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Radio Frequency Identification in the Food Industry: Preliminary results from a bibliometric analysis on case studies

Letizia Tebaldi [1,*], Andrea Volpi [1], Claudio Suppini [1], Natalya Lysova[1], Roberto Montanari [1], and Eleonora Bottani[1]

[1] Department of Engineering for Industrial Systems and Technologies, University of Parma. Parco Area delle Scienze, 181/A, 43124, Parma (Italy)

[*]Corresponding author. Email address: letizia.tebaldi@unipr.it

Abstract

Radio Frequency Identification (RFID) technology allows for automatic and real-time identification of items, by simply attaching a tag to them. In the last years, it was implemented in several contexts mainly for tracking purposes, including the food supply chain and the related logistics activities. In this field, in fact, traceability is essential and above all mandatory, for guaranteeing food quality, customer safety and waste reduction. The aim of this paper is to present the preliminary results from a bibliometric analysis on case studies and applications, in order to derive the last trends. In more detail, bibliographic research was carried out through the Scopus database, and a total of 52 documents resulted from a query having "RFID", "food industry" and "case study" as keywords. Typical bibliographic features were investigated (i.e., temporal evolution, type of study, most common journal and conference, most prolific authors, geography, citations, keywords), but also interesting contents-related issues were derived, namely the type of food in question, the main aim of the RFID implementation and the level of tagging (i.e., item-, secondary or pallet- level). Research turned out to be quite steady over time among the sample, with most of the published documents produced in the United States and Italy; moreover, an interest towards the item-level tagging was also deduced.

Keywords: Radio Frequency Identification; Food Industry; Traceability; Food Supply Chain; Packaging; Case study.

1. Introduction

Radio Frequency Identification (RFID) refers to a relatively recent technology (the first appearance dates back to 1987 - Domdouzis et al., 2007) allowing for an automatic identification of something, through radio frequency; trivially, this is suggested by the name itself. Let's go into detail.

The "something", basically, is a tag, a very small object attached to the item which must be identified, hosting a lot of information to be conveyed. In the logistics field, this item could be, for instance, a product on sale in a store (in this case we refer to an item-level tagging), a secondary or tertiary packaging (e.g., a pallet). Thanks to external antennas which allow for the transmission of radio signals, specific RFID readers can collect data recorded in the tags and are able to post-process this information; this enables an automatic and real-time identification, in turn allowing the tracking and monitoring of these tags and, therefore, of the items they are attached to (Jia et al., 2012). For these reasons, it is not surprising that

RFID technology is quite spread in contexts such as logistics and more in general supply chains, mainly for asset and items tracking purposes (Munoz-Ausecha et al., 2021; Casella et al., 2022).

The topic of tracking is essential for some industries, especially those for which there are laws and regulations that make monitoring along the whole supply chain mandatory; this is the case, for instance, of the food supply chain (Stazi and Jovine, 2022), for ensuring food safety and quality. To support this, at the European level, at the beginning of 2005 the EU General Food Law (178/2002) came into force, requiring that food processors ensure the identification of the origin of the raw materials and the destination of final products, i.e., one step forward and one step backwards in the production chain (Aarnisalo et al., 2007). In other, and fewer, words: track and trace are mandatory.

The use of RFID in the food industry is not new; indeed, several other authors have previously discussed this issue. For a complete overview, readers can refer to the two literature analyses written by (Costa et al., 2013) and (Bibi et al., 2017), both specifically focusing on the use of RFID in this field, stressing the positive effects and the enormous savings. What differentiates this work, however, is that the focus of the present literature investigation is at the level of "case studies".

Based on these short premises, the aim of this manuscript is to propose initial results from a preliminary literature survey on case studies of RFID implementations in the food context. To do that, a proper query was set, allowing to define a final sample of 52 documents. These documents were subjected to bibliometric and contents analysis, the results of which are proposed in the next sections. Identifying the temporal evolution, the most active journals, authors and countries, as well as the food on which the tag is applied and the purpose of the RFID implementation are the research questions to be addressed by the present study.

The remainder of the paper is structured as follows: section 2 proposes the methodology implemented for carrying out the study, followed by section 3, in which the results from both bibliometric and contents analyses are detailed. Finally, section 4 presents the conclusions and important recommendations for future research.

2. Methodology

The following query was performed on the Scopus database (https://www.scopus.com/) in January 2024, covering the whole year 2023 and without an inferior time limit:

((TITLE-ABS-KEY (RFID) AND TITLE-ABS-KEY ("food industry"))) AND (case AND study)

From the query, 55 documents resulted; after a first screening, 3 out-of-topic articles were removed, resulting in a final sample of 52 papers. Specifically, the exclusion criterium implemented for these 3 documents was the fact that RFID was simply mentioned as an existing technology for tracking purposes, but the documents did not focus explicitly on an RFID application. The criterium on the English language of the documents was also included, but all the sources were English written. No other criteria was implemented for defining the sample at this stage, and all the documents were included, for the sake of completeness.

Both bibliometric and content-related analyses were performed using Microsoft Excel™ and VOSviewer software. Specifically, the following bibliometric parameters were investigated: temporal evolution, type of study, top journals/conferences, top authors, geography, citations, and keyword analysis.

With reference to the contents, on the other hand, the following preliminary information was deduced from the abstract (if declared): the type of product in question, the aim of the RFID implementation and the tagging level.

Upon request, authors can provide the full list of the reviewed documents.

3. Results

3.1. Temporal evolution

Figure 1 below shows the temporal distribution of the 52 documents, according to the publication year.

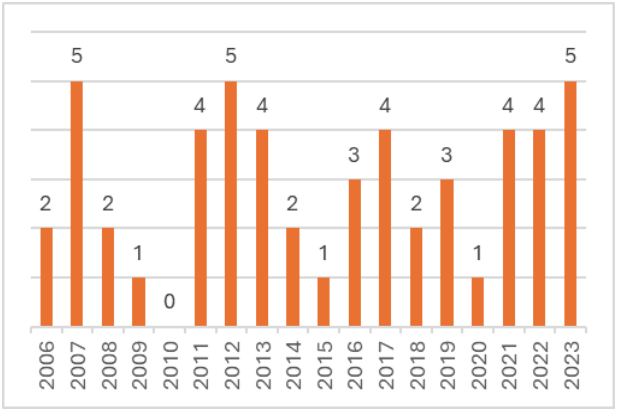

Figure 1. Temporal evolution of the 52 documents.

The first documents appeared in 2006, which is in line with the temporal origin of RFID technology and the fact that the first applications were in fields different from the food industry (Tebaldi et al., 2023). As can be noticed, scientific production is quite steady, and no specific trend can be deduced; it can be surely stated that the interest in the technology in food applications is continuously on and not saturated, but there was no peak in the last years among the reviewed documents.

3.2. Type of study

As far as the type of study is concerned, the sample is composed as shown in Figure 2.

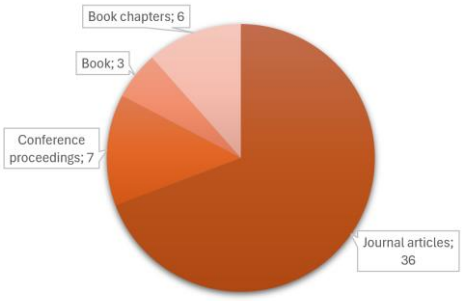

Figure 2. Type of document.

As expected, the majority of documents are article journals (36, among which 7 reviews).

It must be noted, however, that the authors decided to not exclude books/book chapters since they could provide interesting issues and considerations, like the articles.

For completeness and interest of readers, Table 1 resumes the 7 literature reviews, to further stress the contribution of the present manuscript and the reason why it differs from the other studies.

Table 1. Reviews of the sample (7).

Reference	Topic
(Costa et al., 2013)	Review on agri-food supply chain traceability through RFID technology
(Bibi et al., 2017)	Review on food industry traceability through RFID technology
(Dandage et al., 2017)	Review on general food traceability in India
(Cruz Introini et al., 2018)	Review on general food traceability technologies
(Kalpana et al., 2019)	Trends and applications in food intelligent packaging
(Soltani Firouz et al., 2021)	Trends and applications in food intelligent packaging
(Ellahi et al., 2023)	Review on frameworks for food traceability based on blockchain

As it emerges, the two reviews specifically focused on food traceability enabled by RFID technology date back to 2013 (11 years ago) and 2017 (6 years ago); according to this, the authors believe that the present issue should be updated, in light of the latest advancements.

It is possible, however, to recognize a trend in the reviews: in the last years (i.e., 2019 and 2021), the focus has been shifting to item-level tagging for intelligent packaging applications, and even more recently, in 2023, to the blockchain issue. A literature review, to be defined as such, obviously assumes that a certain number of papers have been written on a given topic, and this might be a symptom of where the scientific production is heading.

3.3. Journals and conferences analysis

In this section, the most common international journals and conferences are deepened, so as to guide the researchers towards the most suitable and pertinent ones both for their publications and for reference (note that books and chapters, i.e., 9 documents, were excluded from this analysis).

Out of 43 remaining documents, 38 journals/conferences were derived, meaning that only 5 sources contributed with more than one document. Specifically, they are all scientific journals from five different publishers and propose 2 articles each. The following Table 2 proposes the list.

Table 2. Journals contributing with 2 documents.

Journal	Publisher
Direccion y Organizacion	ADINGOR - Asociación para el Desarrollo de la Ingeniería de Organización
Food and Bioprocess Technology	Springer
Intelligent Agrifood Chains and Networks	Wiley Online Library
Sustainability (Switzerland)	MDPI
Trends in Food Science and Technology	Elsevier

Exception made for the Spanish journal *Direccion Y Organizacion* and *Sustainability*, the remaining three sources are specific journals whose covered areas include technologies for the food sector, supporting the topic treated in the present manuscript. Perhaps, the reason for the presence of *Sustainability*, is that through traceability (and thus RFID), food waste can be significantly reduced in line with sustainability targets. As far as conferences are concerned, none emerged for its particular contribution to the topic.

3.4. Authors analysis

The fourth investigated feature refers to the authors of the 52 papers and aims at identifying those researchers who have contributed with more publications, meaning that they potentially could be considered specialists and experts in the field. This aspect was analyzed using VOSviewer, to deepen the co-authorships and check whether the most prominent authors had worked together. Overall, 182 authors were recorded, with an average of 3.5 authors per paper. The most productive (more than 2 publications in the sample) are mentioned in Table 3, together with their affiliation, the number of papers and the cluster resulting from VOSviewer. Unfortunately, due to the number of pages constraint, it is not possible to report the graphical network built through VOSviewer.

Table 3. Most outstanding authors, proposed in alphabetic order.

Author name	Affiliation	Nr. of co-authored papers	VOSviewer cluster
Alemany M.M.E.	Spain	2	3
Bianco G.M.	Italy	2	1
Choy K.L.	Hong Kong	3	2
Ho G.T.S.	Hong Kong	3	2
Kumar S.	United States	2	4
Lao S.I.	Hong Kong	3	2
Marrocco G.	Italy	2	1
Mostaccio A.	Italy	2	1
Occhiuzzi C.	Italy	2	1
Tsim Y.C.	Hong Kong	2	2

It does not surprise the fact that the same affiliation corresponds to the same cluster; in fact, the two main clusters (i.e., the first – Italian and the second – Hong Kong), include authors who worked together on the same research. Alemany and Kumar, on the other hand, published their documents with other authors, not present in the list. For the Italian research group, the studies in question are (Mostaccio et al., 2022) and (Mostaccio et al., 2023); in the first, RFID is functional for the monitoring of fruit ripening, while the second reviews solutions and applications of RFID in the food field on a more general level. The Hong Kong group is represented by (Lao et al., 2011) and (Lao et al., 2012), thus including more dated research. Both articles deepen the use of RFID technology in warehouses and distribution centers for enhancing performance. It is worth noting that this last group evidently has stopped its research activity on this issue.

3.5. Geographical analysis

The geographical analysis aims at defining where the majority of documents was produced. Figure 3 shows the trend and the most active countries (with more than 2 publications), based on the affiliation of the first author of each document.

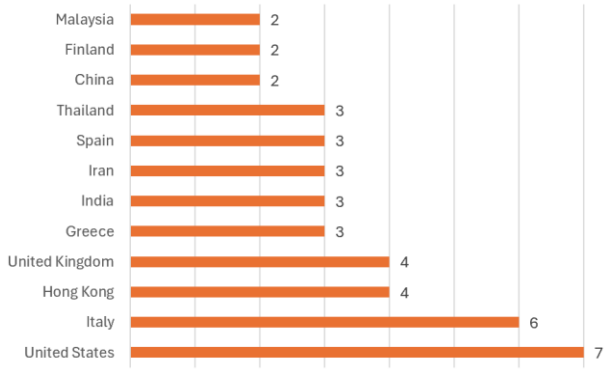

Figure 3. Geographical origin of the documents.

Immediately, the contribution of the USA stands out, since it represents the country with the majority of documents, followed by Italy with only one document less. This result, however, does not surprise at all, since in both countries there are two main RFID research centers, namely the MIT AUTO-ID LABORATORY (which also coined the terms Internet of Things; https://autoid.mit.edu/) and the Future Technology Lab (https://www.centritecnopolo.unipr.it/futuretechnologylab/). It is worth noting the absence of Germany, where the term Industry 4.0 was coined, as RFID is one of the enabling technologies of the Internet of Things (Cui et al., 2019) and, accordingly, of Industry 4.0.

In terms of institutions, two Spanish universities and one from Hong Kong emerge: the Escola Tècnica Superior de Enginyeria Industrial València and the Centro de Investigacion en Gestion e Ingenieria de Producion, both from the Universitat Politecnica de Valencia (the authors of these institutions worked together and finalized 2 documents); finally, the third is the Department of Industrial and Systems Engineering (Hong Kong Polytechnic University), again with 2 documents.

Finally, note that the geography of the first author does not always correspond to the country in which the study was carried out; for instance, in Haj Khalifa and Dhiaf (2019) the first author is from the United Arab Emirates, but the study was carried out in Tunisia, and this happens in other works. This interesting aspect surely deserves to be deepened.

3.6. Citations analysis

The citation analysis here presented simply proposes the most cited documents at the time of writing. These documents, being cited many times, are supposed to be relevant in the field (Tahamtan et al., 2016). Of course, it should be noted that more recent papers did not have time to have the same resonance and diffusion as those older; according to that, results cannot be fully representative of the whole sample.

In support of this last statement, the most cited document of the sample (in absolute number) is the oldest one, (Kerry et al., 2006), which represents the first document in which active and intelligent packaging systems are recalled in the context of the meat supply chain; the authors are from Ireland, a country in which meat is one of the most relevant food products. The document counts 642 mentions.

It is then possible to find most of the previously mentioned literature reviews, in the following descending order (in brackets the number of mentioning): (Kalpana et al., 2019) (264), (Costa et al., 2013) (238), (Soltani Firouz et al., 2021) (228) and (Bibi et al. 2017) (203). It is interesting to note that the two most cited documents do not deal specifically with RFID but with the more general topic of intelligent packaging; probably, this is also the reason for their wider diffusion. Also note that between the first document and the second, the gap is approximately

400 citations, a noteworthy number.

With reference to most recent works, in terms of reviews it is worth mentioning the paper by Ellahi et al., (2023), dealing with the blockchain issue, with only 6 citations but surely destined to increase this number given the relevance of traceability for the food supply chain as already stated, and the importance of RFID for blockchain.

3.7. Keywords analysis

Before proceeding with the deepening of contents, the last bibliometric aspect investigated is the keywords analysis; the analysis in question was carried out again with VOSviewer, and only performed on the *author keywords* (as directly retrieved from Scopus), considered more representative and more reliable than the *index* ones.

The network of authors' keywords is shown in Figure 4, including only terms with frequency equal to or greater than 2.

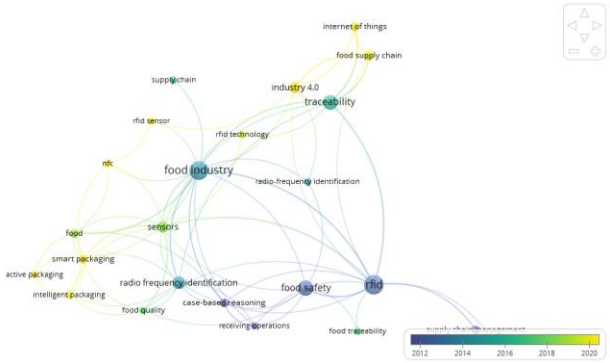

Figure 4. Keywords network (VOSviewer).

In the network created by the software, the size of the labels depends on the frequency associated with the keywords (i.e., the occurrence); more specifically, the greater the size, the greater the frequency.

In this specific case, the emerging and relevant keywords are *RFID* (occurrence = 14); *food industry* (occurrence = 13), *food safety* (occurrence = 9) and *traceability* (occurrence = 8); as discussed later, all these terms are also linked to each other. These results do not surprise at all, since *RFID* and *food industry* are the keywords involved in the initial query for setting the present research; it is interesting to note, instead, the second two keywords: *traceability*, which is the activity that RFID enables par excellence, but it is also worth noting *food safety*, with a +1 frequency compared to *traceability*, that stresses the fact that the use of RFID technology also allows for a greater protection in terms of safety.

The colors of the labels refer to the average year of appearance of the keywords; it is interesting to note, at the bottom left corner, a group of recent keywords (average year 2020), all linked to the packaging, i.e., *smart packaging* (occurrence = 3), *active packaging* (occurrence = 2) and *intelligent packaging* (occurrence = 2). This reinforces the previous consideration about the relevance of the topics related to smart packaging.

The links refer to the co-occurrence of terms, thus highlighting the keywords that appear together. The two keywords with the strongest link are, as expected, *RFID* and *food industry* (both with 22).

Overall, from these outcomes we can deduce the presence of 4 main clusters of keywords associated with the topic in question: (*i*) keywords related to the food context and in general to the supply chain (i.e., *food supply chain, supply chain, food industry, supply chain management, food, logistics*); (*ii*) those related to the RFID technology (i.e., *RFID*, both spelt out in full or through its acronym, *Internet of Things, NFC, sensors, RFID sensors*); (*iii*) those related to the packaging (i.e., *active*, *intelligent* or *smart packaging*); (*iv*) those related to the usage and the functions of the RFID technology (i.e., *traceability, food safety, food quality, food traceability, receiving operations*).

Finally, we encountered a noteworthy keyword with an occurrence of 3, namely "*case-based reasoning*", to further stress the context of the present research and the pertinence of the retrieved documents.

3.8. Contents analysis

In this final section, we enter a little more into the details of the papers' content. Specifically, for the documents in which it was possible to derive the following details in the abstract, we traced: (*i*) the type of food in question, (*ii*) the aim of the RFID implementation and (*iii*) the level of packaging on which the tag was attached.

As far as the targeted products are concerned, most of the documents (37) generically deal with "food", without further specifications. The remaining cases are reported in Table 4 together with the declared aim of the RFID implementation, which represents the second aspect investigated in the documents. Note that at this stage no food categorization was performed, but in Table 4 simply the food declared in the papers is reported. In the future, hoping for a greater sample, a classification is in plan to be defined.

Table 4. Type of food products analyzed and declared aim of RFID implementation.

Type of food	Nr. of documents	Declared aim of RFID	Reference
Grocery	2	Traceability	(Hingley et al., 2007);(Tarnanidis et al., 2023)
Meat	2	Traceability; Food quality and safety	(Kerry et al., 2006); (Kafetzopoulos et al., 2020)
Agricultural products	1	Consumer health	(Farooq et al., 2016)
Agricultural products and food	1	Multiple	(Wang and Li, 2012)
Berry	1	Traceability	(Rendon-Benavides et al., 2023)

Carasau bread	1	Traceability	(Cocco and Mannaro, 2021)
Dairy products	1	Traceability	(Barge et al., 2014)
Food service	1	Data sharing among partners	(Sigala, 2007)
Fruits	1	Traceability + estimation of ripening status	(Mostaccio et al., 2022)
Halal food	1	Anti-counterfeiting	(Nasir et al., 2011)
Lemon	1	Temperature control	(Jiménez-Ariza et al., 2014)
Livestock management	1	Animals traceability	(Teng et al., 2012)
Sushi	1	Traceability on the belt	(Ngai et al., 2008)

Table 5, on the other hand, proposes the general aim of the 52 documents. Overall, nearly always the combination is food + traceability + not specified level of tagging (19 cases). Traceability, in general, is the macro aim which includes all the possible functions enabled through an RFID control, such as track and trace, food security and safety, food waste reduction, anti-counterfeiting, improved operations in warehouse or distribution centers, data sharing, customer experience in and post-sales etc.

Table 5. Declared aim of the RFID implementation.

Function	Nr. of documents
Traceability	27
Food quality, safety and security	11
Multiple	7
Not specified	4
Consumer experience	2
Anti-counterfeiting	1

As it is possible to deduce from the table above, in most of the documents the RFID solution is implemented for traceability purposes, which is primarily the scope of this technology. Sometimes, the reason for traceability is further stressed and specified: Jahanshahee Nezhad et al. (2022) have implemented the RFID technology for managing a closed-loop supply chain; Lao et al. (2011) have used RFID for managing and improving operations first in a warehouse, and the subsequent year in a distribution center (Lao et al., 2012); Kumar and Budin (2006) have used track-and-trace for food recall purposes; Ngai et al. (2008) have dealt with the optimization of the inventory management in a sushi restaurant. Note that warehouse operations management optimization is essential nowadays, due to the increase in time-reduction competition and the growth in e-commerce (Montanari et al., 2021), including the food context.

It is worth noting the unique document in which RFID is implemented for anti-counterfeiting; specifically, in this case, the aim is to avoid halal food labels being improperly used (Nasir et al., 2011).

Among the food quality, safety and control, instead, it is worth noting the functions of temperature control (Jiménez-Ariza et al., 2014) and estimation of the ripening fruits status (Mostaccio et al., 2022).

With regard to the level of tagging, first of all, it must be noted that normally three levels are possible:

- item-level (sales unit, e.g., a bottle of water);
- secondary packaging level (multiple packaging, e.g., shrink-wrapped water bottle packs);
- tertiary packaging/case-level (shipping unit, e.g., a pallet hosting several water bottle packs, used for transportation).

Clearly, depending on the level, different operations can be activated and optimized; for instance, item-level tagging allows to optimize the in-store activities, inventory management and accuracy, the anti-counterfeiting aspect, and the customer experience (note that according to the recent trends, this case is referred to as "smart" packaging). Different is for the other two levels, allowing for an efficiency enhancement of the inventory management and in general of the logistics operations (i.e., the real traceability).

Given the fact that these are preliminary results achieved by only reading the title and abstract, at the current state it was not possible to deepen this aspect since all three levels could allow for traceability and RFID functions. However, in 12 documents out of 52, the item-level tagging was clearly stated, and in 8 of them, the reference was specifically to the "smart packaging", with its declinations in "active" and "intelligent" packaging, two terms that differ among them (this is also supported by the analysis of the keywords, as already stressed).

"Active packaging" refers to the inclusion of additives or inserts for maintaining or extending the quality and shelf-life of products; these can be loose within the pack, attached inside or incorporated within the packaging materials.

Intelligent packaging, instead, closer to the concept of smart packaging, allows for detecting defects, quality monitoring and tracking to control the storage conditions from the producer to the consumer, by using sensors and indicators such as time-temperature indicators, gas indicators, humidity sensor, etc. (Kerry et al., 2006; and Soltani Firouz et al., 2021).

Overall, these 12 documents do not reflect a specific temporal evolution of the item-level tagging, since they are well-distributed among the sample in the whole timespan. However, other research demonstrates a trend that is increasingly going towards this direction (Tebaldi et al., 2023) as also confirmed by the previously mentioned literature reviews, even if with some products the economic convenience should not be forgotten and should be related to the cost of the tags (Aarnisalo et al., 2007). However, it should also be noted that among the

technologies enabling localization issues RFID is the one that better satisfies affordability in economic terms (Volpi et al., 2023).

4. Conclusions

This paper aimed at presenting some initial results starting from an equally preliminary literature research, whose focus was on case studies of RFID technology implementation, and that returned a useful sample of 52 documents taken from the Scopus database (without specific constraints).

The sample was at first subjected to bibliometric analyses. As far as the temporal evolution is concerned, it is possible to derive a steady trend starting from the year 2006, when the first two research papers of the analyzed sample were published. Most of the analyzed documents (i.e., approximately 69%) are journal articles, and the 5 scientific journals which published more than 2 documents each were determined. Among the most outstanding authors, it is worth noting a group from Hong Kong that contributed with 3 documents, and another one from Italy, that proposed again 3 articles. These results, however, partially confirm those of the geographical analysis carried out based on the affiliation of the first author: indeed, the most productive country turned out to be the United States with 7 documents, followed by Italy (6) and Hong Kong (4). Some of the first industrial applications of RFID technology were in the fashion industry; Italy and Hong Kong are famous for their fashion production, and this probably could have impacted the spread of the technology in these countries. As far as citations are concerned, the most cited documents were identified; it does not surprise that the most mentioned documents resulted in being, in the first place, one of the two oldest documents of the sample, followed by the literature reviews. The keywords analysis allowed to confirm the pertinence of the reviewed documents with the present investigation, and the only interesting emerging element is that a recent keywords cluster is packaging-related, stressing the recent shift to item-level tagging.

When dealing with contents, at first the product in question was derived; most of the paper generically dealt with "food" without specifying the specific type. However, among the 15 documents in which the product was declared, 2 dealt with grocery and 2 with meat, the latter being a product with higher monetary value. Other interesting and particular applications that emerged were the use of RFID for the anti-counterfeiting of halal food and traceability in a sushi restaurant (i.e., mainly inventory monitoring). To address the question related to the purpose of the RFID implementation, in most cases, the reason is pure traceability, which embodies other sub-purposes, as already stated in the dedicated section. However, some documents precisely refer to a specific issue, and the most common turned out to be "Food quality, safety and security". To conclude with the contents, the last investigated aspect was the item-level tagging; unfortunately, in almost all the cases it was not possible to derive this specific information, since it was not mentioned; the only exception is represented by those 12 documents in which an item-level tagging was used for "smart" packaging applications. As also highlighted by the recent literature reviews, this underlines an evolution of the usage of RFID in this sense. Finally, please be again reminded that these contents were derived only from the abstract, given the fact that this research is at an embryonic stage, so for sure this part will be deepened and further confirmed.

To conclude, the present manuscript surely presents some limits, which are expected to be overcome in future research activities. Indeed, the sample could be increased by performing new queries. With a greater sample, bibliometric analyses as well will acquire more reliability. With respect to the analysis of the contents, a comprehensive reading of the current 52 documents, as well as those of the future increased sample, is planned.

Moreover, in addition to the abovementioned contents-related information, the stage of the supply chain involved is planned to be tracked, i.e., supply (mainly dealing with agriculture or farm activities), production (transformation), or distribution, including in this last group the selling activity and the customer-related enabled functions; also, Key Performance Indicators are expected to be identified and defined.

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