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Implementation of Automatic Identification and Data Capturing technologies in the Agri-Food Supply Chains: a review and framework

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Abstract

Automatic identification and data capturing technologies, such as radio frequency identification (RFID) technology and quick response (QR) codes, have been proposed as tools for enabling Internet of Things (IoT) and blockchain applications in the agri-food supply chain, allowing for the tracking and tracing of products and sharing data among various actors. While these technologies offer advantages, such as contactless reading, automation, information sharing and traceability management, their adoption in the agri-food supply chain remains limited, hindering digitalization efforts. This paper addresses this gap by analyzing studies that have implemented automatic identification technologies in the agri-food supply chain, focusing on RFID technology and QR codes, mainly for traceability purposes. Drawing from the literature, a framework for implementing those technologies is proposed, aiming to overcome challenges related to product perishability, seasonal variability, and weather fluctuations.

Keywords: radio frequency identification technology; QR codes; automatic identification and data capturing; agri-food supply chain; traceability; framework.

1. Introduction

Process automation, automatic identification and traceability in the agri-food supply chain (AFSC) have potentials to improve product quality, production efficiency and consumers' safety (Lusvisi, 2016). From the consumers' side, the need for certified information about the origins and qualitative characteristics of agri-food products is a main requirement worldwide. At the same time, the current market pressure is more and more pushing towards offering products globally, thus forcing agri-food companies to optimize their supply chain to survive in the market and gain more share of product sales. This implies being able to respond quickly to the consumer's needs, while providing products at the lowest cost, safeguarding quality (Tavakkoli-Moghaddam et al., 2022). The latest historical events such as COVID-19, coupled with the increasing need for developing sustainable agri-food systems (Iakovou et al., 2015), are spurring the search for innovative solutions to respond to current problems and future challenges (Bigliardi et al., 2022).

To achieve these goals, all levels of the AFSC must be carefully monitored and controlled. The need for mapping and knowing the system encompasses not only the finished products, but rather, it begins with the agricultural phase and ends with the final consumers. Indeed, from a structural point of view, an AFSC typically consists of a variety of players, such as farmers, food process industries, retailers, and logistics operators; it is not by chance that the "farm-to-fork" paradigm is typically associated with the management of AFSCs (Lusvisi, 2016).

Paper-based solutions, e.g., barcodes, quick response (QR) codes, or other codes, have been traditionally used for food traceability (Buhr, 2003; Ferrero et al., 2018). Although these solutions could track data about orders and deliveries, they do not provide features like transparency, traceability or auditability (Caro et al., 2018). This is why, in recent times, there has been a push towards a higher level of automation of the AFSC. The introduction of automatic identification and data capturing (AIDC) technologies, Internet-of-Things (IoT), and Industry 4.0 tools in AFSCs has become a popular topic, given the relevant role of these technologies for data collection, process monitoring and traceability (Moysiadis et al., 2022; Bigliardi et al., 2022; Tavakkoli-Moghaddam, 2022). Smart farming based on IoT technologies, for instance, allows farmers to collect real-time data related to irrigation and plant protection processes (Villa-Henriksen et al., 2020). AIDC solutions may improve the efficiency of many processes, at the same time allowing for monitoring the product quality and also reducing environmental impact (Lee and Lee, 2010). Moreover, these tools provide unprecedented opportunities for tracking and tracing agrifood products (Astill et al., 2019; Villa-Henriksen et al., 2020). In line with these considerations, various studies focusing on the AFSC have highlighted that the adoption of innovative technological tools for data collection and sharing is imperative (Linaza et al., 2021; Spanaki et al., 2021).

Radio frequency identification (RFID) technology or QR codes have been suggested as possible tools enabling IoT applications in the AFSC (Lusvisi, 2016), for capturing the data useful to track and trace the agri-food products and sharing them within the various actors of the agri-food system. RFID technology is particularly suitable for food supply chains, as it does not require physical contact for reading, reading itself is quick and fully automated, and information can be easily shared among supply chain players; also, full visibility of the product flow can be achieved, which is relevant to consumers (Violino et al., 2019). However, despite these expectations, researchers have reported that the usage of advanced technologies for automatic identification in the AFSC is still limited, and as a result, the AFSC is little digitalized (Cocco, et al., 2021). Indeed, while the usage of AIDC technologies in the operations and distribution phases of the supply chains is well-established (Tavakkoli-Moghaddam, 2022), challenges exist in realizing traceability systems at the agricultural stage of the AFSC (Luvisi, 2016). Issues range from the perishability of the agrifood products and consequent need for specific transport and storage requirements and their related monitoring (Vlajic et al., 2018; Zissis et al., 2017), to the seasonality of crops cultivation, or variability in weather and consequent quality/quantity of the product (Despoudi et al., 2018). This paper makes an attempt to fill this gap, thus contributing to the literature by answering a specific research question: how can AIDC technology be successfully leveraged fro traceability in the ASFC? To answer this question, a two-step methodology is followed. First, the paper analyzes the relevant studies that have proposed the adoption of AIDC technologies, mainly in the form of RFID technology or QR codes, for monitoring the flow of agri-food product at various levels of the AFSC, for traceability purposes. Then, by gathering the knowledge from the literature, a framework is delineated for the implementation of AIDC technologies in the AFSC.

The remainder of the paper is organized as follows. Section 2 describes the two-step methodology mentioned above. Section 3 provides the results from the analysis of the literature and, on the basis of the related findings, proposes a framework to be followed for the implementation of AIDC technologies in the AFSC. Section 4 ends by highlighting the contribution of this paper to the existing studies, discusses the main implications and limitations, and suggests future research steps.

2. Materials and methods

This paper follows a two-step research methodology, such as *i)* a review of the relevant literature, and *ii)* the proposal of a framework obtained by gathering the outcomes from the literature (see Figure 1).

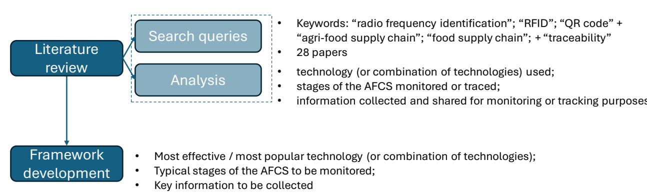

Figure 1: methodological approach.

2.1. Step 1: literature analysis

The literature relevant to this study was retrieved from the Scopus database, by making several queries with specific keywords. In particular, the queries made combined terms related to the technologies (such as "radio frequency identification" or "RFID" or "QR code"), with terms referring to the context ("agri-food supply chain" or "food supply chain") and to the intended aim of the application (e.g., "traceability"). The retrieved studies were screened manually to ensure their relevance to the aim of this research; this led to a useful set of 28 papers.

Because of the limited number of papers, a traditional non-systematic literature review was conducted, as it offers a more comprehensive and in-depth view of the existing knowledge on the topic under consideration. A non-systematic review also allows for more flexibility in source selection and data analysis, enabling to analyze a wide range of perspectives emerging from the academic literature.

For the papers analyzed, the following main aspects were mapped:

1. The technology (or combination of technologies) used;
2. The stages of the AFCS monitored or traced;
3. The information collected and shared for monitoring or tracking purposes.

The outcomes of the literature review are presented in sections 3.1-3.2.

2.2. Step 2: framework development

On the basis of the evidence from the literature review, a framework was delineated for the implementation of AIDC technologies (either RFID tags or QR codes) in the AFCS. The framework encompasses the main aspects listed above, as well as a set of guidelines on how to use the different technologies in the various stages of the AFSC. Suggestions about the reading points and the key data to be recorded are also provided. These outcomes, and relating implications, are presented in section 3.3.

3. Results and Discussion

3.1. Overview of the papers

The 28 papers resulting from the Scopus query were published between 2007 and 2024 (Figure 2); this time span is consonant with the beginning of the studies on AIDC technologies and their application to the logistics/supply chain processes, including the AFSC.

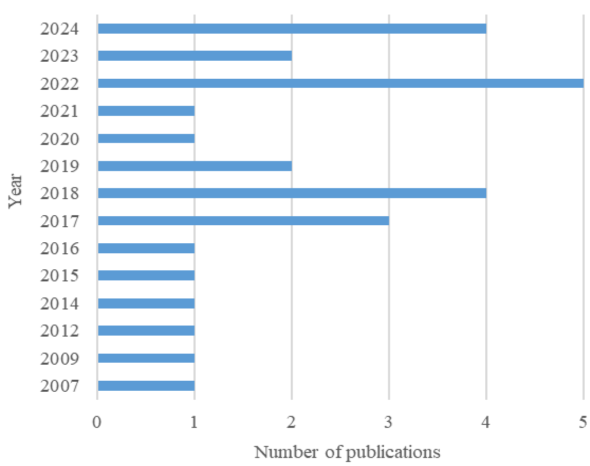

Figure 2: number of papers per year.

Most of the studies (21 out of 28, 75%) retrieved are original research papers, while 7 studies (25%) are review papers. As such, these latter do not always focus on a specific AIDC technology; rather, they describe the usage of more technologies or do not specify any particular technology (Figure 3). To be more precise, one paper refers to the usage of AIDC technologies in agriculture, thus spanning across various solutions, also including RFID, barcodes, or QR codes, but without focusing expressively on any of them (Luvisi, 2016). Seven studies describe the usage of QR codes only, while in two studies, these codes were combined with RFID tags. Overall, the most widely used technology appears to be RFID, with 15 papers describing its usage. Finally, three studies do not specify the technology they refer to; again, this is typically the case for review papers (e.g., Luo et al., 2018) or, alternatively, of papers that cite both RFID and QR codes as possible solutions, but then propose different (new) tools for managing traceability in the AFSC (e.g., Takemoto et al., 2023).

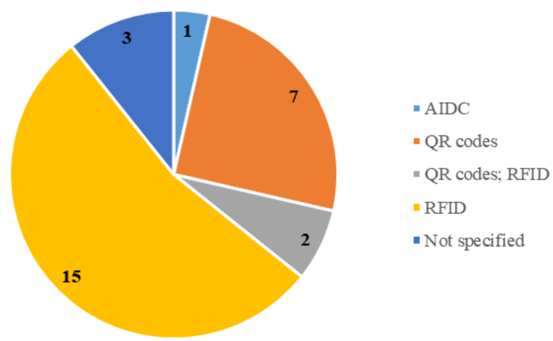

Figure 3: technologies used in the various papers.

As far as the AFSC players involved in the implementation of the traceability solution (Figure 4), most of the studies (15 papers) assume the farmer as the first actor of the system, in line with the farm-to-fork representation of agri-food systems; similarly, the consumer is typically taken as the last player of the system (11 papers). Intermediate players included in the analysis are producers (15 papers), logistics activities carried out either in an internal warehouse or by logistics operators/third-party logistics service providers (9 papers), distributors (11 papers) and retailers (11 papers). A limited number of studies (4 papers) include the provider of seeds or plants in the analysis, as the very beginning of the AFSC, and similarly, 4 papers mention the possibility of extending the usage of the solution developed to external players, such as authorities or stakeholders.

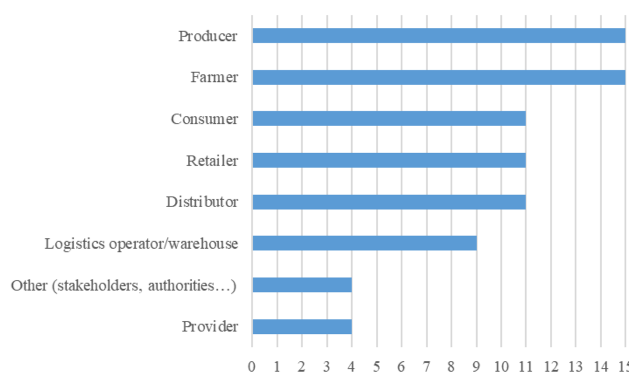

Figure 4: AFSC players targeted in the study.

3.2. Detailed review outcomes

The review papers included in the sample have in general evaluated the technical aspects of AIDC application to the AFSC for traceability purposes. The only exceptions are two bibliometric reviews (Luo et al., 2018 and Violino et al., 2019), which, given the type of study, did not explore the technical aspects of the solutions in great detail.

Luvisi (2016) has provided a comprehensive review of AIDC technologies that can be used to support product traceability in the AFSC. The author has observed that a very simple way to manage traceability in the AFSC is the usage of one-dimensional codes (i.e. barcodes) directly printed on food packaging. Linking these codes to a homogeneous plant or food category could provide a very cheap, but also automatic, method for tracing items along the AFSC. Strong points of these solutions, therefore, are the low cost and the ease of application. However, the usage of barcodes has some limitations, due to the coding capability, but also to the fact that barcodes cannot manage the identification of single plants or food products; also, barcodes do not properly work as sensors. Transmission of barcode data on the IoT has also shown limitations. Electronic identification tools, such as RFID and QR codes, appear to be more reliable to this end, with some successful implementations for AFSC traceability (Costa et al., 2013). RFID, in particular, has progressively increased its usage in time, and in the context of AFSCs, implementations were made for tracing high value products (e.g., wine; Exposito et al. 2012). Examples of RFID usage for tagging food plants are also reported by the author, with reference to fruit trees. Another important strong point of RFID technology is the possibility of associating the tags to thermal sensors, which allows for further preserving food quality by monitoring temperature-controlled systems.

The review by Kumari et al. (2015) has focused expressively on the usage of RFID technology in the AFSC. On the basis of the analysis made by the authors, the main advantages of using RFID in agriculture include real time monitoring of products, quality control, enhanced food safety and traceability, but also the possibility of providing online information systems for end-users. For traceability purposes, in particular, various RFID implementations are identified, targeting fruits and vegetables, meat, and cheese products.

Bhat et al. (2022) have presented a review on AFSC management using blockchain and IoT applications (supported by RFID tags), for effectively handling product traceability. The proposed analysis covers various actors of the AFSC, from the farmer to the consumer, and also includes external stakeholders, such as, in particular, authorities that could ask for traceability data about the food product, for verification purposes. According to the authors, a traceability system based on blockchain and IoT must contain all information relating to food production, processing, transportation and storage. The consumer must be enabled to access all the information about each stage of the AFSC, but also about the single ingredients of the final product. In addition, an effective traceability solution must be able to distinguish the stage from where the food came ("one step back") and where the food is going to ("one step forward"). The usage of IoT, again supported by RFID tags, for AFSC management was also discussed by Tavakkoli-Moghaddam et al. (2022), who found that the basic processes to be monitored for ensuring an effective traceability system are transportation, procurement, food production and, interestingly, resource/waste management. Among the additional characteristics of the traceability system, food safety, food quality, and transparency of the AFSC must be monitored. Interrelations among those aspects are also explored. Li et al. (2024) have instead examined the role of QR codes printed on product packaging (smart packaging) for sharing some key product data and compare those codes with other technical solutions. After reviewing successful examples of traceability solutions based on QR codes, the authors conclude that smart solutions for food traceability, integrating blockchain, 5G systems, cloud computing and proper identification technologies, can effectively enable food recognition, monitoring, and tracing in the AFSC. Blockchain technology, in particular, is suggested for ensuring transparency, integrity, and security of information collected, through data encryption. Cloud computing, instead, enables to store and process data from multiple actors, providing configurable services and real-time data sharing across the different AFSC partners.

The research papers of the sample describe, in most cases, real implementation examples of either the RFID tags or QR codes for traceability management in the AFSC. Six research papers have described the usage of QR codes as the main technology for supporting traceability in the AFSC. Gao et al. (2019) have shown the usage of QR codes and GPS solutions for tracing the golden pear planting and processing industry. The basic idea of the application, which focuses on the farmer only, is that GPS positioning and QR code scanning allow for identifying precisely each tree seedling and each planting plot; these latter are then numbered, and subsequent field operations (e.g., irrigation, fertilization, weed control, pollination, fruit thinning, bagging, pest control, picking, or detection) are recorded using mobile phones, thus automating the process of data collection and management. A similar study was made by Zhao et al. (2022), who again targeted the initial players of the AFSC, i.e. farmer and producer, in the case of vegetable production. The traceability solution proposed by the authors owns specific functions, for effectively monitoring the vegetable production process. Specifically, three macro-categories of traceability information were included in the solution, namely: 1) basic information about the production and origin; 2) vegetable variety information, including seedling source; and 3) vegetable production information, namely cultivation, watering, fertilization, pesticides, etc. The collection and management of the above data were supported by a combination of QR codes as the AIDC device, plus UCC/EAN-128 standards for coding and a software application, designed *ad hoc* using MySQL as database and C# and Java as the development languages. The solution is effective for controlling the nodes of the vegetable supply chain, ensuring quality and safety. The vegetable (in particular, leafy vegetable) supply chain has also been examined by Dong et al. (2020): in this case, the solution proposed by the authors grounds on the combined usage of QR codes and a browser/server architecture, which allows to collect data from various key processes of the AFSC, i.e. planting, harvesting, processing, storage and transportation, and sales, thus covering numerous players, from farmers to customers. The ultimate goal of the solution is to provide the customers with a means for obtaining information about the quality and safety of leafy vegetables; this is indeed the rationale for taking into account the whole AFSC, from the production to the sales of vegetables. Interestingly, the proposed solution also allows for evaluating the nutritional quality of vegetables, by analyzing some key indicators that are added to the traceability system. This latter is grounded on the well-known principles of the Hazard Analysis and Critical Control Point (HACCP) approach combined with fault tree analysis (FTA). Rizwan et al. (2024) have focused on the greenhouse cultivation of fruits, for which an optimal control system is developed. That system is intended to minimize energy consumption, at the same time providing accurate traceability information using blockchain-based mechanisms and IoT. The farmer is therefore the main AFSC player involved in the study; nonetheless, traceability information can be made available to other players, including the end-users. Similarly, Fiore et al. (2024) have designed a blockchain-based food traceability solution for Apulian products, with the aim of improving the perception of consumers of agri-food products. The implementation consists of a front-end application for both the consumer and the producer, a private blockchain for sensors, and a back-end application. The platform can be accessed using appropriate devices (smartphones, tablets, etc.) and allows any user (e.g., consumer, producer, etc.) to verify the origin and the product information, its chemical–physical characteristics and organoleptic properties, as well as to control and monitor the agri-food chain of the product itself thanks to the possibility of accessing information relating to the production phases. The latest study (i.e., Tran et al. 2024) is less technical in nature, and focuses on a particular facet of traceability, namely on the consumer's perception; in particular, the authors have investigated the influence of scanning QR codes and reading product information embedded in the codes on the consumer's valuation of traceable food products. Obviously, the study focuses expressively on the last AFSC player, i.e. the final consumer.

A group of 11 studies have described the implementation of RFID tags, possibly coupled with other equipment, for AFSC traceability. Bernardi et al. (2007) have proposed the usage of UHF RFID tags, coupled with other sensors and blockchain, for traceability management in a generic AFSC, spanning from farmers to retailers, but also including the possibility of sharing data with external authorities. The designed traceability system requires, among others, the identification of operator and its role, the geographic location, the product and the kind of treatment it was subject to, with particular attention to processes that "merge" ingredients or parts of the product. The main contribution of the study by Gandino et al. (2009) is an analysis of the automation characteristics of traceability systems implemented in the AFSC and the evaluation of the improvements achievable by RFID technology. The main elements of the traceability are also described, namely: data storage; tagging of objects; and type of data to be recorded. To this latter extent, a minimum set of requirements is established, including an identification code for the item, the commodity characteristics, and the operation data, so as to track the history of the object. A case study is presented for a warehouse handling fruits. Cuiñas et al. (2012) have designed an RFID-based traceability system for wine production, mainly targeting the farmer and producer. For producing the selected wine, the grapes must come from a strictly delimited area; hence, a main requirement of the system is to identify the location of the vineyards with precision. The control of different weather parameters (rain and temperature) is also important; to this end, specific sensors are installed in the field. The studies by Todorovic et al. (2014) and Jedermann et al. (2017) have both focused on the traceability of perishable products along the whole AFSC, from farmer/producer up to the retailer. Because of the additional requirements of perishable products, RFID tags are coupled with temperature sensors. Products tagging must be made by the producer of perishable goods, who will also install the additional sensors, record the origin data for traceability and encrypt the data with its own electronic signature. The logistic operator will read the RFID data when the container is picked up and check whether the sensors indicate any problem with the contents. A similar check will be made to the products arrived at the retailers. Again in the context of perishable products, Lorite et al. (2016) have developed a new sensor for temperature monitoring (called critical temperature indicator), that can be embodied into RFID tags for an effective usage in the AFSC. The authors conducted some laboratory experiments, while a real implementation lacks in the paper. A similar consideration holds true for the study by Gautam et al. (2017), who have focused on an RFID-based traceability system for the kiwi supply chain from a very specific perspective, i.e. determining the best structure of the AFSC via multi-objective optimization.

Ferrero et al. (2018) have proposed the usage of RFID technology for managing some specific traceability data of agri-food products, with a particular attention to production and storage activity, and to the development of a solution whose cost is affordable for small and medium-sized companies. The proposed solution thus owns a minimal architecture, consisting in a personal digital assistant (PDA) equipped with an RFID reader; all data collected in the production and storage activities are stored locally and occasionally sent to a central data warehouse.

The latest studies have all proposed the integration of RFID tags with blockchain technology, to enhance the effectiveness of the traceability solution. Rajput et al. (2021) have discussed the requirement of a traceability system integrating RFID tags and blockchain, on the basis of previous finding from the literature. Caro et al. (2018) have instead designed and implemented a particular tool, called AgriBlockIoT, working as a decentralized, blockchain-based traceability solution for AFSC management; the tool makes use of IoT devices along the chain, and has potentials to monitor the whole system, from the raw materials (seeds) provider to the consumer. The whole AFSC structure is also the object of the solution developed by Cocco et al. (2021) for traceability of a typical Italian product.

Two studies only have described the combined implementation of RFID and QR codes for traceability management in the AFSC. One study (Subashini and Hemavathi, 2023) is general in nature and describes the challenges of traceability implementation in the AFSC. On the contrary, Yang et al. (2018) have designed an integrated approach to AFSC traceability, leveraging both RFID tags and QR codes. The proposed solution embodies nine functional modules, which range from the management of cultivations to the storage of the finished products. The key data about cultivations include plot code, field code, crop code, responsible technician, and planting date.

3.3. Framework development

On the basis of the findings from the above review, a framework for applying AIDC technologies in the AFSC can be summarized as shown in Figures 5-6.

As far as the technical solution, the first evidence from the literature is that RFID technology is somehow more popular than QR code/barcode technology, but at the same time, successful implementations can be found for both technical solutions. The strong points of RFID usage encompass the wider data storage capacity, the non-need for line-of-sight scanning, the robustness of the tag and the possibility of embodying additional sensors (e.g., temperature sensors) inside the tag itself. At the same time, QR codes are easier to print and attach to products, less expensive and almost known to any user, including the final consumers, who could personally scan the codes and retrieve the relevant information about the product. For both technologies, the integration with blockchain solutions is recommended, in the light of their capability to enable real-time traceability of the information recorded on the history of the product and ensure immutability of the related information.

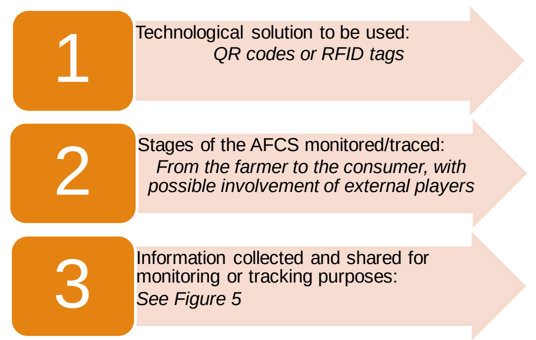

Figure 5: basic structure of the framework.

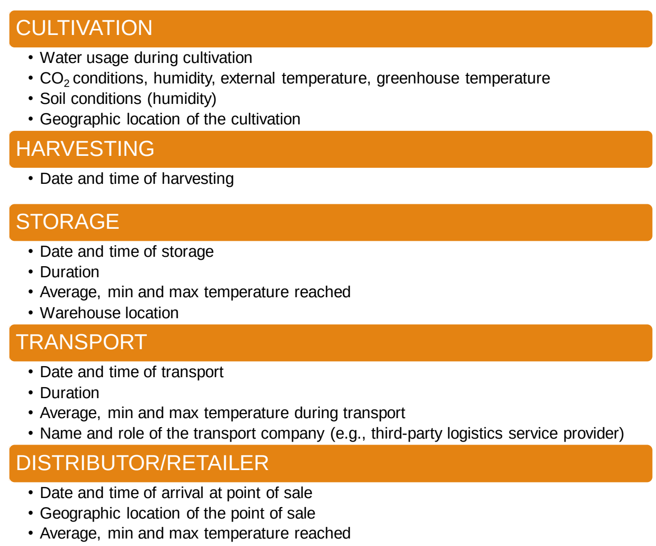

Figure 6: detailed data to be collected.

To this latter extent, it can also be observed that the traceability system begins at the farmer stage, rarely involving the provider of seeds or plants, and ends at the consumer, after the sale of the products. The basic idea is that the consumer could access product data, for checking, e.g., its origin, ingredients or other traceability information. Making these data available to other players, however, also appears as relevant; indeed, because traceability requirements are established by law, it is always possible that external authorities require the certification of the final product. Again, blockchain solutions can be leveraged to this end, as effective tools for guaranteeing the various stakeholders, from the agronomist to the final consumer to transparently verify the whole history of the product.

4. Conclusions

This study has conducted a review of 28 studies describing implementations of AIDC technologies, mainly in the form of RFID tags or QR codes, for collecting and managing data in the AFSC, and has delineated a framework encompassing the key points to be taken into account when implementing those technologies in a real agri-food system.

The framework reflects the findings from the extensive literature analysis, which, at the same time, highlights the current state of adoption of RFID, QR code, and other AIDC solutions in the AFSC, together with the goals of implementation and associated challenges. Furthermore, the framework identifies three main intervention points for the effective implementation of AIDC technologies, i.e. the selection of the most suitable technology, the definition of the data to be collected, and the identification of the key players to be involved in the process. This framework provides practical guidance for companies wishing to adopt traceability solutions in the AFSC. Obviously, improvements to the proposed framework are always possible; for instance, taking a scientific perspective, relationships could be identified between the selected technology and the information mapped or the success of the implementation. These considerations could enhance the robustness of the proposed approach.

From a practical perspective, the natural progress of the research, on which the authors are working at present, will be the design and implementation of a traceability solution in a real agricultural context, following the outlined framework. The data derived from the in-field implementation will be carefully analyzed to evaluate the effectiveness of adopting AIDC technologies in the selected context, and the related impact.

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