formal analysis, visualization. DB took part in conceptualization, writing—review & editing, methodology, formal analysis. AD involved in funding acquisition, supervision. MF took part in project administration, writing—review & editing, formal analysis, validation, funding acquisition. FC involved in funding acquisition, supervision. AG took part in conceptualization, project administration, writing—review & editing, formal analysis, validation, funding acquisition.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests
The authors declare no conflict of interest.

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