ISSN 1980-5411 (On-line version)
Production, 34, e20240009, 2024
DOI: 10.1590/0103-6513.20240009

Thematic Section - Digital Transformation of Supply Chain Management

Traceability in the agri-food supply chain: a new perspective under the Circular Economy approach

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Abstract

Paper aims: This study aims to investigate the traceability and its technologies in the agri-food supply chain under the light of the Circular Economy (CE).

Originality: The originality of this study relies on conducting an integrative research of traceability in the context of agri-food supply chain under the light of CE.

Research method: A systematic and structured process was adopted to conduct the SLR. The literature search was conducted in the Scopus and Web of Science databases and operationalized using the PRISMA tool. The initial portfolio was analyzed and a content analysis was conducted using Rayyan, leading to the inclusion of 79 articles. A bibliometric and content analysis was performed using a deductive approach.

Main findings: Traceability is essential at all levels of the supply chain, contributing to the management of food waste and sustainable practices. Various technologies are presented and a framework was developed to illustrate the application of these technologies at different stages of the supply chain and their relationships with the dimensions of ReSOLVE.

Implications for theory and practice: The paper bridges theory and practice by developing a framework that illustrates how these technologies have been used and their relationships with the dimensions of ReSOLVE.

Keywords

Literature review. Industry 4.0. ReSOLVE. Transparency. Reliability.

How to cite this article: Kersten, C. C., Kerber, J. M. C., Silva, J. S., Bouzon, M., & Campos, L. M. S. (2024). Traceability in the agri-food supply chain: a new perspective under the Circular Economy approach. *Production*, *34*, e20240009. https://doi.org/10.1590/0103-6513.20240009.

Received: Jan. 26, 2024; Accepted: July 29, 2024.

1. Introduction

The agri-food sector is one of the main economic sectors in many countries, responsible for producing food not only for domestic consumption but also for exporting to the international market, generating numerous job opportunities (Singh et al., 2023). Therefore, Agri-Food Supply Chains (AFSC) are complex structures with multiple links, formed from rural producers to large distributors to the final consumer, requiring a high level of integration and coordination of their processes (Gupta et al., 2023; Kumar et al., 2023).

Despite its economic importance, the agri-food industry faces complex hindrances concerning efficiency, food safety, and environmental impact, which have been increasing the interest towards sustainable strategies, especially in supply chain structures (Petruzzelli et al., 2023; Soares & Silva, 2023). In this context, the adoption of the Circular Economy (CE) has risen as a way to minimize natural resources exploitation and waste generation, as well as promoting economic development (Ardra & Barua, 2022; Govindan & Hasanagic, 2018; Kumar et al., 2023). Aligned with this perspective, product traceability has been drawing attention as a practice capable of substantiating CE principles in AFSC (Kumar et al., 2024; Hassoun et al., 2023).

Product traceability is defined as the capability of tracking the origin, the history, and the trajectory of a product throughout the supply chain and has been a topic of rising interest in academia and among companies (Fernandez et al., 2023; Zhang et al., 2022). For efficient implementation of the circular economy, there must be effective information sharing between stakeholders. This sharing is especially important in cases where products are perishable and decisions need to be made quickly (Durrant et al., 2021). In this context, traceability technology is an enabler of the circular economy in the food chain (Weetman, 2021). The ability to monitor a product's path from production to final consumption not only creates reliability in food quality and safety but also offers valuable information to optimize processes and decision-making (Anwar et al., 2023; Curto & Gaspar, 2021). It allows waste to be reduced by better sizing inventories in real time, and collaboration between stakeholders to become more efficient and trustworthy, since the information is permanent and cannot be manipulated (Friedman & Ormiston, 2022).

Through traceability, the final consumer can exercise greater control over the origin of food, ensuring enhanced food safety (Ding et al., 2024). On the other hand, traceability applied to processes such as "smart packaging" represents a tool for reducing waste and minimizing waste generation, which are the objectives of CE (Chen et al., 2020). Therefore, technological innovations have contributed to enabling these practices, such as blockchain-based systems for enhanced information security among multiple links in the chain (Panghal et al., 2023; Friedman & Ormiston, 2022), or even Radiofrequency Identification (RFID) systems, responsible for greater traceability and connectivity among informational systems in the global chain (Yadav et al., 2023). However, the traceability of food products still encounters many challenges, such as technological and logistics issues, the requirement of high investments, the need of consumer acceptance, and even the lack of eco-innovation (Sharma et al., 2019).

Although the literature increasingly addresses technological advancements in traceability within AFSC, there is a lack of research exploring the link between these technologies and their potential to drive circular economy principles within the sector. While some studies provide comprehensive reviews of blockchain applications in agriculture, their focus remains primarily on this single technology, overlooking the possibilities offered by other technological solutions (Panwar et al., 2023; Sendros et al., 2022). This observation is consistent with those of Amentae & Gebresenbet (2021) regarding digitalization in the AFSC, where blockchain is a dominant topic of discussion. Another study examined the use of IoT in the AFSC and revealed that the concepts of traceability and sustainability are closely related after a cluster analysis was conducted (Yadav et al., 2023). It is notable that there is no substantial examination of the ways in which these technologies can be utilized to advance a circular economy. In particular, previous research has not employed a framework for the in-depth analysis of the various aspects of this potential. This research aims to address this gap by examining how a wider range of I4.0 technologies can be leveraged to advance circularity within the AFSC by employing the ReSOLVE framework.

In order to achieve this objective, this study seeks to address the following research questions (RQ):

RQ1 - How does product traceability promote the CE?

RQ2 - Which technologies used in traceability are associated with the promotion of CE in AFSC?

RQ3 - What is the current global scenario of product traceability in the AFSC?

RQ4 - Which are the future perspectives for the use of these technologies in the AFSC?

Therefore, *this article aimed* to investigate traceability technologies in AFSC from a CE perspective. To this end, the Systematic Literature Review (SLR) was adopted as a research method and the ReSOLVE framework was used as part of the codebook.

After introducing the subject of research, the present study unfolds to the theoretical background in section 2 used to substantiate the discussion, followed by the presentation of the methodological steps and decisions in section 3. A bibliometric analysis is done in section 4 and section 5 presents the discussion and conclusion of this literature review.

2. Theoretical background

In the face of the market's dynamic, characterized by high competitiveness and even stronger pressures from stakeholders, sustainable issues have become a recurring topic in organization's strategies (Kumar et al., 2023). In this sense, CE arises as a new paradigm taking place from the traditional linear production model (Abdelmeguid et al., 2022). The latter comprises a one-way product flow influenced by consumption, having as main consequence the waste generated at the product's end-of-life (Kekic et al., 2020; Tagarakis et al., 2021).

Despite CE coming forward as a contemporary model, its theoretical foundation lies on different schools of thought that already used CE principles, such as cleaner production, waste management, and eco-design.

Examples of CE predecessors are Cradle-to-Cradle, Industrial Ecology, Biomimicry, Blue Economy, Natural Capitalism, and others (Homrich et al., 2018; Kekic et al., 2020; Verbrugghe et al., 2023). According to Weetman (2016), technological transformations are key enablers for the implementation of the CE model. Therefore, Industry 4.0 and its technologies provide essential tools for circular practices, ratifying the importance of the present research (Abdelmeguid et al., 2022; Nurgazina et al., 2021).

One of the several CE frameworks available in the literature is the ReSOLVE framework, proposed by the Ellen MacArthur Foundation (2015). It categorizes CE practices among six actions (Ellen MacArthur Foundation, 2015), namely:

- **Regenerate:** this action refers to the regeneration of production systems and of natural resources, which demands renewable energy, biodegradable materials, among others (Boz & Martin-Ryals, 2023);
- **Share:** it comprises all the actions that aim to extend product's life cycle, such as products and business models of shared economy (Holmes, 2018);
- **Optimize:** optimization seeks the efficient use of resources within the system, Thus, technological innovations and model simulation tools represent crucial contributions of CE promotion (Boz & Martin-Ryals, 2023);
- **Loop:** this category alludes to the reverse flow of the product in the production chain, whereas the residue might be seen as input for the supply chain itself or others (Gonçalves & Maximo, 2023);
- **Virtualize:** it consists in a paradigm change about product and functionality. This category is based on the concept of servitization with the aim at digitally transforming the consumption experience of certain products, without the need to produce a tangible asset that generates waste in its end-of-life (Han et al., 2020);
- **Exchange:** this last category promotes the substitution of dated processes, technologies and tools for more modern ones that cause less impact to the environment (Boz & Martin-Ryals, 2023).

The present study opts for the ReSOLVE as a theoretical framework to analyze the technologies related to traceability in the AFSC, since it is considered more adequate when the implementation of new technologies for circularity are under analysis (Gonçalves & Maximo, 2023).

3. Methods

This article has the objective to present the state-of-art about the traceability technologies used in the AFSC aiming at implementing CE strategies. To that end, a Systematic Literature Review (SLR) was conducted, which enables the replicability of the research process, enhances its transparency, and identifies main contributions in a specific field (Tranfield et al., 2003).

The SLR method is adequate for addressing this research objective because it provides a comprehensive and structured approach to gathering and analyzing existing literature. By systematically reviewing the literature, the SLR allows for the identification of trend topics, and gaps in the literature. This approach ensures that the analysis is thorough, transparent, and replicable, enabling researchers to draw meaningful conclusions and make informed recommendations based on the available evidence. Furthermore, the SLR comprises a systemic approach that seeks to reduce the subjective bias associated with this method (Fink, 2019; Prodanov & Freitas, 2013; Seuring & Gold, 2012).

In this sense, Razak et al. (2023) conducts SLR to analyze traceability technologies used in the AFSC and help decision-makers to take well-informed decisions to promote efficient traceability in the supply chain. Distinctly, the present research uses SLR in this subject with a focus on the implementation of CE.

Literature review in management has a tendency of being an exploration process of what is intended to research; hence, its planning needs to be more flexible before presenting the final research protocol, in which the researcher must thoroughly explain the steps taken during the SLR (Tranfield et al., 2003). Therefore, this study adopts the six-step SLR approach suggested by Sauer & Seuring (2023), namely: (i) research problem definition, (ii) inclusion and exclusion criteria specification depending on the aim of the study, (iii) search of potentially relevant references in literature databases, (iv) appropriate literature selection, (v) literature synthesis, and (vi) results reporting.

The first step (i) was presented in the previous section followed by the research questions. As for the second (ii) and third (iii) steps, three axes were defined to conduct this literature review: AFSC, CE, and traceability. Then, the articles were extracted from the Scopus and Web of Science databases, due to their representativeness (Govindan & Hasanagic, 2018). The research strings used are presented in the Research Protocol in Table 1.

Table 1. Research protocol.

Databases	Scopus and Web of Science (WoS)
Timespan	Without limitation
Thematic axes	Axis 1: Agri-Food Supply Chain
	Axis 2: Traceability
	Axis 3: Circular Economy
Research strings	*traceability AND "supply chain" AND ("food" OR "agri-food" OR "agrifood") AND ("circular economy" OR sustainab* OR green)*
Research strategy	Configurative
Initial filters	- Only the document types "*Articles*" and "*Reviews*"
	- Only documents in English and Portuguese
Eligibility criteria	Citation number
Screening criteria	Inclusion:
	- Articles that discuss product's traceability technologies in AFSC linked to CE or similar concepts, such as sustainability and green practices
	Exclusion:
	- Articles that only have the above cited expressions, but they are not really in the scope of the referred study
	- Articles that do not correspond to the scope of this research

A configurative approach was adopted in this research with the objective of thoroughly analyzing the topic understudy in a more broadened manner, in contrast with an aggregative approach, which involves the verification of theories and hypotheses through the compilation of results from primary studies, as suggested by Brizola & Fantin (2016).

To the following step (iv), the method Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) proposed by Moher et al. (2009) was used for an appropriate literature selection. Figure 1 presents the operationalization flowchart of the method.

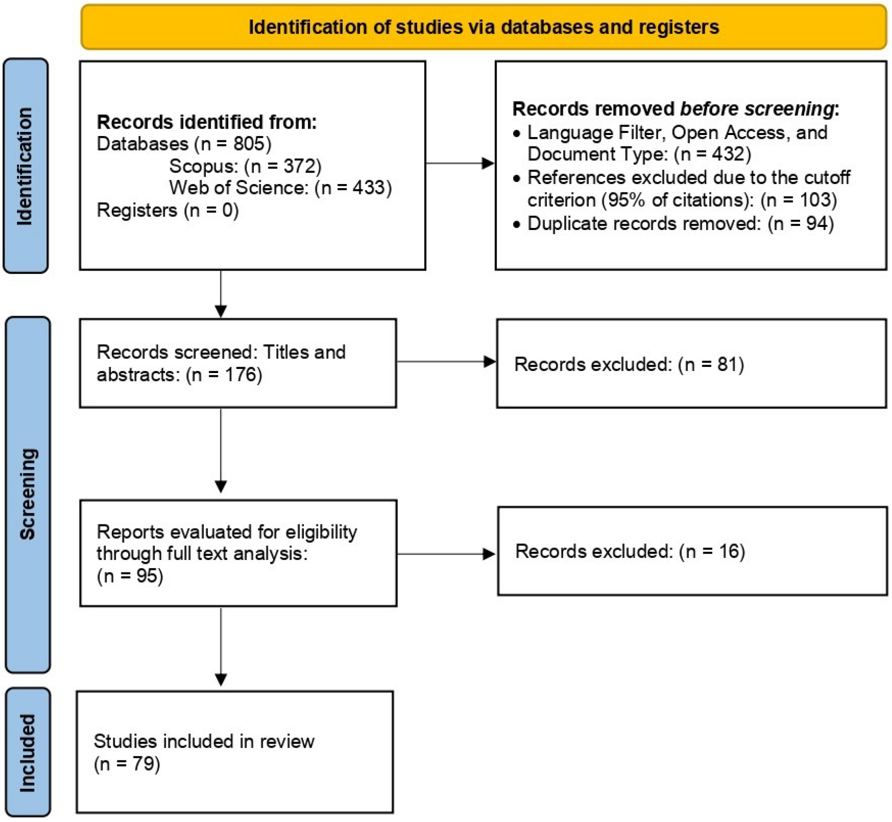

Figure 1. PRISMA flowchart.

The literature search was conducted in April 2024 taking into consideration the parameters established in the Research Protocol presented in Table 1. As a result, 805 articles were found, whereas 94 were duplicates and 432 were excluded due to the initial filters described in the protocol. Moreover, the number of citations was defined as an eligibility criterion in order to limit the sample to only research-quality articles, established by their peers' citations (Ensslin et al., 2014). Therefore, a limit of 95% of citation distribution was used. To avoid the exclusion of relevant recent articles, another filter was used in the articles that were not selected when the first selection criteria by number of citations was applied. Only articles from 2020 until today, including articles "in press", of this previously excluded sample were selected, and then a new limit of 95% of citation distribution was applied. This way, not only the most relevant recent research papers were considered for the construction of the Bibliographic Portfolio (BP), but also the more recent, ensuring the novelty of the study.

Then, a screening process of the final sample was conducted. This analysis was managed using the Rayyan platform, which allows each one of the authors to evaluate the articles without the influence of their peers' opinions. Then, their decisions on the articles are confronted to define which articles will be selected to compose the BP (Ouzzani et al., 2016). After the screening process, a total of 95 articles were selected. These articles were fully read, and 16 articles were excluded, resulting in 79 articles in total composing the final BP.

Then, the last steps of the SLR approach proposed by Sauer and Seuring (2023) took place. A bibliometric analysis was conducted using the Bibliometrix package, which comprises a set of R-based functionalities executed in RStudio with the aim to support bibliometric and scientometric research (Aria & Cuccurullo, 2017). At last, a content analysis was coordinated using electronic spreadsheets to explore the constructs, using a deductive approach based on the ReSOLVE frameworks, and technologies discussed in the articles. The synthesis of the literature (v) and reporting of the results (vi) are presented in the following sections.

4. Findings

This section comprises the bibliometric and content analysis of the selected BP. The first presents an analytic overview of the BP data, bringing to light gaps in the literature that justifies the present research. Then, the latter reveals important aspects in the integration of traceability technologies in a CE context.

4.1. Bibliometric analysis

One of the main insights of the bibliometric analysis involves the evaluation of scientific production over the years. Figure 2 shows the ups and downs of the number of publications since 2015 and the consistent rise since 2019, having an annual growth of 11.33%. On one hand, the first spikes of scientific articles about traceability in the AFSC were probably pushed by food safety concerns related to several notable food safety incidents, such the horsemeat scandal in Europe in 2013, a Salmonella contamination in peanut products in the USA in 2014, milk adulterations in Brazil in 2014, among others. On the other hand, the consistent peak of publications is probably related to the COVID-19 outbreak that caused critical disruptions in the AFSC, whose consequences are still to be measured.

Food safety incidents might also be the reason for the result of the scientific production by country, displayed in Figure 3. UK, China, India, Italy, Greece, and the USA are among the ten countries that most conducted research in the subject, along with Australia, South Korea, Portugal, and Thailand. These latter countries also had issues with food safety; however, India's population presents certain religious restrictions towards some food products that could justify its interest in the topic.

It is possible to notice the interest of researchers in the current topic and, despite the fact that a CE focus of traceability in the area is not a sore subject, it is notable the introduction of sustainability topics in the BP, as shown in the world cloud in Figure 4 with the keywords "sustainable development", and "sustainability".

A word map was created by conducting a Factorial Analysis using the method of Multiple Correspondence Analysis, as presented in Figure 5. With this graph it is possible to see four main clusters of research topics of the BP. In three of them there are topics related to two out of the three research axes of this research, namely traceability and AFSC. Furthermore, in these three clusters, it is notable the presence of keywords that address technology use, such as "blockchain", "system" and "information", and "technology" *per se*, which indicates that the BP of this SLR is compatible with the research subject. The analysis also pointed out a cluster related to sustainability, quality, and safety, which are linked to the keyword "implementation" that, considering the nature of the research, is probably related to the implementation of a traceability system or its technologies. Taking this association into consideration and the fact that this last cluster does not have any keywords directly related to the axes Traceability and Agri-Food Supply Chain, is possible to imply that there is a missing link regarding on how the traceability technologies of AFSC relate to CE principles, justifying once more the relevance of the present study.

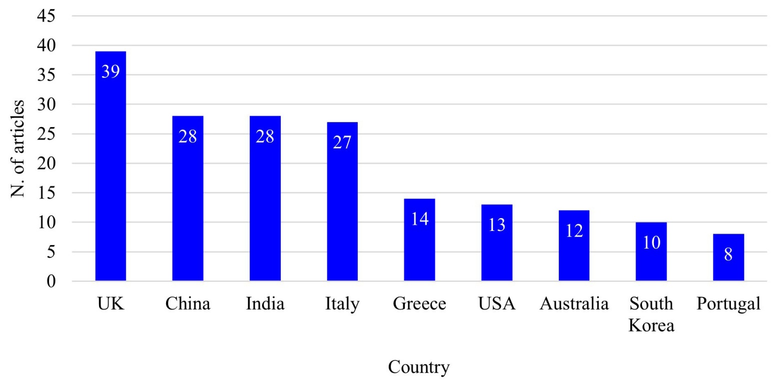

Figure 3. Country's scientific production.

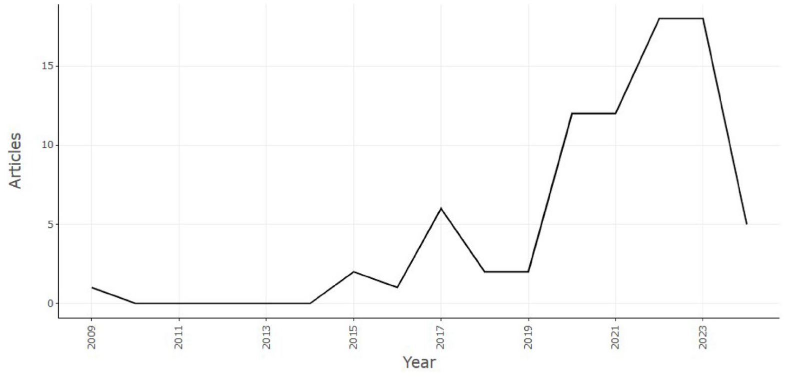

Figure 2. Annual scientific production of BP.

Figure 4. Word cloud of the BP.

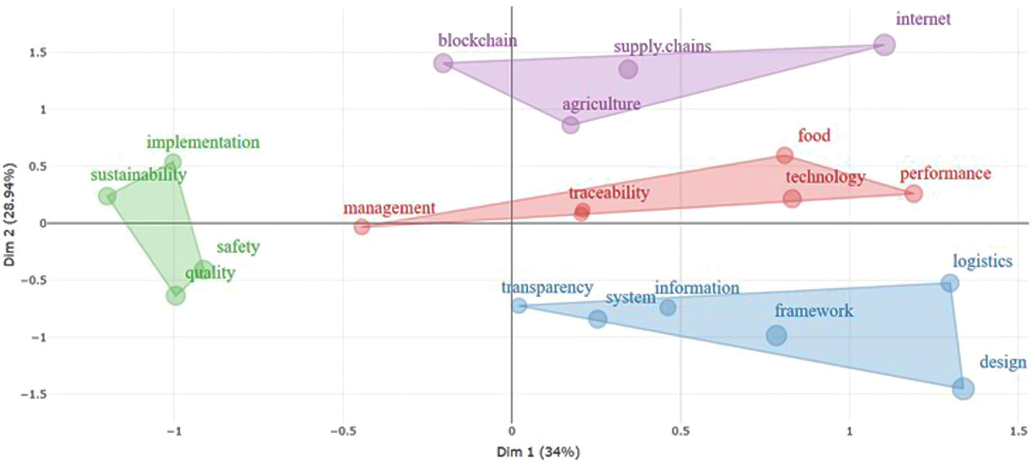

Figure 5. Word map of BP using Factorial Analysis.

By using the data around the keywords of the BP, Bibliometrix was able to generate a trend topics graph, presented in Figure 6. The graph shows a primary interest in quality that lasted for 5 years with a peak in 2018, probably related to the various food incidents already discussed, corroborating the analysis presented in Figure 2. The interest in quality is followed by studies using the keyword "safety", probably due to the same reason. Afterward, the focus has turned to more managerial issues represented by the increased use of the keywords "management" and "traceability", probably influenced by the challenges imposed by the COVID-19 pandemic. In fact, the keyword "challenge" was also frequently used after the pandemic's outbreak in 2020. The most used keywords recently are "sustainable development" and "adoption", which indicates a tendency for studies that seek to understand the impact of traceability and its technologies in sustainable development and how to adopt these technologies in the supply chain.

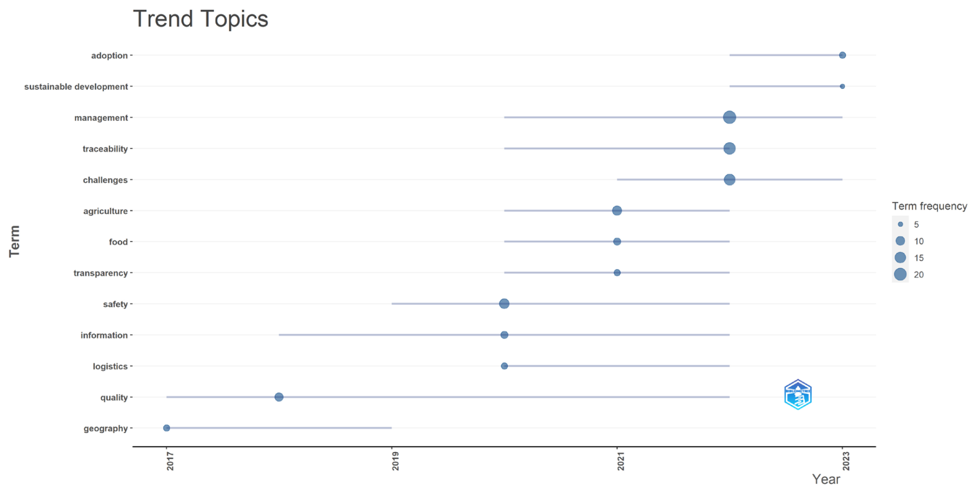

Figure 6. Trend topics.

Regarding the main journals in which the articles of the BP were published, the journal Sustainability and Journal of Cleaner Production held most of the number of publications, 22 and 5 articles respectively, as presented in Figure 7. Due to the scope of these journals, the suggestion that the inclusion of sustainability issues in research about traceability in the agri-food supply chain is corroborated. This evidence also corroborates previous discussions in the literature, which point out the necessity to include the sustainable dimension in

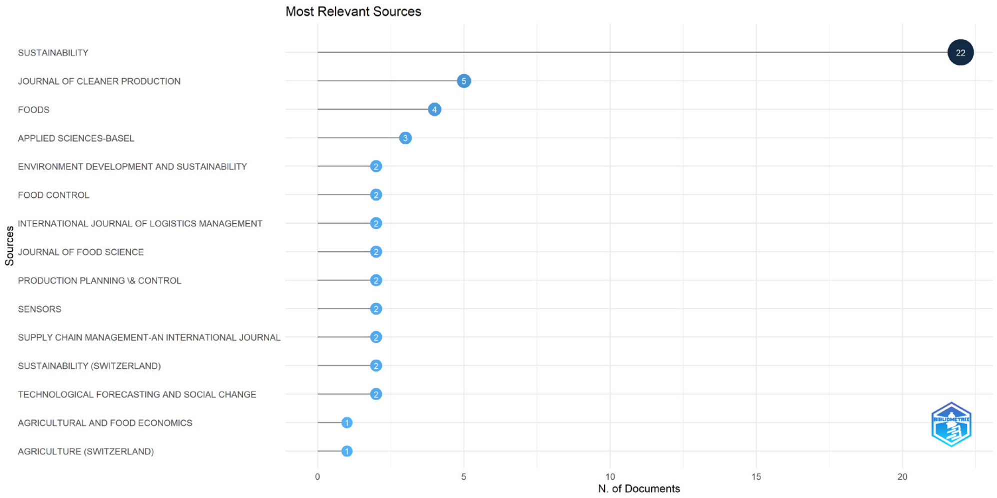

Figure 7. Most relevant sources.

structural operations of companies, such as the supply chain, especially in the agri-food sector (Petruzzelli et al., 2023; Soares & Silva, 2023). Furthermore, it is possible to notice variability in the scope of the sources of the BP, ranging from sustainability issues to food and agriculture and technology subjects.

4.2. Content analysis

The content analysis of the BP discusses how traceability can contribute as a CE practice. Afterwards, a new perspective is proposed concerning the use of this practice and its technologies in a CE context.

4.2.1. Products' traceability as a CE practice

The BP literature has highlighted the importance of traceability for the food supply chain, being crucial for food quality and safety (Friedman & Ormiston, 2022) and enhancing reliability in products and companies (Duan et al., 2020). However, Friedman & Ormiston (2022) emphasize that traceability presents one of the greatest challenges in ensuring sustainability in AFSC. Globalization of the food supply network creates vulnerabilities, which makes it essential to track food products at all levels, especially considering their life cycle (Islam et al., 2021).

The perishable nature of food products requires precise management to meet safety and quality standards. Additionally, traceability is crucial for effective recall management, minimizing risks that could compromise food safety (Hoang et al., 2023). In turn, food safety can be promoted by increasing confidence in the global food trade, while enhancing the sustainable development of this chain (Farooq et al., 2016; Qian et al., 2020).

In order to expand the discussion in this field and address *RQ1 - How does product traceability promote the CE?,* the ReSOLVE framework categories were used to identify the potentialities for promoting circularity by implementing traceability technologies in the AFSC, as shown in Figure 8.

Regarding the regenerative aspect, the literature highlights the relationship between traceability and consumer perception (Hoque et al., 2022; Lewis & Boyle, 2017). In their study, Hu & Xu (2019) argue that the effort to demonstrate the traceability of organic food is directly proportional to consumers' perception of how organic the food is. This effort is related to the richness of information that consumers obtain about an organic product through its traceability. This influence was also observed by Anastasiadis et al. (2021), who noted an increase in consumer confidence in the supply chain of organic tomatoes related to the nutritional value of the product because of traceability information. By providing reliable information about the origin of food, as well as details about logistics, production, and distribution, consumers can make more responsible purchases by considering the sustainability of the food industries, thus promoting sustainable consumption (Nurgazina et al., 2021).

Considering the share dimension, when evaluating information management in the AFSC, it was found that product traceability reduces information asymmetry along the supply chain (Bager et al., 2022). According to these authors, stakeholders need information about environmental actions and operational performance among their peers, such as transferring price premiums to producers or implementing environmentally friendly agricultural practices. Furthermore,

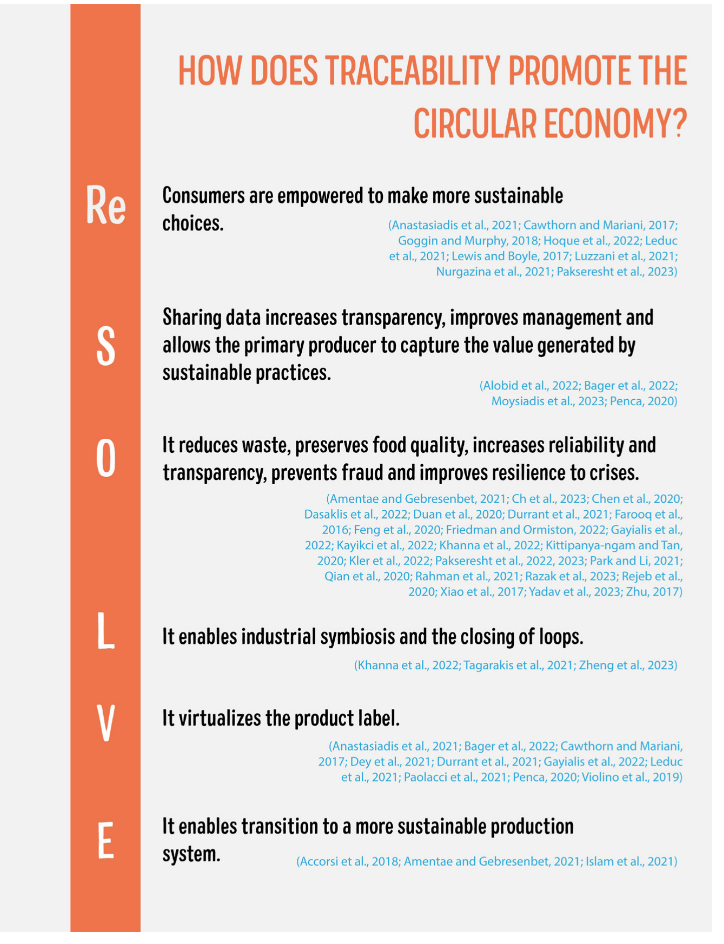

Figure 8. Traceability as a CE practice based on the ReSOLVE framework.

real-time information about stocks in a shared network allows distributors to predict demand fluctuations more accurately, helping to adjust deliveries and reduce waste of highly perishable products (Chen et al., 2020; Kayikci et al., 2021; Rahman et al., 2021). However, there are currently transparency issues regarding information about food export, transportation, and importation, especially in the information reaching consumers. Moreover, differences in food safety standards required in each country can lead to misunderstandings (Qian et al., 2020).

In the optimization dimension, managing food waste emphasizes the need for a targeted traceability system, especially at the retail stage and after raw material collection. Kittipanya-ngam & Tan (2020) highlight that the maturity of AFSC is heterogeneous in different types of foods and depends on the pressure exerted by the consumer market. For instance, the European Union has been intensifying pressure for the implementation of regulations favoring producers with sustainable practices, monitoring products with robust traceability systems and chemical analyses (Goggin & Murphy, 2018). These analyses allow checking at the DNA level whether products are genuinely what they are claimed to be, avoiding common frauds involving the sale of non-sustainable products with fake labels and documentation (Lafargue et al., 2021; Ramli et al., 2020).

Therefore, traceability systems should encompass all activities in the supply chain in order to ensure an adequate flow of materials, properly manage time at each stage, and use only the necessary raw materials, hence minimizing waste (Gayialis et al., 2022; Rejeb et al., 2020). Only through such a system can a company ensure and prove adherence to sustainable practices, such as organic certification and carbon neutrality (Dasaklis et al., 2022; Luzzani et al., 2021). These certifications and initiatives increase stakeholder confidence, profitability through tax incentives, compliance with international regulations, and efficiency of relationships in the supply chain (Stranieri et al., 2017).

For instance, in the case of food from marine ecosystems, an efficient traceability system and certifications are essential elements to protect consumer interests and health and ensure the sustainability of their exploitation

(Cawthorn & Mariani, 2017; Paolacci et al., 2021). Meanwhile, Tagarakis et al. (2021) propose a solution that supports the traceability of biodegradable waste, providing documentation on Corporate Social Responsibility (CSR) among the stakeholders, promoting industrial symbiosis, whereby the waste from one production is reused by another production unit in the supply chain. From a resource utilization perspective, traceability can further improve environmental sustainability by offering information to reduce water and natural resource usage, enhance soil quality, and reduce waste with the aid of real-time data for decision-making (Luzzani et al., 2021).

Ultimately, traceability improves efficiency by reducing manual tracking time and resources, allowing rapid recall of contaminated products. It reduces food waste through supply chain transparency, enabling data-driven decisions and avoiding prolonged storage losses. Furthermore, it enhances producer credibility, mitigating food safety risks, fraud, and subsequent waste (Krstić et al., 2023, Gupta et al., 2023). Industrial symbiosis, closing loops where the waste becomes an input, needs real-time data about the quality and quantity of products to be shared between companies. This becomes possible with the use of traceability technology (Tagarakis et al., 2021).

4.2.2. Traceability digitalization of the AFSC

From the analysis of the BP and aiming at answering *RQ 2 - Which technologies used in traceability are associated with the promotion of CE in AFSC?* Table 2 presents the traceability technologies and tools in the sector.

The evolution of traceability systems began with paper-based systems, still widely used in less developed countries. However, these are inaccurate and unsuitable for handling real-time issues (Gayialis et al., 2022; Tan & Ngan, 2020). Subsequently, there was automation with barcode systems, where consumers could access and verify information about the product as it is linked to a database. The barcode is categorized as a parallel marking technique and is extensively used on food products, but its information storage capacity is limited (Dey et al., 2021). A recent advancement in this technology is the QR Code, a two-dimensional code printed on packaging or directly on products. When scanned, the QR Code can display a small text or a link to a webpage. This extends the code into the virtual environment, allowing consumers to access more information about product's origin and production (Dey et al., 2021; Gayialis et al., 2022).

Table 2. Traceability technologies and tools used in the AFSC.

Technologies and tools	Description	Dimension of Circular Economy framework	References
Paper-Based Recording	It refers to the process of registering information related to the traceability of products in physical paper-based documents.		Islam et al. (2021)
Bar Code and QR (Quick Response) Code	Barcodes are graphical parallel lines representations, while QR Codes are bidimensional matrix codes. Both are used to retain information about the identification and tracking of products and data.	Regenerate (Re), Optimize (O), Virtualize (V)	Gayialis et al. (2022), Islam et al. (2021), Violino et al. (2019)
Radiofrequency Identification (RFID)	It uses radiofrequency signals to identify and track objects and products, allowing the automated collection of information.	Optimize (O), Loop (L)	Islam et al. (2021), Violino et al. (2019), Zuo et al. (2022)
Near Field Communication (NFC)	It allows the exchange of information between electronic devices when they are physically near to each other.	Regenerate (Re), Share (S)	Islam et al. (2021), Pigini & Conti (2017), Violino et al. (2019)
Wireless Sensor Network (WSN)	It is a network of interconnected sensors that wireless collect and broadcast data.	Share (S), Optimize (O)	Islam et al. (2021), Xiao et al. (2017)
Smart Packaging	It is a technology embedded in packaging used to monitor and provide real-time information about products.	Share (S), Optimize (O)	Chen et al. (2020), Islam et al. (2021)
Internet of Things (IoT)	It involves the connection and communication between objects and devices to monitor and share data throughout the supply chain, allowing precise real-time product traceability.	Share (S), Optimize (O), Loop (L)	Krstić et al. (2023), Feng et al. (2020), Gayialis et al. (2022), Tagarakis et al. (2021)
Digital Twin	It is a virtual representation of a device, process, or system, including its components and dimension, showing its functionality throughout its life cycle.	Optimize (O)	Rampone et al. (2023), Guruswamy et al. (2022)
Blockchain	It uses a distributed and immutable ledger to monitor product's history, from production to delivery to the consumer, ensuring transparency and authenticity throughout the supply chain.	Share (S), Optimize (O)	Dal Mas et al. (2023), Vern et al. (2024), Albaaji & Chandra (2024), Bager et al. (2022), Dasaklis et al. (2022), Feng et al. (2020), Friedman & Ormiston (2022), Gayialis et al. (2022), Luzzani et al. (2021), Rejeb et al. (2020), Tan & Ngan (2020), Violino et al. (2019)

Some technologies enable the transmission of information at high speed and in batches, such as RFID and NFC. Both technologies rely on a physical element attached to the product or packaging that can be read with wireless readers. On one hand, RFID offers different functionalities, such as active or passive tags and read-write or read-only capabilities, depending on objectives, operating conditions, and cost (Gandino et al., 2009; Islam et al., 2021). A hindrance of RFID is the necessity of a specific reader, preventing the code from being used by the consumer at the time of purchase or consumption. On the other hand, NFC readers are common in smartphones and can serve a dual purpose: within the supply chain and in communication with the consumer. However, it has some disadvantages compared to RFID, such as higher cost and shorter reading distance (20 cm for NFC compared to 1 to 4 meters for RFID) (Pigini & Conti, 2017).

In the case of perishable products that require constant cold chain monitoring, the application of WSN is highly useful, providing real-time monitoring. Xiao et al. (2017) used WSN technology in a grape cold supply chain and created a more accurate expiration date prediction model. Another technology used for temperature-sensitive or short-shelf-life products is Smart Packaging. This type of packaging can monitor internal and external changes of products and transmit this information, aiming to maintain food quality and freshness by tracking time/temperature data, possible gas emissions, and ripening indicators (Chen et al., 2020).

Additionally, IoT supports traceability throughout the entire chain, as presented by Kittipanya-ngam & Tan (2020) in their study on chicken and canned tuna supply chains. According to the authors, consumer concern is growing regarding animal food coming from deforested areas and the impacts related to the location of fish capture. Violino et al. (2019) point out that traceability will be increasingly integrated with intelligent sensor systems, adding data on product characteristics, production methods, and environmental conditions. Another technological solutions are based in data analysis such as a hierarchical data architecture framework, that integrates micro and macro aspects of the supply chain and supporting data-driven decision-making (Accorsi et al., 2018; Kler et al., 2022). However, a significant portion of AFSC still lacks transparency (Essien et al., 2024; Addou et al., 2023; Bager et al., 2022), especially due to the complexity of these structures that comprise multiple stages and extensive coverage, making supervision and tracking difficult in practice (Tagarakis et al., 2021).

These technologies also face challenges of centralization, costs, and cloning (Tan & Ngan, 2020). As the authors state, many companies prefer to use existing integrated information systems, such as Enterprise Resource Planning (ERP), to avoid excessive expenses in implementing traceability systems.

In fact, the centralization of traditional food production systems might result in trust issues due to fraud, corruption, manipulation, and information falsification throughout the chain (Dey et al., 2021). Recently, blockchain has emerged as a dominant solution, offering decentralized and secure tracking. This system facilitates operations, protects consumer health, eliminates fraud, promotes fair trade, and enhances competitiveness by ensuring the safe distribution of products (Alobid et al., 2022; Chandan et al., 2023; Gayialis et al., 2022; Munir et al., 2022; Pakseresht et al., 2022; Pakseresht et al., 2023; Zheng, Xu, Qiu, 2023). The use of a blockchain-based traceability system allows obtaining reliable data at each stage of the AFSC, leading to a more accurate shelf-life prediction of food products and, consequently, reducing economic losses and food waste (Feng et al., 2020). The absence of intermediaries in blockchain applications can simplify and integrate supply chains, reducing risks associated with recalls (Prashar et al., 2020). Additionally, smart contracts can play a crucial role in improving traceability in agricultural value chains, enabling better verification of the origin and quality of products (Friedman & Ormiston, 2022; Khanna et al., 2022; Prashar et al., 2020). However, Lin et al. (2020) criticize blockchain and propose a bidirectional tracking system based on mobile devices that integrates graphical data and a peer-to-peer (P2P) architecture.

Technology applications strategies are developed by combining different technologies, considering product characteristics, logistical chains, and operational conditions (Dey et al., 2021; Penca, 2020; Singh et al., 2023; Violino et al., 2019). Hence, it is evident that the technologies used in food traceability are diverse, and their effects are more pronounced when applied in combination.

4.2.3. Case studies: successful implementations of traceability technologies

Handayani et al. (2021) and Varavallo et al. (2022) presented case studies in the Indonesian canned fish and Italian cheese supply chains, respectively, to illustrate the successful implementation of traceability technologies. Handayani et al. (2021) developed a production-distribution model incorporating traceability and carbon emissions, demonstrating cost reduction and high traceability in the canned fish industry. Varavallo et al. (2022) introduced a green blockchain-based traceability platform for Fontina PDO cheese, demonstrating real-time data availability and immutability while minimising environmental impact and costs. Collectively, these studies underscore the practical importance of traceability systems in the agri-food sector and provide valuable insights for practitioners to implement such solutions for improved efficiency, transparency, and sustainability. For example, practitioners can use these technologies to optimise production and distribution processes, reduce carbon emissions, and increase consumer confidence by providing transparent and verifiable product information.

4.2.4. Future perspectives for traceability technologies in the AFSC

This subsection presents future perspectives on the topic and suggestions for further research in response to *RQ4 - Which are the future perspectives for the use of these technologies in the AFSC?*

Upon analyzing the existing literature, it was found that there is no well-organized methodology based on a quantitative cost-benefit assessment for the selection of food traceability technologies that meet the requirements of the food supply chain (Islam et al., 2021). Those authors proposed a hybrid approach that integrates multi-criteria decision-making methods (MCDM) with integer linear programming (ILP) to select the best technologies that meet the specific constraints of each case and maximize intended benefits. This approach is designed to assist decision-makers in choosing the right food traceability technologies with minimal cost, aiming to improve cold chain performance and, consequently, enhance the sustainability of the AFSC, reducing incidents of food safety, product recalls, and waste with direct impacts on the environment and the economy.

This cost-benefit assessment aligns with the necessity identified by Dasaklis et al. (2022) to develop and test traceability solutions in real cases, especially considering their feasibility to add value in relation to cost aspects in the supply chain. Beyond costs, there are various challenges to the digitalization of food systems, related to infrastructure, user knowledge and skills, legislation and regulation, the nature of technologies, and the nature of food systems (Amentae & Gebresenbet, 2021). The development of reliable and verifiable systems can be enabled by data collection and transmission technologies usage, allowing for further advancement in information flow along the chain (Penca, 2020). Therefore, the implementation of robust traceability mechanisms is necessary to promote an environmentally friendly AFSC and prevent commercial fraud, such as in the case of seafood (Jæger & Mishra, 2020; Paolacci et al., 2021) and organic foods (Anastasiadis et al., 2021).

Regarding specific technologies, the literature indicates that distributed ledger technologies, such as blockchain, and the IoT face barriers such as scalability, network security, cost, privacy, information storage, energy consumption, latency, and interoperability with other systems (Nurgazina et al., 2021). Moreover, these technologies have gained attention due to the energy consumption required to ensure the reliability of stored data. In this sense, initiatives like the Green Blockchain, which aims to achieve the same reliability with lower energy consumption and operating costs, have emerged. However, it is necessary to go further in research to address the hindrances of the implementation of traceability technologies.

Varavallo et al. (2022) propose a traceability system in a dairy chain based on the Algorand Blockchain, designed to be a more sustainable alternative to its predecessors. Specifically, regarding blockchain, it will be necessary to improve data sharing security and foster a culture of collaboration among chain actors, as reaching an agreement on blockchain smart contracts can be a challenge in a large supply chain (Kampan et al., 2022; Qian et al., 2020; Santana & Ribeiro, 2022). Additionally, efforts should be made to increase data storage capacity on the network without increasing the need for computational processing, as well as to facilitate consumer access to this data (Dey et al., 2021).

Blockchain can also be an essential tool for implementing smart farming, supporting the trade of agricultural goods among farmers and other supply chain actors (John & Mishra, 2024; Leduc et al., 2021). Park & Li (2021) noted a growing scientific production on the subject and estimated that this technology will become more widespread due to its potential to improve sustainability performance. Therefore, further research is needed to assess how blockchain and other technological solutions function in the real world, not just in theory, as adoption barriers exist in the real environment (Cao et al., 2023). Understanding and overcoming these barriers are crucial to fully leverage the benefits of digitization and decentralization. This is also necessary because most blockchain-based solutions on the market are still in early stages (Bager et al., 2022; Sendros et al., 2022). Moreover, special attention should be given to the implementation of hardware, storage capacity, transaction speed, and overall performance of food traceability systems based on complex systems (Feng et al., 2020).

The diversity of technologies, applications, and technology associations raises a relevant question about the heterogeneity of the systems being implemented. There is currently no single solution that meets all different applications and needs. Therefore, according to Razak et al. (2023), the focus should be on creating a universally accepted system. Currently, there is the Global Dialog on Seafood Traceability (GDST), which, in February 2020, launched the first industry-focused document on Standardization for Interoperable Seafood Traceability Systems. This document stipulates that data needs to be documented and transmitted to all seafood supply chain actors, creating protocols for how this data should be shared (Penca, 2020). These efforts can help shape the future of traceability in food supply chains and should be implemented to different types of AFSC.

5. Discussion and conclusion

Through the SLR, it was possible to comprehend the current context of technologies for traceability in the sector of agri-food products and address *RQ3 - What is the current global scenario of product traceability in the AFSC?*

One of the primary motivators for traceability is the reliability of the food being supplied and consumed. Concerns about adulteration and fraud of these products are highlighted in the analyzed articles, with a prominent case being the labeling of products as beef, however containing 80% horse meat, in Europe in 2013 (Borit & Santos, 2015; Dey et al., 2021; Farooq et al., 2016). The issue of seafood also raises concerns due to fraud reported by stakeholders involved in trade and consumption (Paolacci et al., 2021). Furthermore, Farooq et al. (2016) point out that Interpol identified over 10,000 tons of counterfeit food and 1 million liters of adulterated beverages in 57 countries. The lack of assurance and trust in the food being consumed, driven by the increasing demand for resources, presents new challenges for the global AFSC (Leduc et al., 2021).

In addition to fraud, traceability in the sector has become an increasingly relevant study topic due to its requirement for importation in some countries, such as the United Kingdom, investments in technology implementation, as seen with the Chinese government (Zhu, 2017), and as being a demand for companies to acquire certifications (Stranieri et al., 2017).

Thus, the digitization of traceability in the AFSC brings benefits to all its stakeholders. The technologies employed can either reach the consumer as well as serve only the managerial part of the chain. For instance, technologies like RFID require specific equipment not available to the general public, limiting their application with consumers. On the other hand, NFC or QR Code can serve both businesses and the end consumer, extracting even more value from the digitization of the supply chain (Pigini & Conti, 2017).

In light of the above, a framework was developed to identify the use of technologies found in the literature in relationships within the AFSC from the perspective of the CE through the stages of ReSOLVE, as shown in Figure 9. Additionally, it identifies which technologies are used only in the managerial sphere of the supply chain and which can reach the end consumer.

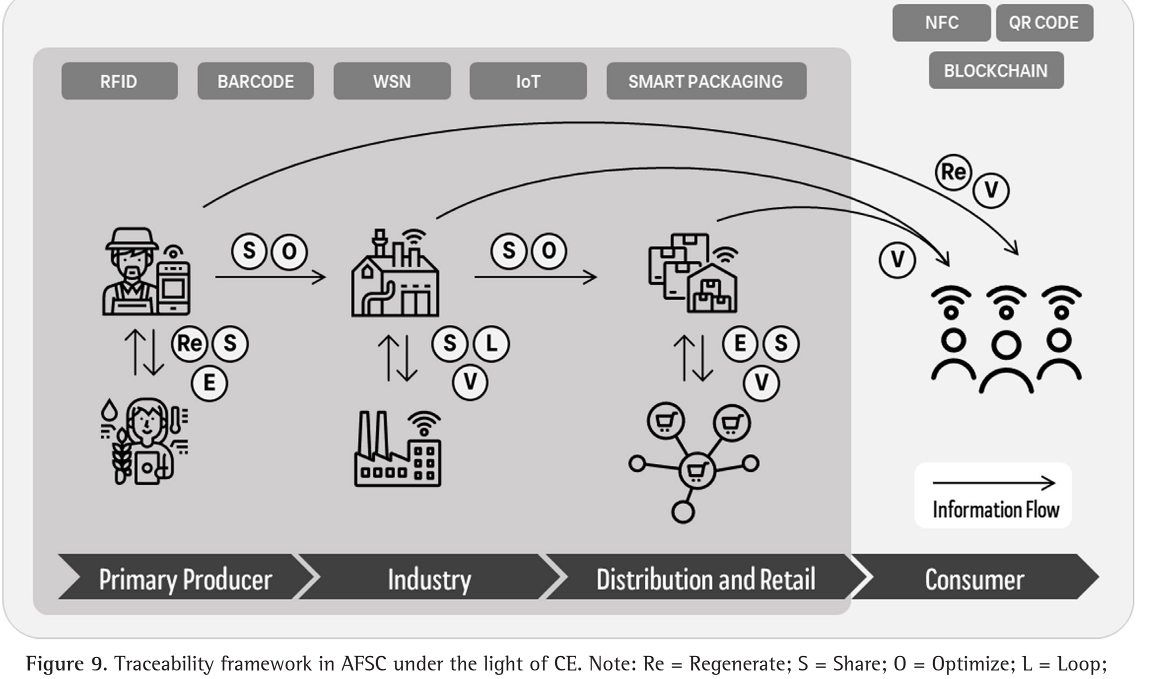

Figure 9. Traceability framework in AFSC under the light of CE. Note: Re = Regenerate; S = Share; O = Optimize; L = Loop; V = Virtualize; E = Exchange.

The framework illustrates how different traceability technologies can be used at different stages of the agri-food supply chain to promote CE principles. The supply chain stages depicted are primary producer, industry, distribution and retail, and consumer. While technologies such as RFID, barcodes, WSN, IoT, and smart packaging are industry standards used by the primary producer, industry, and distribution/retail stages, their benefits rarely reach the consumer directly. However, technologies such as NFC, QR codes, and blockchain stand out because they are directly accessible to consumers without the need for specialised hardware (Essien et al., 2024). At the primary producer level, Industry 4.0 technologies can facilitate activities related to the regeneration (Re), sharing (S), and exchange (E) of resources and information. For example, these technologies can help track the origin and production methods of agricultural products, enabling conscious consumer choices that promote regenerative practices (Bager et al., 2022). At the industrial level, technologies can support the sharing (S) of information among stakeholders, the looping (L) of materials and by-products, and the virtualization (V) of documentation and processes. These technologies can enable real-time monitoring, optimization (O) of resource use, and foster industrial symbiosis (Moysiadis et al., 2023; Tagarakis et al., 2021). At the distribution and retail level, Industry 4.0 technologies can facilitate the exchange (E) of information and processes, the sharing (S) of data among stakeholders, and the virtualization (V) of product information and labelling. This can increase supply chain transparency, enable data-driven decision-making, and provide consumers with detailed information about the product's journey (Dey et al., 2021; Durrant et al., 2021). Finally, at the consumer level, technologies such as NFC, QR codes, and blockchain can support regenerative (Re) choices by providing consumers with reliable information about the product's origin, production methods, and environmental impact (Amentae & Gebresenbet, 2021). These technologies can also enable the virtualization (V) of the consumer experience, allowing consumers to access and share information beyond what is physically printed on the package. The arrows in the framework represent the flow of information facilitated by these technologies, enabling various CE principles and practices across the supply chain stages.

5.1. Theoretical implications

This article aimed to analyse the relationship between traceability and its technologies with the CE in AFSC through a SLR. As a result, it became evident how technologies can contribute to agri-food traceability and enhance circularity principles in the supply chain. However, the use of many presented technologies is still in early stages, requiring further research and greater incentives for the implementation of intelligent tracking systems AFSC (Luzzani et al., 2021; Mol & Oosterveer, 2015). The findings of Panwar et al. (2023) and Sendros et al. (2022) regarding the potential of blockchain technology to enhance transparency and trust in the agri-food supply chain are corroborated by this study. All of the studies demonstrate the capacity of blockchain to enhance data security, reduce fraud, and facilitate real-time tracking of products. Nevertheless, our study goes beyond this by investigating the potential of a multitude of technologies in food traceability. One might reasonably conclude that without blockchain technology, the promotion of a circular economy via traceability is not feasible. Nevertheless, our study has demonstrated that numerous technologies possess the potential to facilitate various aspects of the circular economy. These observations indicate that existing technologies may be utilized to advance different aspects of the circular economy. This is particularly important because traceability is widely used in the AFSC due to regulatory and market standards, and has a dormant potential to advance the circular economy.

Thus, this study contributes to the literature by addressing the identified gap of a shortage of works that relate to the thematic axes of this research. It also provides guidance for companies in the food sector on which traceability technologies promote the CE at different levels of the supply chain and the positive impact of their adoption on organisational sustainability performance.

5.2. Managerial implications

This research addresses a crucial issue for stakeholders in the agri-food industry since food safety and reliability are growing concerns among consumers. Introducing 4.0 technologies in the supply chain to improve traceability in the system could help in the engagement of stakeholders and in the consumers' perception regarding quality. Furthermore, consumers would be able to make more informed purchase decisions, which would be beneficial for companies that are compromised with social and environmental causes. Not only the perceived value of the product will be enhanced, but the companies in the supply chain will also have the proper information to mitigate food loss. Furthermore, in line with the findings of Yadav et al. (2020), it is crucial to recognize the pivotal role of managerial and strategic indicators, such as proactive leadership and well-defined circular economy strategies, in the successful adoption of circular economy practices in the agri-food supply chain.

Moreover, the present work correlates the technologies that are being studied in the agri-food supply chain with their potential to contribute to CE. This information could be useful for companies to strategically choose which technologies they should implement in their tracking activities while seeking to adhere their operations to CE.

5.3. Limitations and future works

Concerning the limitations of this study, it is possible to highlight that the results obtained are based on articles consulted in only two databases and may, therefore, not represent the entirety of the literature pertinent to the subject. However, in order to mitigate this limitation, the chosen databases represent the main indexing bases in the field of knowledge within the scope of this article. Furthermore, one of the strengths of the literature review is the focus on the more disseminated studies, comprising articles that hold 95% of the PB's total citation, giving special focus on the more recent studies. At the same time, this strategy is a limitation of the SLR, which could be worked on in future studies. In this sense, researchers should also consider expanding the BP with grey literature.

One of the article's constraints is relying only on the ReSOLVE framework. Other CE's frameworks are presented in the literature that could have presented a different approach to this review. Researchers are strongly advised to broaden this study by analysing Industry 4.0 tools in the traceability of the agri-food supply chain using other CE frameworks. Another limitation worth highlighting was the lack of practical verification of the proposed framework. This issue could be addressed in further research with the validation of the framework with experts or with empirical data.

In conclusion, as suggestions for future research, a more comprehensive review is recommended considering other databases, as well as a practical evaluation of the presented framework. Other directions for future research would be to explore emerging traceability technologies, investigate consumer perceptions of sustainable food products, or even evaluate policy interventions to encourage CE practices in the agri-food sector. Potential challenges and barriers regarding the adoption of technologies in this sector should also be further studied, as well as considering strategies for overcoming them. Empirical research could be beneficial for this line of study. Moreover, research performing comparative analysis on costs, scalability, data accuracy, and compatibility of Industry 4.0 technologies with CE principles is crucial to enhance traceability in the agri-food supply chain.

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