The concept for an integrated IoT-based traceability platform

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Abstract: A significant proportion of fresh products either does not reach the market due to quality deterioration or reaches the consumer in poor condition raising concerns about marketing and public health. Latest advances in sensing and communication technologies in agriculture and agri-food supply chain, facilitate traceability, monitoring the products throughout the whole supply chain, starting from in-field production and through all steps of transportation, processing, and marketing. In this work, an IoT-based web and android-based platform is proposed which will monitor and guarantee the quality of the fresh products through a traceability system. The system supports enhanced communication between sellers and traders and includes all the significant steps from the farm to the storage, processing, packaging, transportation and placement at the store's shelf and the final receiver, the consumer. Thus, this work contributes with new knowledge, providing an overview of the design of integrated system for advanced traceability of fresh produce.

Keywords: internet of things; IoT; traceability; fresh produce; supply chain.

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1 Introduction

Traceability and food safety are recognised as important pillars in the agri-food sector (Jin and Zhou, 2014; Accorsi et al., 2016; Foras et al., 2015). However, some sectors in the fresh food industry are considered more advanced in their application of relevant processes throughout the supply chain than others. Industry and major players in supply chain management, work together to develop a holistic, integrated traceability process, which can benefit all sectors of fresh produce (Chen, 2017; Badia-Melis et al., 2015), such as seafood, dairy, baked goods, meat, poultry, fruits, and vegetables.

In addition, global players in the fresh produce industry are realising the necessity to align supply chain practices with established procedures which are successfully used by producers and food retail companies. The common denominator in all these supply chain practices is the use of GS1 standards that act as a catalyst to lead the industry towards an integrated and interoperable food tracking process (Xinting et al., 2008; Bai et al., 2017). Therefore, the fresh produce industry is mature enough to take advantage of the operational results from transformational actions of using GS1 standards as a basis for traceability and food safety.

The two main guides to promote traceability in the fresh fruit and vegetable industry are the legislation (e.g., EU Regulation 543/2011), and the increased awareness and demands on the consumers side for accurate and complete information about the foods they consume, especially the fresh foods, which are more prone to deterioration (Francesco Bimbo et al., 2017; Jin et al., 2017; de Boer and Schosler, 2016). Facing the challenges of meeting the legislation requirements, as well as meeting consumers' expectations for safe fresh food, individual sectors in the food industry design separate, often parallel, routes to determine the traceability guidelines and address specific food safety aspects related to the particular characteristics of the individual supply chains. In traceability applications at international level, it is clear that product identification and standardised exchange of product-related data, contribute to food safety while establishing cost-effective business processes for disseminating information to everyone involved in the supply chain.

Therefore, an effective tracking process should be based on a standardised approach of fresh produce, while remaining flexible in terms of the individual roles and responsibilities of the various links in the supply chain within the ecosystem. While many trading partners already have interconnections with external systems and procedures for some level of traceability of their products, the next step towards an integrated approach, is the identification of interoperability capabilities between internal and external processes throughout the food industry. This approach requires:

- Common language and procedures by all stakeholders at the individual levels of the supply chain.
- Interoperable solutions at the levels of hardware and software.
- Evidence of benefits for all companies in the supply chain.

The last point is particularly crucial for the adoption of a holistic traceability process. International studies document the expected benefits for everyone, which include (GS1, 2013):

- Improved food safety through effective recalls.
- New, increased business efficiency for all members of the supply chain. Waste reduction by applying appropriate handling on the basis of traceability at product level.
- Increased revenues.

Using an effective tracking program and technologies that provide real-time data, companies can effectively and accurately isolate and recall only the products that are inappropriate. This reduces the disturbance in the supply chain, minimises the food waste and optimises the company's resources management.

State-of-the-art technologies such as the internet of things (IoT) are particularly promising can play an important role in implementing innovative traceability approaches (Verdouw et al., 2016; Badia-Melis et al., 2015). The IoT is particularly promising as a means that can lead the way towards improved performance throughout all the procedures of the supply chain, including storage, transportation, and final delivery. The IoT can support the automatisation of business processes eliminating the manual interventions, improving quality and forecasting, with the aim of reducing costs. These systems also provide the possibility to improve the synergetic actions of people and systems coordinating and optimising their activities.

From the literature analysis, interoperability of the systems used in the supply chains and their interconnection with IoT, were identified as the main gaps in fresh produce traceability applications. In this work, an IoT-based web and android-based platform, named 'AgroTRACE', is proposed to monitor and guarantee the quality of the fresh produce through a traceability system starting from farm level to the consumer. The proposed system is currently at the stage of experimental proof of concept (TRL3) and technology application (CRL3). It consists of a web platform with enhanced operability for all the participants in the food supply chain, and an Android application for consumers containing all the basic functions for on-the-fly scanning and retrieving the history and all the important information of the agricultural products.

2 The AgroTRACE concept

Based on the consumers' needs, the business environment has matured for the integration of traceability processes throughout the fresh produce fruit and vegetables supply chain using IoT technologies. Towards this direction, the food industry must systematise an integrated whole chain tracking process, following proven good practices in supply chain management at international level, while fulfilling the legislative requirements.

Literature regarding traceability systems with the use of IoT technologies is increasingly enriched, however currently available integrated systems are few and far from being commercially used. Even retail giants like Wall-Mart at the moment are still following pilot integrated approaches for the assessment of the potential use of such technology and how it can be integrated into fully traceable processes of food (Kamath, 2018). In this specific pilot, Wall-Mart collaborates with IBM Watson IoT Centre in Munich. However, there are, already available on the market, some early efforts of integrated systems to support project implementation traceability using IoT technologies. We consider our proposed open modular and integrated system approach, which will be based on open and transparent standards supporting interoperability, will allow faster control of the proper operation and integration of the system in product traceability processes. The following table presents a comparative evaluation of the proposed system with integrated systems currently on the market.

As seen in Table 1, the proposed system incorporates the best features available that the various other systems use. Additionally, Agro-Trace is the first to use an open architecture that clearly differentiates it from other systems in terms of interoperability.

The proposed system aims in supporting both the internal traceability within companies, as well as the overall (external) traceability of products (fresh fruits and vegetables) throughout the supply chain. More specifically, the internal traceability will include packaging procedures for linking the identity of the batches of fresh fruits and vegetables to the final product. Accordingly, external tracking will involve communication between trading partners concerning the identity of the products and their transportation. In this direction, the products identification codes will be notified to those involved in the distribution network, on products labels, and the related electronic documents. These actions will associate the products with the information required for their traceability. The GS1 standards will be used for the delivery of common language that will allow trading partners to exchange data and use them on their information systems for processing and managing purposes.

The proposed system will achieve end-to-end traceability of fresh produce supply chain, combining internal and external tracking processes. Thus, each operator will be able to identify the direct source and direct recipient of the products. The system will apply the 'one step up, one step down' principle to provide effective tracking to the supply chain. More specifically, each distinctive product will be recognised worldwide and with a unique way so that it can be recognised upstream and downstream the supply chain. All participants in the distribution network will be able to use the system to implement internal and external traceability practices. In addition, internal traceability will be applied in such way ensuring that the necessary connections between inputs and outputs are maintained.

Implementing traceability in a supply chain is based on network participants who collect, record, store and share relevant information. The aim of the proposed system, is to effectively support this application through a 4-stage process:

1 Recognition. Following the GS1 standards, the system will distinguish (at unit level) all fresh products (commercial items), infrastructure, sites, etc., from the grower to the consumer. Specifically, our system will use the following standardisation:

   - Global location number (GLN): Distinction of the location of a farm, packaging unit, wholesaler, distributor, retailer etc.
   - Global trade item number (GTIN): Trade item identification – unique number product.
   - Electronic product code (EPC): Commercial item serial number.
   - Serial shipping container code (SSCC): Serial container code for pallets.
   - Global returnable asset identifier (GRAI): Discrimination of returned products.

2 Recording. The GS1 system data carriers will be used for data management aiming to meet different supply chain process needs for different products. EAN/UPC barcodes are to be used for scanning at retail stores. The GS1-128 barcodes will be used for identifying the product units on the packaging and the pallets so as to provide information about the products, monitoring their movement throughout the supply chain. GS1 DataBar barcodes carrying the same – and in some cases larger – information in less space than the UPC barcodes. The latter will be used in small, difficult to track products. The IoT application will use RFIDs connected to the EPC of the products. The data encoded in the GS1 system data carriers, not only will be able to recognise the products (and product units), but will allow trading partners to share large volumes of data (batch number, production date, packaging information, etc.).

3 Evaluation. The collected information, will be evaluated in relation to the objectives expressed in the form of key performance indicators (KPIs), to be set by the supply chain partners. In addition, the system will enable the use of KPIs from the supply chain operations reference SCOR) [ASCM, SCORmark Benchmarking] in order to be able to 'anonymously' evaluate the performance of the chain partners.

Table 1 Characteristics of the proposed and other integrated traceability systems available on the market

System	*Standard*	*Supply chain*	*Minimum reference level*	*Data transfer technologies*	*Modular structure*	*Open architecture*
Agro-Trace (proposed system)	GS1	Field – consumer – field	Product	RFID, LoRa WAN, beacons (BLE)	Yes	Yes (XML, web services)
GR-LIVE [Globeranger]	–	Field – retailer	Product	RFID	Yes	No
iApp [ORBCOMM]	–	Packaging plant – retailer	Container	RFID, Satellite, BLE	Yes	No
AutoSense [PakSense]	–	Packaging plant – retailer	Container	RFID, NFC, GSM	Yes	No
HarvestMark [HarvestMark]	–	Packaging plant – consumer	Product	RFID	No	No
FoodLogicQ's Track + Trace [FoodLogicQ]	GS1	Field – retailer	Product	No	No	No
iris [Ferquentz]	GS1	Packaging plant – consumer	Product	No	Yes	No

4 Sharing. The interoperability of our system will facilitate the smooth exchange of information in trade transactions. The following GS1 interface standards are to be used:

- *Global data synchronisation network (GDSN)*: GDSN connects trading partners with GS1 Global Registry® via GS1 Certified Data, enabling instant electronic exchange of standardised, updated and verified information. It shares information concerning GTINs, unique product owner identity, product description, product classification (GPC – global product classification).

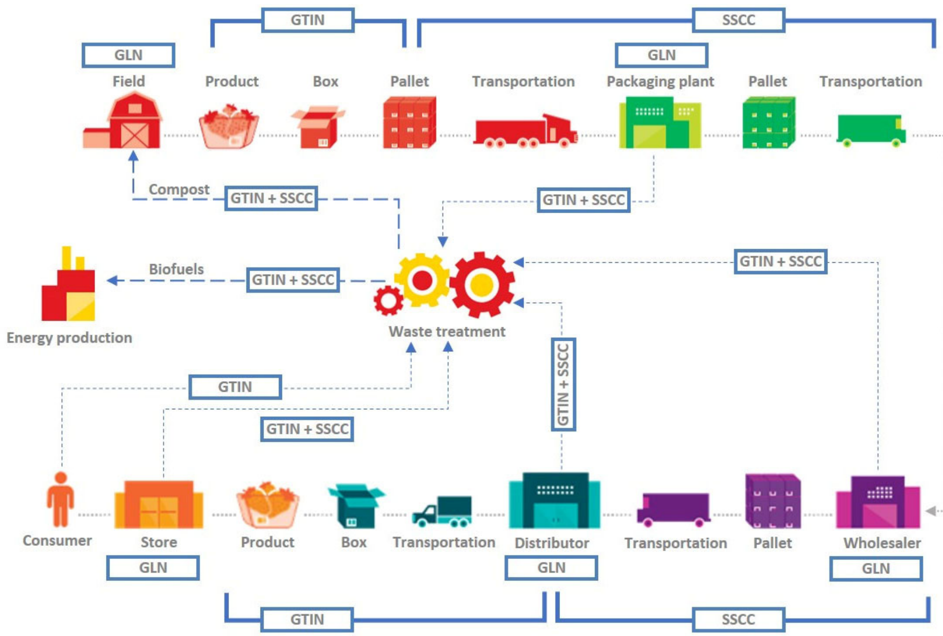
- *Electronic data interchange (EDI)*: EDI allows the exchange of business documents between companies using a standard format. It shares information such as GTIN, GLN, SSCC, order details, delivery information, invoicing, and payment tracking.

- *Electronic product code information services (EPCIS)*: EPCIS is the standard for the exchange of information about critical events, monitoring the progress of a product along the supply chain. It shares information such as GTIN, GLN, event date and time, and location in the action stream.

The Integrated Traceability and Distribution Support System – AgroLogistics of Fresh Fruits and Vegetables (AgroTRACE) will cover the whole range of production and distribution of fresh fruits and vegetables, from the field to the shelf, and even beyond. The innovation of the proposed system is further strengthened by the fact that traceability will go beyond the field-to-shelf route and will cover the part of recycling (biomass, compost, etc.), in the context of the circular economy. Within this concept, the system will implement traceability from field-to-shelf-to-field. In this way the system will enhance food safety by providing detailed information accessible from the entire supply chain, including consumers, certification bodies and audit authorities. The proposed traceability system will fully support traceability of organic waste (biowaste), providing supply chain partners with documentation on their corporate social responsibility, while supporting industrial symbiosis (industrial symbiosis), where the waste or by-products of a production process constitutes an input of another production process unit. An important element of the system is the collection and management of big data related to the real conditions at the various stages of the chain. According to the Food and Agricultural Organisation of the United Nations (Ghamrawy, 2019), 45% of the quantity of fresh fruit and vegetables that have passed through sorting and packaging process, either reach the consumer in degraded quality and are discarded after purchase, or the retailer describes them as non-marketable resulting in their immediate rejection. The intensive use of traceability procedures in the entire length of the chain will minimise this proportion through better management of products and information.

The proposed approach covers the whole range of the fresh fruit supply chain and vegetables as shown in Figure 1. Intensive use of GS1 standards is a prerequisite for the Integrated AgroTRACE System to be fully modular having the ability to connect, receive and distribute information with IoT and event capturing applications (e.g., QR and bar code readers). Also, an important feature of the system will be the efficient management of the big data to be collected. A basic implementation component for the big data management system, is Apache Hadoop framework architecture [APACHE SOFTWARE FOUNDATION], which is open source and allows for distributed processing of large data sets in computer clusters using simple programming models. For the planning and management of processes in the individual Hadoop computing components, the Mesos framework will be used. For processing of distributed data, the system will use the open source and open code Apache Storm which allows very fast real-time data analysis.

Figure 1 Conceptual framework of the Agrotrace system (see online version for colours)

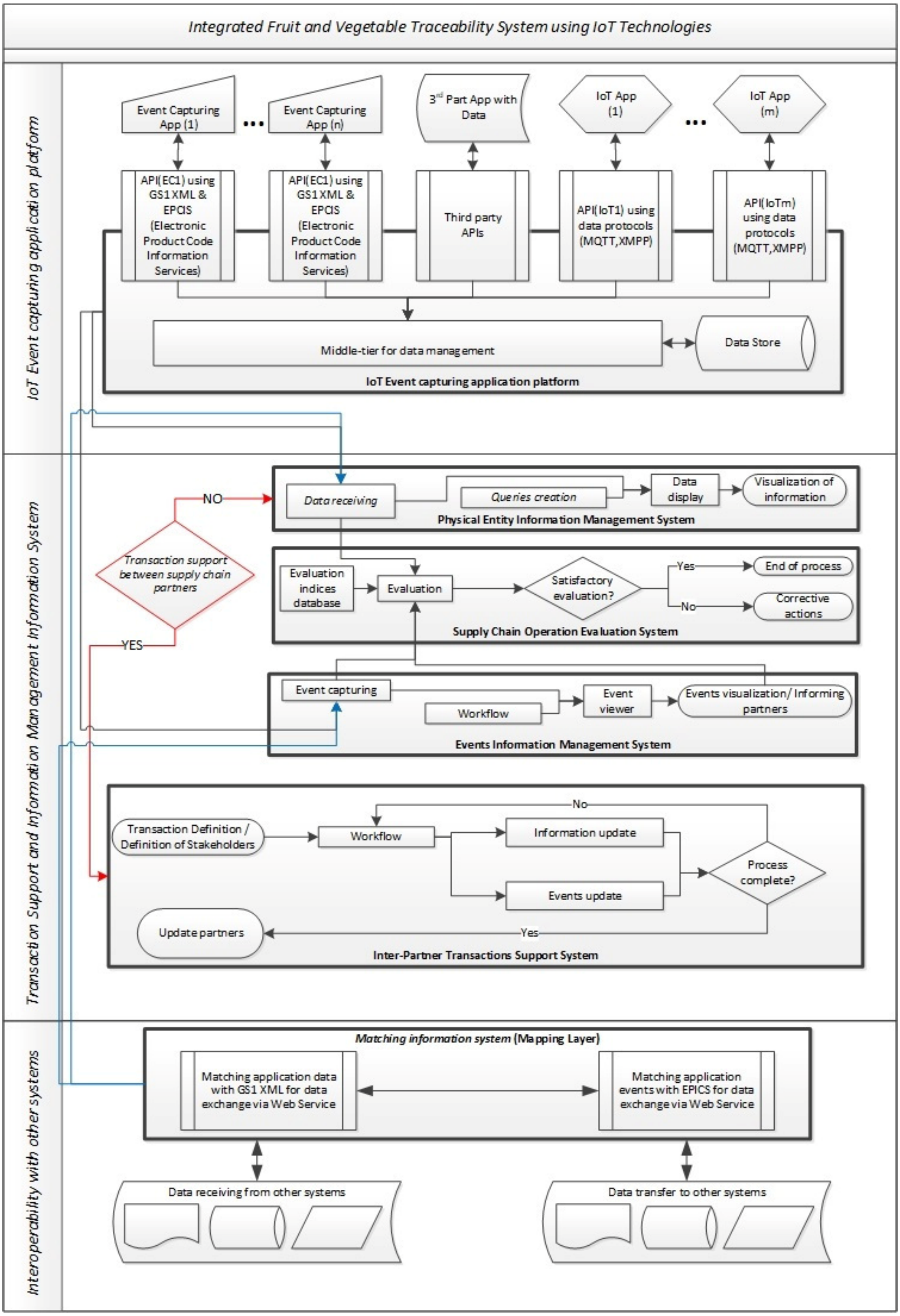


3 The AgroTRACE system structure

The AgroTRACE integrated system using IoT technologies will have the schematic structure of Figure 2. Regarding the IoT applications, specific standards will be followed for the management of the information they provide:

- *Message queuing telemetry transport (MQTT)*: The MQTT protocol allows a model for recording and publishing messages with extremely small data volume. It is useful for connections to remote locations, where a small footprint is required.
- *Extensible messaging and presence protocol (XMPP)*: It is a set of open instant protocols for real-time communication, which supports a wide range of applications, such as sharing instant messaging, multi-party chat, voice and video calling, content sharing, and generalised XML data routing.

Figure 2 Structure of the proposed integrated fruit and vegetable traceability system using IoT technologies (AgroTRACE) (see online version for colours)



For the inter-device communication, a LoRaWAN network will be used, which features wide coverage range (signal transmission at a distance up to 20 km) and low energy consumption. Additionally, the GS1 EPC radio-frequency identity protocols generation-2 UHF RFID Specification for Communications at 860 MHz–960 MHz, will be followed. Finally, the beacons technology and the corresponding Bluetooth low energy (BLE) communication protocols will be used, mainly in the last stage of the chain. Regarding the integrated management of the information received from the applications event capturing and IoT, or other applications with relevant information (e.g., Google Maps, applications meteorological forecast), a middle-tier management plan will be linked to the APIs of these applications. In addition, an information mapping layer will enable data exchange with other information systems in the context of the interoperability of applications along the entire length of the chain. As shown in Figure 2, the Integrated AgroTRACE System is based on three basic pillars:

1. the IoT application platform and event capturing
2. the transaction support and information management information system
3. the data mapping system for enhancing interoperability.

3.1 The IoT application platform and event capturing

This platform is responsible for collecting, processing and strafing the data and events to be received from different event capturing applications, from IoT applications and networks, and third-party applications. The event capturing applications may include visual reading using smart devices for the route from field to the packaging plant and for management purposes in the retail level.

3.1.1 Route from field to the packaging plant

The GRAI application can be used to scan the fresh fruits and vegetables during harvest and imprinted the information in QR codes or barcodes on the pallets. The batch numbers will be scanned throughout all the steps the product passes in the supply chain (e.g., the packaging, sorting line, temporary storage). These numbers are linked to the GLN numbers of the field and the packaging plant, as well as through the sorting line using the GTIN numbers of the products, the extended form (GTIN-128) containing information of different batches, and with the SSCC numbers of the pallets.

3.1.2 Management at retail level

The customer will be able to scan the product numbers with the GTIN-128 application. The numbers will be imprinted in QR codes or data bars on the products, giving access to their history. Thus, the product can be monitored after the store's shelf, until the consumer's refrigerator.

3.1.3 Use of RFID technologies at the route from field to the packaging plant

Each pallet will have an RFID with an EPC number. The packaging plant will be equipped with RFID readers at the sorting lines and at the temporary storage points where the harxested products are pending sorting and packaging.

3.1.4 Use of RFID technologies within the packaging plant

All packed products and each pallet will have an RFID tag with a unique EPC number. The packaging plant will be supplied with RFID readers at the exits of the market-ready products.

3.1.5 Use of RFID and beacon technologies during product transportation

The trucks will be eqiopped with a beacon device recording environmental data (temperature, humidity, ethylene concentration, etc.), and RFID readers. Thus, the conditions during transportation can be continuously monitored. This implementation will utilise LoRaWAN network for data transmission at city-logistics level for rapid response of the supply chain as the products are approaching the retail point.

3.1.6 Use of RFID and beacon technologies in the store

Beacon devices in the retail stores can transmit useful information to the customers' smartphones, and read EPC numbers via RFID readers.

3.1.7 Use of RFID technologies at the level of organic waste management

Waste treatment points with RFID readers will undertake the continuation of traceability at the level of waste treatment and by-products production (biofuels, compost, etc.). Alternatively, special bins for organic waste will be installed (brown, based on international standards). The brown bins (with special RFID marking) can be weighed and identified using automated intelligent waste management systems (Waste Logistics) in garbage trucks and waste quantity information will be integrated in the AgroTRACE System. The corresponding APIs will connect the applications to the middle-tier of the information management platform. Google Maps and Google Surveys APIs will also be connected to the middle-tier (for evaluation in various stages of the chain).

3.2 Transaction support and information management information system

This system consists of four subsystems, and utilises the information collected by the IoT application platform and event capturing for the implementation of tracking procedures.

3.2.1 Physical entity information management system

It enables users, through complex queries, to access the information making full use of its visualisation capabilities data.

3.2.2 Event information management system

This subsystem is responsible to keep track of events that occur at different stages of the supply chain within clearly defined workflows taking full advantage of data visualisation capabilities.

3.2.3 Supply chain performance evaluation system

It will allow continuous evaluation of the supply chain comparing real-time data with KPIs.

3.2.4 Transaction support system between partners

This subsystem supports transactions between partners in full length, utilising data and facts.

3.3 Data mapping system

The information produced both in the platform and in the four subsystems, will be standardised using GS1 standards, in order be able to share information with other systems, inside and outside each supply chain. The information could function as reference knowledge (benchmarking) through its widespread dissemination (knowledge diffusion).

4 Conclusions

In this study, the concept of an integrated traceability system for fresh produce using IoT, is presented. The proposed system is innovative integrating the event application management platform and IoT with focus on interoperability. An important part of the system is the transaction support and information management system, which supports all partners in the fresh fruit and vegetable supply chain, starting from the in-field production up to the store shelf and the consumer. Traceability reaches the organic waste management as part of a circular economy approach. Traceability begins in the farm, where all the information concerning the cultivation management (irrigation, fertilisation, pesticide applications, etc.) is recorded. The produced fresh fruits and vegetables are labelled using a unique batch code which follows the product throughout the whole process and logistics chain. TraceID or QR code is used for labelling each individual product which can be scanned by the consumer or any operator in the food supply chain, to retrieve the product's producer's information and the cultivation, handling, and transportation history. IoT technologies are integrated in the system to support traceability through continuous monitoring of the product throughout the supply chain.

The proposed system described in this study, can be considered as an optimistic approach, since large barriers need to overcome, namely the limited interoperability and interconnectivity of the different systems and technologies throughout the agri-food supply chain. Another drawback of such systems is the limited acceptance by the end users. However, in this work, thorough analysis and careful designing of the system ensures the delivery of a complete product which is applicable to every sector of the agri-food supply chain. The system can significantly contribute to better and more efficient operation of the whole supply chain of fresh fruits and vegetables, by continuously monitoring and improving the processes, providing a competitive advantage in a rapidly growing market. The proposed system is in compliance with GS1 standards and related best practices and integrates a range of IoT technologies (RFID, LoRaWAN, Beacons), for traceability purposes in all stages of the supply chain. Furthermore, the open architecture concept supports its full interoperability with other systems and technologies guaranteeing its broad acceptance.

This work is part of an on-going study. Future plans include the development completion and performance evaluation of the traceability-dedicated IoT systems and of the integrated traceability platform.

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