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Effects of digitalisation on food safety

This paper reviews food safety within the agri-food supply chain (AFSC) literature and presents a comprehensive framework for understanding how digitalisation has reshaped food safety practices within the AFSC. Its significant contribution lies in its identification of novel research streams in food safety that are underpinned by digitalisation techniques, a focus that can be expected to benefit both academic researchers and practitioners who are seeking solutions to pressing challenges related to the efficient achievement of food safety goals. In this paper, the powerful bibliometric analysis capabilities of Biblioshiny and VosViewer were utilised to conduct a comprehensive review of the relevant literature. Biblioshiny's strengths in data visualisation and network analysis were instrumental in identifying key trends and patterns in the research, while VosViewer's ability to create insightful maps of collaboration networks provided valuable insights into the relationships between researchers and institutions. The evolution of the published reviews from the past 10 years and the trending AFSC articles were thus revealed. The used databases were Web of Science and SCOPUS. Based on bibliometric coupling, the identified seven underlying research streams are (a) traceability challenges in AFSC, (b) quality management in AFSC, (c) Agri-food 4.0, (d) future trends of AFSC, (e) impact of the Blockchain, (f) smart packaging, and (g) circular economy. Results show that besides contributing to the efficiency and profitability of companies, digital developments also help to promote sustainable practices and mitigate environmental impacts, while ensuring traceability, proactive risk management and incident prevention.

Keywords: agri-food supply chain, food safety, digitalisation, bibliometric review

JEL classification: Q13

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Introduction

In November 2022, the world's population reached 8 billion people. Research highlights that this figure – albeit at a slowing pace – continues to grow and the current expectation is that the global population will exceed 8.5 billion in 2030 and 9.7 billion people by 2050 (UN Statistics, 2023). In this context, the issue of world food supply represents an ongoing challenge and it must be a unified goal for agri-food supply chain members to work on serving the increasing demand efficiently. This paper aims to provide a comprehensive review and identify recent research streams in the field of food safety, including the connection of food safety and digital solutions.

The paper examines the manifestations of Industry 4.0 and digitalisation in a sector that is not typically considered high-tech when viewed as a whole. Although automation has been present in many sub-sectors of the food industry for many decades, the changes being wrought by the Fourth Industrial Revolution tend most often to be studied by researchers and professionals whose interests lie in the automotive and electronics industries (Demeter and Losonci, 2020; Szász *et al.,* 2020). This paper points out that Industry 4.0 is also present in the food industry and offers a number of opportunities in two areas that are the particular focus of this sector: traceability and food safety (Luo *et al.*, 2018). In addition, the automation of manufacturing processes, intern, and extern logistics and even finances can be supported by Industry 4.0 solutions, which can be indirectly connected to traceability and food safety (Beltrami *et al.,* 2021). The goal of this paper is to uncover the existence of distinct research streams in connection with the triad of "industry 4.0" – "agri-food supply chain" – "food safety" solutions. This paper makes an original contribution to the literature by describing the emerging topics from a holistic perspective regarding their positive and risky effects for the AFSC members. The two research questions are as follows: (1) What are the emerging topics of AFSCM regarding food safety?; and (2) How has the topic of food safety in AFSCM worldwide evolved during the last 10 years?

There are literature reviews (Barbosa, 2021; da Silveira *et al.*, 2021) dealing with the topics above, but this paper aims to complement them in two important ways. On the one hand, the focus has been widened from the previously examined food supply chain to the agri-food supply chain because the author assumes this term is the most comprehensive research scope possible. The term "food" sometimes does not cover the total agri-food supply chain, because agriculture and similarly zootechnics, forestry and fishing are considered as primary activities (Manzini and Accorsi, 2013). On the other hand, this paper seeks to uncover the links between distinct technological concepts and offers a comprehensive framework for both academics and practitioners.

The results of the paper provide an overview of both the positive and the risk-signifying effects of the technologies highlighted here. The paper initially introduces a brief review of the theoretical background. Next, it introduces the review methodology used to analyse the literature. Outputs from the analysis based on software-generated data then follow, after which the results are presented and a discussion of the findings closes the review. The last section concludes.

Theoretical background

This paper aims to analyse the effects of digitalisation from the perspective of food safety solutions within the agri-food supply chain (AFSC). The AFSC sector remains a priority even now; it plays a major role in supplying food. In the previous decades, research in the food sector has tended to focus more on manufacturing and services, while the agricultural sector has been less prominent (Ganeshkumar *et al.,* 2017). Food safety contributes significantly to the resilience of AFSC. Suppliers may require information about the origin and quality of the products (to validate their originality and quality and to be financially accountable in the trading processes) and consumers receive trustworthy information thereby (Xiang, 2015). Food safety can be defined as an approach controlled and regulated by official authorities. The tools used to ensure these two functions can be nationally and internationally valid laws, but mostly international standards such as GHP (Good Hygiene Practices), GMP (Good Manufacturing Practices), ISO9001, ISO22000, or the HACCP (Hazard Analysis and Critical Control Point) system (Gomes-Neves *et al.,* 2007, Wu *et al.,* 2010, Xiang, 2015, Kittipanya-ngam and Tan, 2020). Food safety includes aspects such as preventing food fraud, foodborne outbreaks, and traceability processes to ensure quality assurance compliance (Ehuwa *et al.,* 2021). Recent studies have found that digitalisation can contribute to ensure food safety in various ways: digital solutions or complex management solutions, such as applications for farm management, can decrease risks, increase transparency, and avoid food waste (Jagtap and Rahimifard, 2019, Prause *et al.,* 2020, Barbosa, 2021).

The term traceability can be interpreted as a trade link between stakeholders of various agri-food supply chains (Dabbene *et al.,* 2014) and is a highlighted part of food safety which can be supported by digitalisation. Key stakeholders of the AFSC, like representatives of governments, corporations, and customers must be involved in implementing traceability to ensure its effectiveness (Qian *et al.,* 2020). Traceability as a trade link is not only a commercial link between partners, but also a financial commitment in form of a technological investment. This paper aims to complement the previous research with a special focus on the effects of digitalisation on food safety within the AFSC.

Methodology

The aim of this work is to provide an insight for agri-food supply chain researchers and professionals from the focal industry into the digitalisation-based support for food safety over the last 11 years (2011-2023). Another aim of this paper is to reveal a summary of the topic along the existing literature through identifying key themes building on previous practices (Apriliyanti and Alon, 2017; Maditati *et al.*, 2018). The aim of author was to find out which are the most researched areas in relation to food safety that have come to the fore in recent years, including the question which new research trends are emerging. The interpretation of the methodology of bibliometrics is that both statistical analysis as a part of quantitative research methodology and in-depth interpretation as a way of qualitative analysis may appear in literature review (Maditati *et al.*, 2018). Bibliometric literature review builds on statistical statements regarding the relationships and performance of scholars. It may lead to a better prepared searching process, while looking for the most impactful publications. Figure 1 illustrates the research methodology adopted in this paper.

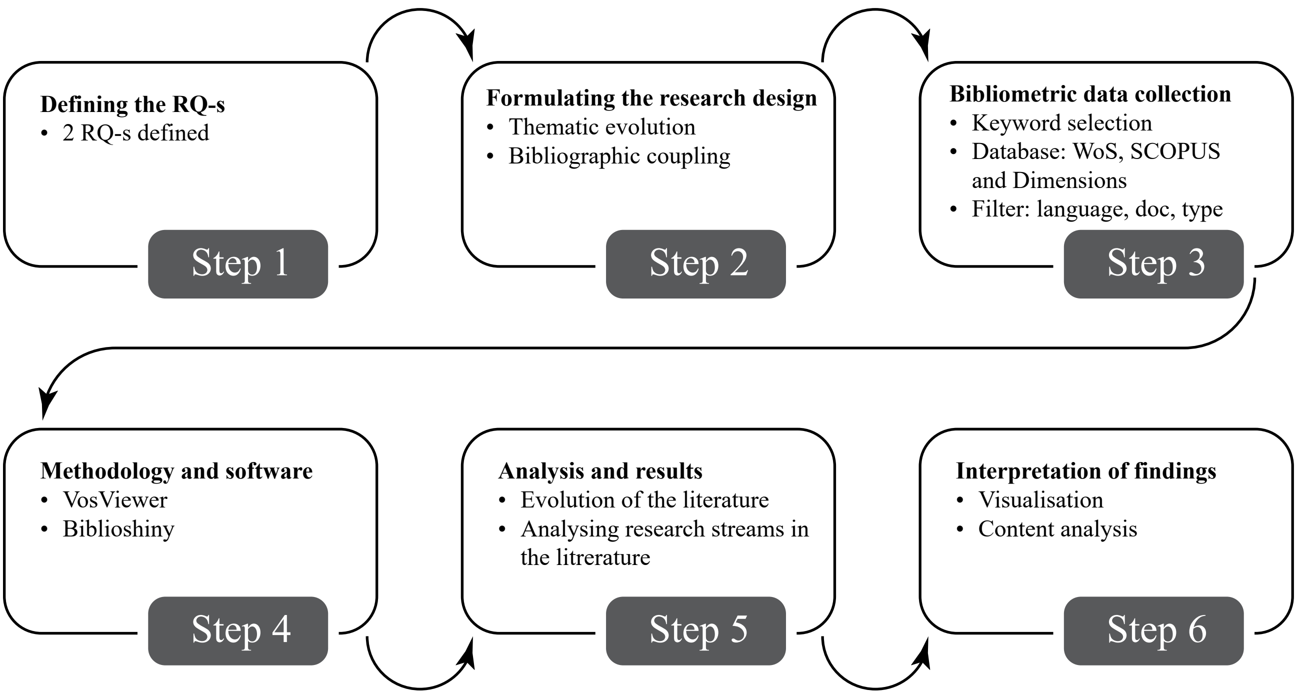

Figure 1: Steps of the methodology.
Source: Own composition

Table 1: Keyword search used on SCOPUS and WoS databases.

Keyword search	Number of articles (SCOPUS)	Number of articles (WoS)
Before filtering: (“agr* food supply chain” OR “food supply chain”) AND („food safety” OR trac*) AND “digi*” OR “*4.0” OR „blockchain” OR „big data” OR „internet of things” OR „robot*” OR „machine learning” OR „sensor” OR „cloud” OR „network”)	9,958	755
After filtering: TITLE-ABS-KEY ((„agr* food supply chain” OR „food supply chain”) AND („food safety” OR „trac*”) AND („digi*” OR „*4.0” OR „blockchain” OR „big data” OR „internet of things” OR „robot*” OR „machine learning” OR „sensor” OR „cloud” OR „network”)) AND LIMIT-TO (DOCTYPE , „re”)) AND (LIMIT-TO (LANGUAGE , „English”))	1,339	110

Source: Own composition

According to experts (Apriliyanti and Alon, 2017; Aria and Cuccurullo, 2017), thematic evolution can provide an answer for RQ-1 as it shows how the examined research topic changes over a period of time. Bibliographic coupling (BC) is a useful analysis tool to check how scholars are related to each other (Jose and Shanmugam, 2020). Bibliographic coupling “uses the number of references shared by two documents as a measure of the similarity between them” (Aria and Cuccurullo, 2017, p. 434). The author chose BC because of the intense development of technologies which may have an impact on AFSC. BC creates clusters from recent publications which cite previous ones. BC also allows to observe in which direction the field is evolving, as well as the emerging topics (Aria and Cuccurullo, 2017).

As Table 1 shows, SCOPUS listed more papers. All variations of keyword search were run on both websites and the table only contains the end searching combination. While managing the search engines based on the previously read literature topics, it turned out to be important that entering the keyword “blockchain” emerged the number of articles within the search. It may appear that the importance of blockchain will be shown within the scope of this paper. As similarly important keywords “internet of things” and “sensor” can be listed.

The following step was the examination of the titles and keywords of the articles. Researchers need to read all the abstracts to check whether the found results are relevant for the research. Reading the papers led to complementing the existing keyword list with new ones in addition. New keywords/topics appeared in the listed publications. The term “RFID” and “digital twin” appeared as new ones in contrast to the keywords from the original search. Bouzembrak *et al.* (2019) highlights RFID (radio frequency identification) as a facilitator in food traceability and product authenticity measures helping IoT (Internet of Things) systems enabling communication with other machines or humans and computing resources. The publication of Bhandal *et al.* (2022, p182.) presents the term of “digital twin” together with the term “cyber physical system” as “the most recent instalment of Industry 4.0 technologies that promises to further exacerbate the ongoing trend”. These terms completed the preconception of the author. Since none of the places showed direct reference to the combination “agri-food supply chain & food safety & digitalisation”, the publication was excluded from the database. Bibliometric research requires that the analysed papers are literature reviews. Other than this, a language limitation to English was applied. These two steps reduced the database (see in Table 1).

The observed dataset contained data from two important databases. Web of Science (WoS) and SCOPUS served as searching engines for this bibliometric literature review. The listed papers were manually checked in regard to the question, whether the scope is fulfilling the requirements. The author filtered out the biological papers because nanotechnology is not the focus of the current research. The author aims to provide a management related view and she assumes that nanotechnological developments would have changed the direction of the paper. After having checked the validity of the searched paper, 466 articles remained on the SCOPUS list and 78 articles on the WoS list. To reach an appropriate database without duplications, the merging function of R Studio’s bibliometrics package was used. As a result of the merging process, 499 documents form the dataset of the current literature review. The publications are all literature reviews. Conference proceedings, case studies and other empirical studies are excluded. The timespan is wide enough to examine the second research question (RQ-2). Papers that appear on the list were published between 2005-2023.

Results and Discussion

Results were generated using the bibliometric analysis software Biblioshiny and the network visualisation software VosViewer.. Biblioshiny was used to answer both RQ-1 and RQ-2 and VosViewer to present the interpretation for RQ-2.

Before applying the methodology, the author filtered the data through the search criterion “publication year”. 438 articles of the original 499 remained, after having set the year range between 2012 and 2023. Citation data from the year 2023 may not influence the result, but the aim was to take into account the recently published papers to interpret the evolution of this literature.

The annual scientific production indicator shows a huge increase from 2017 until the beginning of 2023. Figure 2 shows the average citations per year, so the graph visualises the results until the end of the year 2022 since the paper was conducted in spring 2023. The annual growth rate is 16.195% and a protrusion is seen in 2022 when the number of the published articles more than doubled compared to 2020. This exponential growth is followed from the year 2018. This might mean that the improvement of the technology (Rejeb *et al.*, 2022a) may have served as an inspiration of the authors. Articles in connection with the digital improvements regarding the agri-food supply chain management seem to appear as a consequence of this rapid technical development wave.

Besides this, the average cited data declares a significant decrease from 2020, which shows that due to their recent appearance of papers from the last 2 years, the citations could not be that high yet. The arrival of the Covid-19 pandemic cannot be disregarded. In spring 2020 (~March) European countries started to implement actions like lockdowns, which generated interest in digital technologies (European Comission, 2022). The agri-food industry is not a typical home office-capable industry, so the application of digital support must appear in another forms. Based on this, the sudden increase in publications might be tracked back to the general awareness about the application of digital technologies. It is also a possible that the shortage of human workforce (especially the migration wave in the direction of Western-European countries (e.g., Germany) might have led to the application of non-human resources within the AFSC as well (Mitaritonna and Ragot, 2020, Nagy *et al*., 2020). On the other hand, this increases the need for an IT-educated workforce (Demeter *et al*., 2020), something which also pushes academics in the direction of research areas which can contribute meaningfully to future workforce training.

The three-field plot can adequately represent the connection between the most important authors based on the number of papers they have publisheᴅ, their countries, and the research topics, which appear in their published papers. The size of the nodes represents frequency data, the bigger the node is the more dominant role publication has. Figure 3 shows which topic was the most dominant research topic in the respective year in the sample existing origin

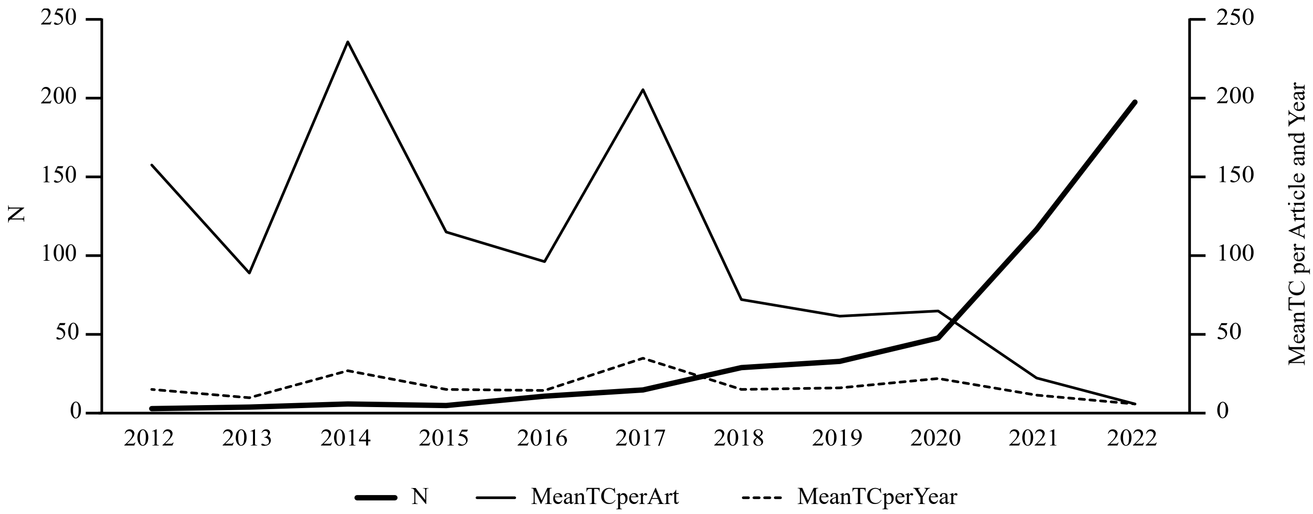

Figure 2: Annual citation per year.

Source: Own composition based on data generated from Biblioshiny (2023)

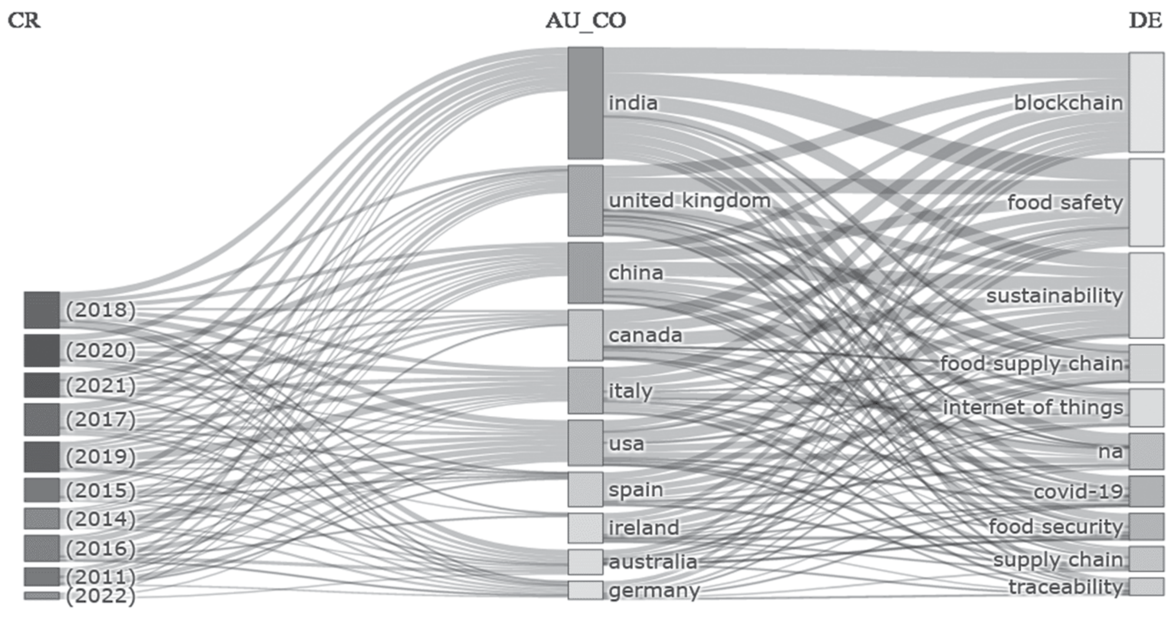

Figure 3: Three field plot.

Source: own composition based on data generated from Biblioshiny (2023) countries. India seems to be the most influential country due to its publication volume. This country is from where all kinds of topics are researched within the examined research frame. The food supply is a prominent issue in these regions of Asia (such as China and India). The parameters of the population justify a country's ongoing work on security of food supply. These developing countries must manage the problem of the large amount of necessary food supply.

In whole sample, blockchain counts as one of the dominant Industry 4.0 solutions (11.22% of the listed articles deal with blockchain), which support the establishment and maintenance of food safety (Lezoche *et al.*, 2020; Srivastava and Dashora, 2022). According to experts (Creydt and Fischer, 2019), blockchain is a technological solution to accomplish an efficient traceability on the entire way of the product.

Besides blockchain, Internet of Things appears as a tool for ensuring traceability during the food supply chain. IoT can be interpreted as a package of devices and technologies enabling sharing of data (Ben-Daya *et al.*, 2021). As an umbrella term, food safety is in the centre of this analysis as well. Food safety incorporates all standards and regulations, which regulate and control the transactions within the agri-food supply chain.

In addition, the importance of sustainability seems to have increased. 19% of the reviewed articles deal with the phenomenon of sustainability regarding food safety characteristics as well. This figure also reveals that the topic of sustainability is strongly connected to countries with a large population (e.g., India, China, Canada, USA). It may happen that organising food sector developments implementing a sustainable aspect is important for those countries that have to provide for a huge population. Furthermore, national, and international efforts of authorities (e.g., EU) can push scientific research in the direction of sustainability by applying funding and tender opportunities (European Commission, 2023).

As to topics of the published papers, Figure 4 demonstrates the evolution of these between 2012 and 2023. The author decided to cut the timeline into four as Figure 4 shows because the rapid growth of the annual citation data highlighted the importance of the period between 2017 and 2023.

This thematic evolution shows a huge wind-up of the topic after 2017: more and more Industry 4.0 solutions appear in the publications. As Figure 4 shows, blockchain is indisputably an emerging topic. Its dominance has not changed in recent years. However, it is interesting to observe that the factor "human" appears, and this is regularly connected with sustainability. The evolution of the topic shows a wide opening in which mostly the core definitions, like food supply chain and food safety and traceability, were in focus. Their existence is important for the future publications because they serve as the basis for recent theories about the technological solutions supporting food safety.

Regarding results made by VosViewer, Figure 5 presents the bibliographic coupling of the articles and the visual indicator of clusters by colour. The closer two articles are related the more references they share (Marchiori and Franco, 2020). This literature analysis states that two documents are bibliographically coupled if they both cite one or more documents in common (Aria and Cuccurullo, 2017). A minimum of five common citations were set. The nodes' size in Figure 5 represents the total number of citations of the 285 articles which met the threshold. It can be seen on Figure 5 that more than the half (285 out of 466) of the examined papers are bibliographically coupled.

Using the papers and meeting the threshold, seven clusters have been implemented by applying bibliographic coupling methodology with the VosViewer software. After reading and interpreting the articles, the author tried to name the clusters, with a view to starting the in-depth analysis. Table 2 contains the labels and the distribution of the seven clusters that were generated by the software.

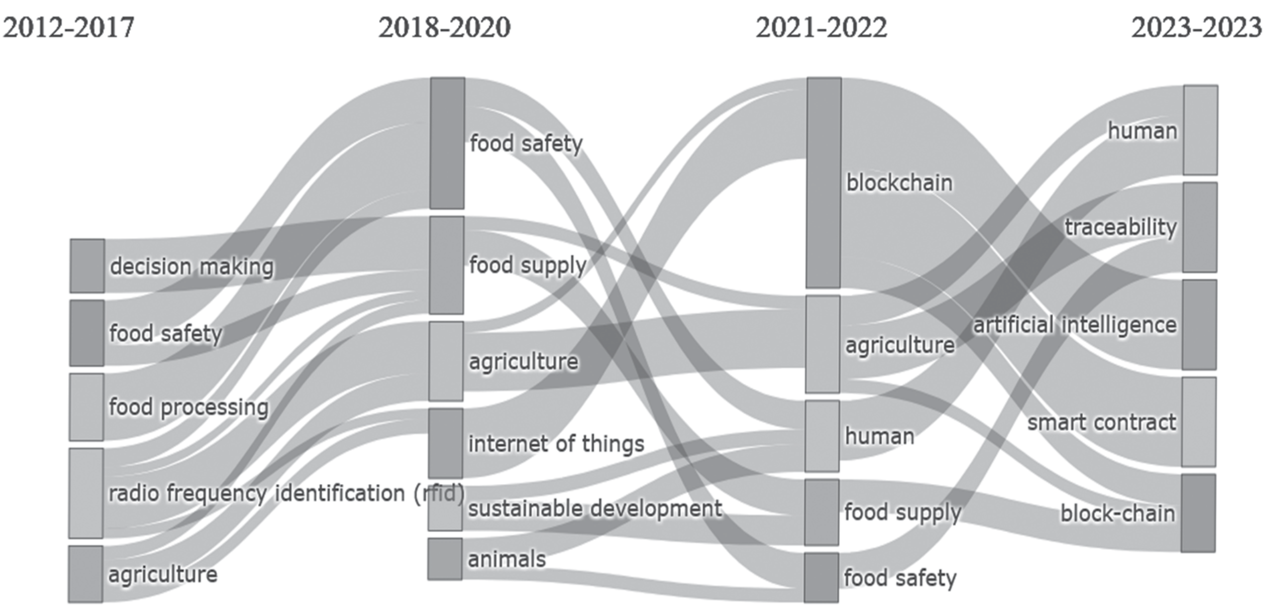

Figure 4: Thematic evolution of papers

Source: Own composition based on data generated from Biblioshiny (2023)

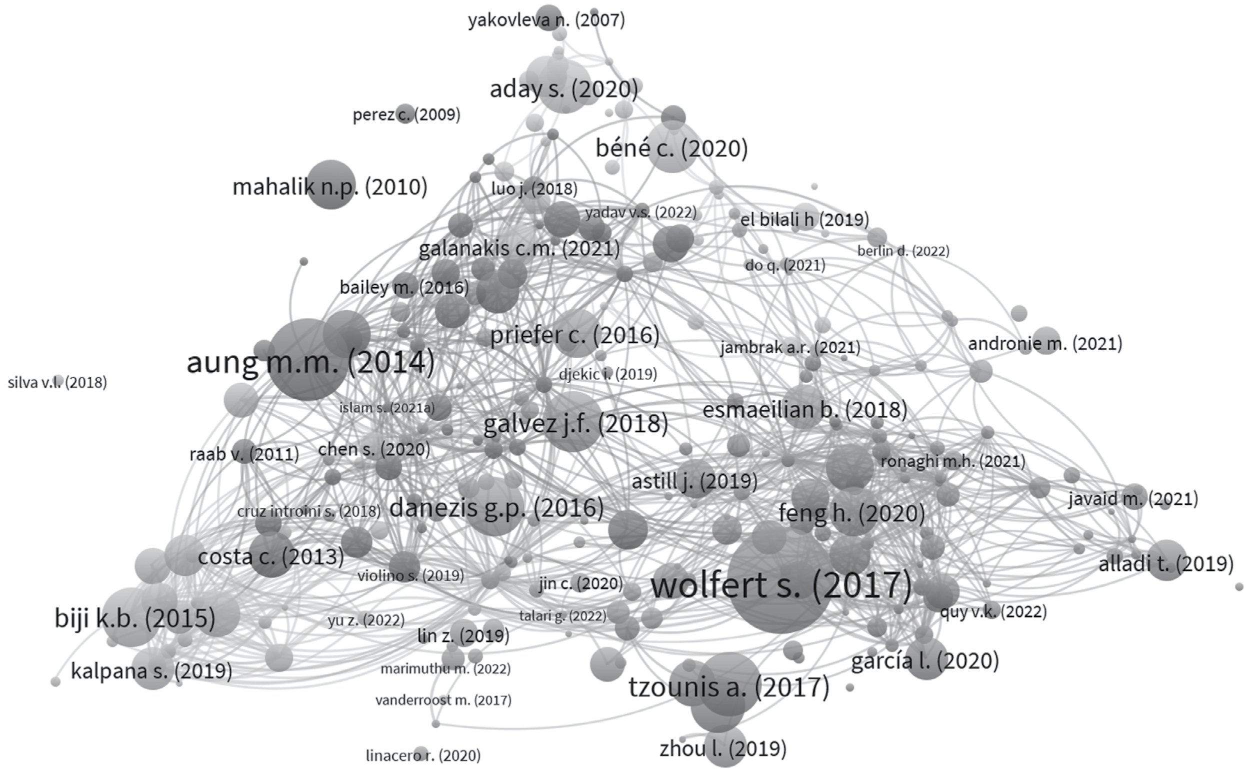

Figure 5: Bibliographic coupling of selected articles from SCOPUS.
Source: Own composition based on data generated from VosViewer (2023)

Table 2: Identification of clusters.

Cluster ID	Distribution of the analysed papers	Name of cluster given by the author
Cluster 1	20%	Traceability challenges in AFSC
Cluster 2	18%	Quality management in AFSC
Cluster 3	17%	Agri-food 4.0
Cluster 4	15%	Future trends of AFSC
Cluster 5	12%	Impact of the Blockchain
Cluster 6	10%	Smart packaging
Cluster 7	8%	Circular economy

Source: Source: own composition based on data generated from VosViewer (2023)

Traceability challenges in AFSC

Generally, agri-food supply chains face comprehensive traceability challenges. The biggest cluster contains literature reviews about possible traceability solutions. According to experts, there are drivers such as legislation, sustainability, consumer satisfaction, international standardisation or even food safety itself, which may contribute to define traceability (Islam and Cullen, 2021). As can be seen in the reviewed literature, technological improvements supported by digitalisation are seen as enablers for the traceability requirements of the 21st century (Magalhães *et al*., 2019; Violino *et al*., 2019).

Furthermore, technologically supported traceability within the AFSC ensures a high level of reliability. Technological solutions for traceability provide stakeholders of AFSCs a social, economic and environmental sustainability as well, with its characteristics of reducing food waste and food loss, building trust and creating transparency within the AFSC (Rahman *et al.*, 2021). Reducing food waste and loss can contribute to environmental sustainability by optimising consumption. On the one hand, society should learn how to avoid the production of food waste (traceability data can provide data to calculate it). On the other hand, harvesting and processing less food leads to a sustainable natural environment. A comprehensive view about the AFSC processes serves as a pillar for trust both from a social and financial (economic) perspective. Negative effects, like mislabelling products, can ruin trust processes. However, technology supported traceability (e.g. blockchain solutions) can lead to stability within food safety (Lo *et al*., 2019).

Quality management in AFSC

While traceability is a highlighted and specific area of food safety, there are also general factors of quality management in AFSC, in which digitalisation may be an important contributor. Quality management can be discussed from an enabler perspective with regard to its consequences. The *enablers* can be technological solutions or standardisation and regulation processes of decision makers. According to the reviewed studies, companies need to have special technological solutions if they wish to manage their agri-food supply chain successfully.

There are numerous software-provided methods supporting quality management systems. The main question of ensuring a stable quality management system is the ability to collect, store and analyse data. Data can be collected with the help of sensors (Hitabatuma *et al.*, 2022). To analyse and interpret the gained data, Big Data and IoT are suitable (Ben-Daya *et al.*, 2021; Rejeb *et al.*, 2021). Artificial Intelligence, Deep Learning and the creation of a Digital Twin serve as simulations for decision making, monitoring and maintenance (Mavani *et al.*, 2022; Verboven *et al.*, 2020; Zhou *et al.*, 2019). Cloud and smart storage represent the surfaces where these data can be responsibly stored for future usage (Nychas *et al.*, 2016). Blockchain is a technology which offers a comprehensive solution for producing, storing, and transferring data real time with full transparency and irreversibility (Galvez *et al.*, 2018).

An interesting fact is that the second cluster does not contain regulation specific papers, which the author will consider in the conclusion part of this paper. The consequences may appear in form of food frauds, food waste and food loss and they mean both financial and social quality managerial losses for corporations (Visciano and Schirone, 2021; Wu *et al.*, 2021).

Agri-food 4.0

The agri-food industry has obtained a dominant position in the literature recently. Terms such as Agriculture 4.0 and Agri-food 4.0 have appeared, generally referring to an interpretation of Industry 4.0 in this sector (da Silveira *et al.*, 2021; Lezoche *et al.*, 2020).

Table 3: Technological solutions characterising Agri-food 4.0.

Name of technological solution	Areas of usage	AFSC members meeting with it	Effects of technology on AFSC members
Artificial Intelligence (AI)	obtaining useful information, enables computers to interpret data	producers, software & hardware service providers (suppliers), distributors, consumers	Pros: quick “ready-to-go” information available, huge data processing capacity, no need of regular human interruption Risks: surface handling capability needed, misleading information/fraud based on non-human led processes, mistrust in given information
Big Data	food processing, food transportation, and food retail: data processing, obtaining useful information	producers, software & hardware service providers (suppliers), distributors	Pros: huge volume of data collectable, comprehensive, by human unmanageable dataset available Risks: data analytics capability needed, misunderstanding of data analysis, unsure decision-making input
Blockchain	“farm to fork” availability: tracks data, proves the originality (indirectly raises trust in food safety)	producers, software & hardware service providers (suppliers), distributors, consumers	Pros: theoretically proven trust in data, tracking solved if each member participates Risks: huge investment required within the whole AFSC to run it, possibility of being declined by users because of lack of understanding/trust
Cloud Computing	better cooperation between logistics and consumers with shared surfaces	producers, software & hardware service providers (suppliers), distributors	Pros: easy availability of real time data, available for all AFSC members in real time Risks: stable internet access must be ensured permanently, risk of cyber-attacks
Cyber Physical Systems (CPS)	farming, food processing: real-time integration of physical and computational algorithm and so facilitating to food safety and food waste reduction	producers, software & hardware service providers (suppliers), distributors	Pros: no need of human interruption, mainly maintenance and program setting are required by the human workforce Risks: problems may occur because of instable electricity networks/internet access, risk of cyber-attacks
Digital Twin	farming and food processing: real-time monitoring of physical world (farm) and updating the state of virtual world	producers, software & hardware service providers (suppliers), distributors	Pros: suitable for simulations (interruptions without endangering animals/plants/ manufacturing processes are possible) Risks: huge investment required, lack of real-life simulations can lead to doubts of users
Drones	farming: spreading pesticides, logistics: package delivery	farmers, producers, software & hardware service providers (suppliers), distributors (e.g., logistics)	Pros: quick transportation, high-quality observation, precise processing methods Risks: non-applicable at each sector, e.g., pesticides for grape yards (while corn can be sprayed from above, grape must be sprayed from the side between the lines), disturbing noises, doubts in people: feeling of being observed

Name of technological solution	Areas of usage	AFSC members meeting with it	Effects of technology on AFSC members
Flexible Wearables for plants	farming: gaining data from animal behaviour, performance management	farmers, software & hardware service providers (suppliers)	Pros: functioning can be controlled, suitable for moving animals (location change does not mean a problem) Risks: non-applicable for all AFSC members (mainly farmers), plants or even animals can suffer from being analysed on a real time basis
Information and Communication Technologies (ICT)	farming, food processing: monitoring conditions (e.g., temperature) and serving with real-time data to extend shelf life	farmers, producers, software & hardware service providers (suppliers), distributors (e.g., logistics), consumers	Pros: availability of communication and storage for all AFSC members, being connected Risks: problems may occur because of instable electricity networks/internet access, risk of cyber-attacks
Internet of Things (IoT)	whole AFSC: data analytics, operating drone farming, monitoring farm/processing operations	farmers, producers, software & hardware service providers (suppliers), distributors (e.g., logistics)	Pros: comprehensive service during the whole value creation Risks: investment into devices capable of communicating with each other is required, problems may occur because of instable electricity networks/internet access, doubts/ misleading because of non-human interruptions are possible problems, risk of cyber-attacks
Machine Learning	Food processing, farming: substance of AI, interpretation of raw data	producers, software & hardware service providers (suppliers), distributors (e.g., logistics)	Pros: advantages of cost-efficiency (based on enabling machines create algorithms instead of programmers) Risks: problems may occur because of instable electricity networks/internet access, failures may occur because of small human control
Precision Farming	Farming: farm management, from gaining to interpreting data and making decision-making offers to farmers	farmers, software & hardware service providers (suppliers)	Pros: comprehensive management tools are available for farmers mainly, decision-making support Risks: non-applicable for all AFSC members, IT infrastructure needed to be synchronised with by the authorities required IT software
Robotics and Autonomous Systems (RAS)	Farming, food processing, distribution: material handling, processing	farmers, producers, software & hardware service providers (suppliers), distributors (e.g., logistics)	Pros: fewer human resources are needed, capacity problems can be solved by RAS Risks: non-applicable at all AFSC members (mainly processing), human contribution: mainly programming, maintenance, higher value-adding jobs
Radio Frequency Identification (RFID)	Food processing, logistics: identification, serving data for tracking	producers, software & hardware service providers (suppliers), distributors (e.g., logistics)	Pros: identification and data transfer available in connection with devices, materials, animals or even humans Risks: danger of radio frequency, non-readable situations may decelerate processes
Sensor	Food production: monitoring food safety and collecting data	farmers, producers, software & hardware service providers (suppliers), distributors (e.g., logistics)	Pros: investment is not too expensive any more, suitable for data collection within the whole AFSC Risks: positioning might cause difficulties (e.g., at a crop field)

Source: own composition based on the collection of Cluster 2

Table 3 demonstrates the technological trends appearing in literature reviews recently. Agri-food 4.0 can be interpreted as a merged technological solution building on data. As Table 3 shows, there are technological solutions which are responsible for gaining and transferring data or even taking special interventions. The hardware-intensive methods are mainly: Cyber Physical Systems (CPS) (Smetana *et al.*, 2021), drones (Rejeb *et al.*, 2022a), Radio Frequency Identification (RFID) (Gómez *et al.*, 2021), Flexible Wearables for plants (Qu *et al.*, 2021) and sensors (Tsolakis *et al.*, 2019). After having collected data, the surface of data storage, transfer and sharing follows as a next group of Agri-food 4.0 technologies. Big Data is suitable not only for storing data in a structured way, but it can also be used for analysis and decision-making processes (Wolfert *et al.*, 2017). Cloud computing (Mustapha *et al.*, 2021) can be a helpful tool for serving real time data for humans or even machines within processes and enable them to analyse or even intervene in processes observed.

IoT (Raj *et al.*, 2021; Sinha and Dhanalakshmi, 2022), Information and Communication Technologies (ICT), and Robotics and Autonomous Systems (RAS) contribute to managing agri-food operations automatically while reducing human interventions in the process. These are followed by Artificial Intelligence (AI) (Ben Ayed and Hanana, 2021), Machine learning (Raj *et al.*, 2021), Digital Twin (Nasirahmadi and Hensel, 2022), which are solutions for handling processes without human interruption to achieve the highest safety possible. AI can learn, interpret, and process huge amount of data coming from e.g., Big Data on its own (Zhou *et al.,* 2022). This capability can affect the AFSC both in a positive and a negative way. Technologies operating (quickly) without human interruption can avoid instability in the information flow but may also raise doubts in the mind of their users. AI can learn on its own and this also creates an uncontrolled sphere, in which rational interruptions can be hardly implemented. "Facts" that are wrongly interpreted but treated as data may have negative effects for AFSC members (e.g., financial consequences, or misinformed consumers) (Rana *et al.,* 2022). However, these technologies are suitable for simulating processes, testing the possible outcomes of interventions and they can make decisions based on their previous analysis.

Precision farming and Blockchain (Finger *et al.*, 2019; Rejeb *et al.*, 2022b) are comprehensive solutions for the stakeholders to track, record and manage changes within the agri-food processes. While precision farming is rather a collection of suitable technologies listed above for management tasks, blockchain is an enabler surface for both managerial and financial tasks. Table 3 includes also pros and risks connected to the prior effects of technologies introduced within this cluster. As observable, most of the listed solutions can replace human workforce, which is on one hand a great capacity enabler. On the other hand, risks as cyber-attacks appear in the results, because of relying on technologies hundred percent. All examined solutions need electricity and internet connection to function, and their ensuring process is paramount for AFSC members.

Future trends of AFSC

The cluster of future trends incorporate the reaction of the AFSC to signs from the changing world. First, it is important to state that food supply is a critical task of governments to be ensured for the citizens and is a part of food safety tasks too. The Covid-19 pandemic has played a dominant role in changing the food safety and especially food supply processes recently (Aday and Aday, 2020; Alabi and Ngwenyama, 2022). According to experts, the resilience of AFSCs should be strengthened, in order to be able to deal with coming crises (Béné, 2020; Derossi *et al.*, 2021). This empowerment can be connected to both national and international authorities and organisations with a special focus on sustainability within the agri-food sector (EU Green Deal, 2020). The necessity of these adjustments is paramount as a reaction to the challenges of climate change processes. The European Union has worked on strategies to achieve a sustainable condition from an economic, environmental, and also social aspect. Policy aims regarding AFSCs within the European Union can be described by CAP (Common Agricultural Policy) aims to achieve fair, healthy, and environmentally friendly food systems (Farm to Fork Strategy) while ensuring and maintaining biodiversity (EU Biodiversity) with a view to mitigating climate change effects (EU Green Deal, 2020).

There are various ways to establish resilience, which is a difficult task, especially within wide AFSCs. Resilience and sustainability goals can lead to one direction if using improved food safety methodologies (Agnusdei and Coluccia, 2022). On one hand, combined usage of Agri-food 4.0 solutions can lead to the maintenance and stabilisation of agri-food processes (Hassoun *et al.*, 2022). They contribute to establish digitalisation supported processes both within production and consumption (Musa and Basir, 2021). This cluster revealed an important method as an enabler of food supply challenges. According to experts, 3D food printing may contribute to deal with the effects of crises, like the Covid-19 pandemics (Derossi *et al.*, 2021). Derossi *et al.* (2021) state that 3D food printing is characterised by ensuring food safety (programmable production solutions without human interruption), producing only the required quantities (reducing food waste) and offering personalised food. 3D printing can also imply a food safety risk from the perspective of cleaning opportunities. Printers should have CIP (clean in place) systems to ensure the regular hygienic cleaning process during the production. On the other hand, applying 3D food printing could entail a limitation of the shelf-life of products because of the artificial changes of the structure of food. Thus, post-processing steps may be required because of customisation (Demei *et al.,* 2022).

Impact of the Blockchain

Coming from this cluster, blockchain can be interpreted as a platform, which stores blocks strung on a chain. Due to its characteristics blockchain is "a distributed ledger feature, every record in this ledger is secured by rules of cryptography which makes it more secure and tamper-free" (Gad *et al.*, 2022, p. 2). There are blocks, filled with data about transactions during the whole process (Ronaghi, 2021; Xu *et al.*, 2022).

From the perspective of members of the AFSC who have stable IT knowledge and infrastructure, blockchain technology can build trust because it provides a faster and more reliable traceability. Challenges of the food supply chain, like food safety, food fraud, fair trade, foodborne illness outbreaks, or even the environmental impact of food production can be supported by blockchain technology (Astill *et al.*, 2019). The stakeholder group of consumers or even smaller farmers and suppliers might have doubts related to the blockchain because of a lack of understanding of the technology. They might not even have a financial background that is stable enough to invest into this solution. The mechanism of blockchain is very complex. Theoretically, it relies on a mathematical basis which allows the technology to be handled in a tamper-proof manner (Gad *et al.*, 2022).

Experts claim that blockchain is a disruptive technology which can lead to changes of business and supply chain models (Ronaghi, 2021). Frizzo-Barker *et al.* (2020) add that this disruptive characteristic may appear not only with a financial focus (e.g., lower transaction costs), but that it has also several risk opportunities, such as unreliability of data provided first and being saved or that the lack of universal standardisation might lead to difficulties in its disruptive growth on the market (Frizzo-Barker *et al.,* 2020).

According to Zhang *et al.* (2022) both upstream and downstream supply chain members participate in information sharing and storage regarding traceability. They point to the characteristics of blockchain-enabled traceability models. They can ensure efficiency, trust, quality and resilience within the food supply chain (Zhang *et al.*, 2022). The impact of blockchain shows itself as an effective tool of traceability. Both the end consumer and the processor can require data about the food, so this is a two-way process. According to the literature blockchain is sufficiently accurate to serve these needs.

Smart packaging

The sixth cluster represent papers about a prominent operation within AFSC: smart packaging. Smart packaging is also a tool of food quality monitoring (Azeredo and Correa, 2021). Smart packaging can contribute to establish food safety, meet the customer requirements, and reduce food waste at the same time (Soltani Firouz *et al.*, 2021). Emerging packaging technologies have an impact on the protection of products, extending their shelf-life and informing all AFSC members, and even the consumers about the entire background of the products from farm to fork (Drago *et al.*, 2020; Nemes *et al.*, 2020). According to experts, smart packaging covers the areas of food safety and quality, traceability, managing food loss and waste and due to these characteristics, it contributes to the sustainability of food processing as well (Chen *et al.*, 2020; Yousefi *et al.*, 2019).

Circular economy

The sustainable development of AFSCs has already appeared within the results coming from Biblioshiny (see Figure 3 and 4). Experts point to the fact that there are links between circular economy, sustainability and digitalisation-supported developments (Ada *et al.*, 2021; Rejeb *et al.*, 2022c). Circular economy represents a perspective that can establish sustainable production and consumption with keeping resources in usage as long as possible (Ada *et al.*, 2021). On both of the sides (production and consumption) waste management represents a dominant part of the circular economy concept which may be supported by digitalisation providing prevention by the technological solutions introduced above in the clusters (Esmaeilian *et al.*, 2018; Oguntegbe *et al.*, 2022).

Discussion

This bibliometric analysis focuses on determining the research trends in terms of thematic evolution and bibliometric coupling. Based on the read and analysed references, a two-sided structure emerges. The literature lists both hardware (e.g. sensors, robots, etc.) and software (Big Data, cloud, etc.) solutions (Derossi *et al.*, 2021; Duong *et al.*, 2020; Lezoche *et al.*, 2020).

Figure 6 demonstrates the relevant pillars of traceability. Beside the two-sided approach (hardware and software), there are other technological solutions which require both sides to function efficiently (e.g., blockchain, IoT, etc.). The intersection of the triad of (1) agri-food industry, (2) digitalisation and (3) food safety depends primarily on the level of the data quality available, and the analyses derived from it. The results show that, in terms of the collection of adequate real-time data, the introduction of digital technologies such as Industry 4.0 solutions can be helpful. Considering the entire food supply chain, the key to implementing digitalisation technologies is the use of tools such as Big Data, IoT, or cloud-based communications (Astill *et al.*, 2019; Niknejad *et al.*, 2021). The implementation requires hardware that can collect data, and on the other hand, software that makes the system capable of handling data. For ensuring traceability cooperation of these two factors is indispensable. Reading the literature it turned out that some authors deal with the coherence of technological solutions

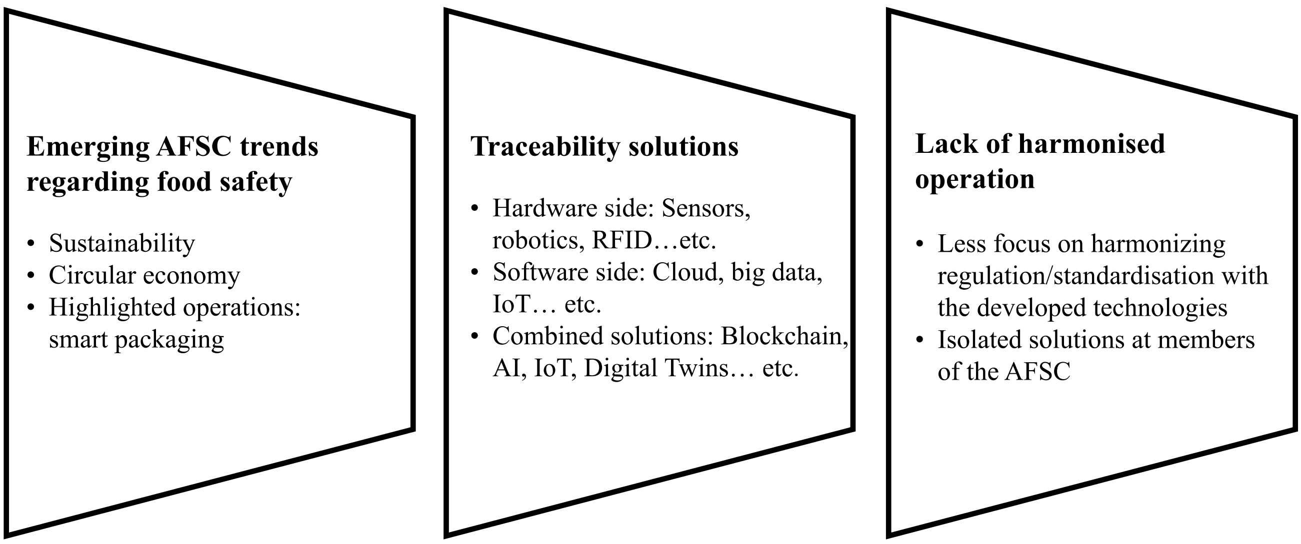

Figure 6: Interpretation of the results.
Source: Own composition

such as blockchain and IoT (Ben-Daya *et al.*, 2021; Kaur *et al.*, 2022), but only a few focus on the total harmonisation of advanced technologies. The requirement for implementing a well-functioning food traceability system consists of at least three fundamental areas. First, a network-capable device (sensor, RFID, etc.) is needed to transmit real-time data (Nasirahmadi and Hensel, 2022). Second, due to data collection big data is generated. Big Data analysis can contribute to decision making, tracking or even prevention processes (Astill *et al.*, 2019; da Silveira *et al.*, 2021). Third, the storage and sharing of a large amount of data is possible with the help of cloud-based repositories or IoT solutions (Kaur *et al.*, 2022). Nevertheless, the results also present that not only technological solutions are needed for ensuring traceability. After the clarification of the possible positive and risky effects of each digitalisation solution, AFSC members must ensure that both the workforce and management have an appropriate understanding of the possible developments.

Bibliographic coupling showed us 7 clusters based on the calculations of VosViewer. The analysed clusters represent an interesting situation about the emerging trends of AFSC's digitalisation regarding food safety. Cluster 1, 2, 3, and 4 describe comprehensive research areas in connection with the agri-food supply chain specifical, technological and quality managerial issues. Meanwhile, it can be observed that even though cluster 5, 6, and 7 would fit the first 4 clusters, they appear in the results highlighted separately – and this is an important new finding. Their importance and dominant role either within the technology or in the AFSC processes might be the reasons for this separated appearance. Incorporated in the clusters 6 and 7 (smart packaging and circular economy), social-environmental-economic impacts also appeared in the findings. Their less-than-dominant position within the findings of the literature search signifies that these effects of digitalisation have not been subjected to detailed academic research so far. The dominant pattern in the results instead relates to technological solutions.

Conclusions

The current paper aims to provide a bibliometric analysis of the publications on food safety supporting technologies applied in the agri-food supply chain. However, a considerable amount of literature is available in the observed research field, in which it can be observed that bibliometric analysis has not yet been commonly applied to the field. The usage of a workflow of bibliometric literature reviews generated a complex methodology relying on a statistical background. The trend of scientific review publications was investigated, and the author aimed to uncover recent research streams and define potential future directions within the field.

Two main research questions appeared in the paper. RQ-1 focused on the area: "Which are the emerging topics of AFSCM regarding food safety?" and RQ-2 dealt with the question: "How has the topic of food safety in AFSCM evolved during the last 10 years?". For accurately answering RQ-1 a bibliometric analysis in form of bibliographic coupling by using VosViewer was conducted and for answering RQ-2, a bibliometric analysis was carried out by using bibliometrix R-package (Biblioshiny platform).

The analysis highlights that there are some "popular" digital solutions such as blockchain or IoT which influence the literature (Astill *et al.*, 2019; Niknejad *et al.*, 2021). This dominance of the technological solutions leads the author to think about their role within the agri-food supply chain. It takes a long time to make the products flow from farm to fork and many members of the agri-food supply chain are involved in digitalisation-based development projects (Dadi *et al.*, 2021). The accurate cooperation of the members may serve a full line traceability which requires a huge financial and professional investment from each member. Due to this it is rarely seen that one or two technological solutions can appear during the whole supply chain. One of the main findings of this paper which is a new result is that not only the 4 previously expected topics (traceability challenges in AFSC, quality management in AFSC, Agri-food 4.0 solutions), but also the last 3 topics of the clusters (the impact of the Blockchain, smart packaging, and circular economy) are emerging and are gaining significance, which is also reflected in the bibliographic analysis results. Table 3 shows the characteristics of the examined technologies. It is seen that there are positive and sometimes risky effects, which have as well social (considering stakeholders), environmental (emissions, production, and functioning data), and economic (financial effects, as investments, maintenance, but also cost efficiency) effects.

Furthermore, there are unexplored topics which are suitable for further research. It has been showed that standardisation and regulation are the basics of food safety. Nevertheless, researchers have not really focused on combining the requirements of regulations with the emerged technological solutions. Cyber security appears as a second future research direction. It should be more researched and published from a managerial point of view. If professionals (e.g., managers or engineers or operators of a farm) do not start to deal with technology-based solutions that were introduced in this paper, it may lead to cyber-attacks or other negative consequences (Bayramova *et al.*, 2021). Limitations of the research are on one hand the broad scope of the research questions, and the lack of the appearance of the term cyber security during the searching steps. However, it is recommended to mix the software for the analysis, and VosViewer software cannot work with the merged database, something which also counts as a limitation of this research. A more detailed analysis can be conducted in the future examining co-citation or co-word relations with a view to obtaining a stronger overview of the pillars of the field. In addition, emphasising the social-economic-environmental effects during the search for the existing effects can widen the list of findings within the literature.

In general, traceability within a whole agri-food supply chain is difficult to implement due to the large number of AFSC members. This paper shows that recent technological solutions can support food safety. Research dealing with the consistency of technologies and regulation platforms can potentially pave the way for a yet more holistic understanding of the AFSC.

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