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Digitalization of Fresh Chestnut Fruit Supply Chain through RFID: Evidence, Benefits and Managerial Implications

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Abstract: This study provides evidence of supply chain (SC) management based on the digitalization of a fresh fruit-supply chain (i.e., chestnuts) using a radio-frequency identification technology (RFID). This research adopted the value-chain operation reference (VCOR) to assess the implications, issues, and benefits of the SC digitalization, and to explore how RFID can be configured regarding the VCOR blocks. Within this framework, the SC stages, processes, and operations were assessed using a tailored performance measurement system (PMS) including a set of metrics tracked, quantified, and evaluated alongside a monitoring field campaign. The results indicated that: (i) the benefits deriving from the RFID are constrained by specific organizational procedures adopted in operations management; (ii) the PMS Indicators of the centralized warehouse, balancing the inventory between the processing line and the distribution channels, presented the most significant improvements across the whole SC.

Keywords: supply chain traceability; radio frequency identification (RFID); value chain; fresh fruit; chestnuts

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1. Introduction

Supply chain management (SCM) is used to plan operations and design SC systems able to meet customer demand within the due date and at the lowest cost. Such a target can be achieved with an efficient SC management that attempts to avoid errors and measure' uncertainties, as well as through the timely and precise monitoring of the inventory at the warehouses [1].

In this context, the value chain pattern [2] allows for the optimization of the SC stages by focusing on the benefits for customers and on certain added-value processes that they are willing to pay for. Nevertheless, value is subjectively perceived and dependent on context [3]. First, products or services may have not the same values worldwide, and furthermore, such values are not constant over time. Secondly, value occurs when needs are met through the provision of products, resources, or services. This is reasonably true for some agri-food products (e.g., fresh fruits, dairy) featured by low added value from suppliers' perspectives.

This study evaluated the problem of SC management in the fresh chestnuts industry with a twofold objective. The first was to explore the drivers of choice for the adoption of RFID technologies in food SC management and how these can be applied toward an enhanced control of chestnut storage/distribution operations. The second objective was to appraise the practical impact of this technology on SC management within the food supply chains. With regard to the undertaken methodology, the framework adopted in the study is the VCOR model, used to unpack the potential application of RFID within this model.

The paper is organised as follows. Section 2 presents a review of the literature focused on the value chain and RFID in SC, while in Section 3, research questions are formulated. Section 4 describes the chestnuts supply chain of the case study and its configuration.

Section 5 relates technical details of RFID deployments, while in Section 6, the operations observed are detailed. Section 7 presents the results of the study, while Section 8 discusses the managerial implications and concludes the work.

2. Literature Review

2.1. The Value Chain Modeling

The VCOR model is organized upon seven attributes, linking the three domains of product development, supply-chain management and the customer chain across the supply networks. The structure of VCOR models supports and enables companies to integrate these three critical domains using one reference model to support the vision of an integrated value chain [4]. VCOR uses a "process-based, common language" of syntax and semantics while, at the same time, creates a base for the successful service-oriented architecture game plan.

The main objective of VCOR is to increase the performance of the SC and support its evolution through four different layers:

The Top Level (TL) of the model includes all the high-level processes. It is depicted through the process categories of plan-govern-execute seen as the "Strategic Level" (SL), where high-level decisions are made on gaining competitive advantages for the whole SC. The VCOR SL has three macro-processes:

- Plan: this balances the current strategic objectives with the current asset status and produces decisions on activities to drive organizations toward the goals;
- Govern: this identifies and enables value-chain rules, policies, and procedures to control the implementation of plans and execute processes;
- Execute: this transforms customers' and product requirements into value-chain features. The executive processes operate within the limits of the management criteria.

The second level of the model contains the processes decomposed from the SL to implement the goals set into a panel of tactics. This level, defined as "Tactical Level" (TL) can be described as an "horizontal value-chain process re-engineering".

The third level of the model regards the gist of this study. This level focuses on the specific processes of the value chain and aids process improvements or process re-engineering, including new technologies deployment and KPI. Over a value chain perspective, this is the level where fine tunings occur.

The VCOR model is based on high-level generic process categories suitable for all types of firms. Yet, the feature that perhaps is the reason for its success is the capability to define the level of performances for each process of the SC and to introduce best practices for the management of productive processes. Table 1 describes the processes considered within the model.

Table 1. VCOR Processes.

Phase	Description
Market	Processes are finalized to understand market's needs and translated into product service requirements
Research	Processes used in assessing, developing and transferring technologies
Develop	Creating the virtual definition and/or prototype of the product/service
Acquire	Procuring goods and services to forecasted or actual SC demand
Build	Transforming product to a finished state to meet the demand
Fulfill	Providing finished goods and services to meet planned or actual demand
Brand	Aligning brand strategy to business strategy and customer touch points
Sell	Activities associated in product/service selling
Support	Maintaining operational/economic performances of products/services

Some interesting applications of VCOR and the value chain can be found in the seminal work of [3], in food wastes problems [5], in [6], and recently in the work of [7], in which the VCOR was implemented with green concepts.

2.2. RFID and Supply Chain

RFID may offer several contributions to SC management, through (i) the identification of products, (ii) ease of communication and (iii) real-time information [8,9].

In the last decade, RFIDs have been applied in different types of supply chains for warehouse management, inventory, and asset management [10,11].

RFID mainly acts toward an efficient location and traceability of products, as well as their visibility throughout the SC [12,13]. Through RFID, companies can achieve better SC management by storing more accurate data in their IT systems [14–16].

These studies, along with the finding of [17], indicate that reengineering models may increase the possible RFID benefits for all processes of distribution centres and retailers, thus enhancing IT-driven service innovation.

Other applications of RFID include: [18] inventory routing problems and [19] the visibility of components in an engineering-to-order SC.

RFID benefits, in terms of competitive advantages, have been assessed by [13] with an interesting investigation in retail networks, while [20] explored potential factors in a vertical SC.

Along the same lines, Ref. [21] explored the potential enabling factors of RFID in SC, when cost and competitiveness are the priorities of firms.

Based on these findings we may argue that RFID can bring the following main benefits: (i) cycle-time reduction, (ii) self-service enabling, and (iii) loss prevention. In the food industry, an interesting application of RFID is the one evaluated by [15], to improve the location of products in stores.

Still in the food sector, Refs. [12,22] reviewed RFID-based systems to address food safety. These studies considered RFID technology as an operational tool able to increase control over SC operations, thereby ensuring higher food-safety targets.

The above findings are supported also by the works of [23] and of [24], who concluded that the benefits of RFIDs are mainly in safety, operation times and labour costs. In this research context, we may argue that the main benefits of RFID are in value-chain management and this view may be supported by others [25,26].

In comparison with recent scientific contributions, the present work aimed to introduce an RFID technology within a fresh-fruit supply chain under the VCOR framework with an attempt to improve operational cycle times, gain real-time information about inventory levels, and improve service levels by tackling delivery errors. Table 2 summarizes the main research objectives of the implementation of RFID to the observed SC. In Table 2, it is worth noting that the RFID technique has not been considered yet in the framework of the VCOR model, with the aim of improving the management of warehousing operations to the best of the authors' knowledge. This paper attempts to fill this gap in the literature.

Table 2. Literature classification regarding the research objectives based on RFID.

Reference	Research Objective							
	Efficiency	Productivity	Feasibility Study	Cycle Time	Inventory Management	Security	Traceability	Delivery Time
Khan et al. (2020) [27]	✓		✓		✓	✓	✓	
Podduturi et.al (2020) [28]	✓	✓					✓	
Ali and Haseeb (2019) [29]	✓					✓	✓	✓

Table 2. *Cont.*

Reference	Research Objective							
	Efficiency	Productivity	Feasibility Study	Cycle Time	Inventory Management	Security	Traceability	Delivery Time
Biswal et al. (2018) [30]	✓					✓		
Tsao et al. (2017) [31]	✓		✓	✓				
Gautam et al. (2017) [32]			✓		✓		✓	
Tian (2016) [33]			✓			✓	✓	
Tanner (2016) [34]	✓				✓	✓	✓	
Shin and Eksioglu (2015) [35]		✓						
Ren (2015) [36]	✓					✓		
Rossi and Pero (2014) [19]			✓				✓	
Chen et al. (2013) [9]	✓		✓					
Laosirihongthong et.al (2013) [21]			✓					
Miaji et al (2013) [37]			✓				✓	
Liu et al. (2012) [22]						✓	✓	
Min et al. (2012) [24]		✓	✓			✓		
Neubert et al. (2011) [17]	✓		✓					
Bendavid and Boeck (2011) [23]							✓	
Sarac et al. (2010) [38]			✓		✓			
Battini et al. (2009) [11]			✓				✓	
Jindae et al. (2008) [25]							✓	
Choy et al. (2007) [16]			✓	✓	✓			✓
Shrikant et al. (2007) [18]			✓					✓

3. Research Questions

Notwithstanding that VCOR is acknowledged as a tool to optimize SC operations, few agri-food supply chains have been able to tap into these potential benefits. In general, the potential applications of IT technologies in the agri-food supply chain have never referred to this model to determine (i) how such technology can be integrated with profit; and (ii) how such a model can be applied to other potential users.

The benefits provided by RFID technology include increased supply-chain visibility, greater speed and efficiency of operations, reduced labor costs, improved security, and better customer service [39]. Some authors expect that RFID will offer more competitive advantages to companies [40,41]. To investigate the potential benefits of RFID in the Value Chain framework, a case study related to chestnuts SC was proposed.

This kind of SC, made of high-quality products with controlled origin-denomination constraints, is featured by specific constraints, such as (i) the bulk storage of fresh fruits, (ii) time-processing constraints after harvesting and (iii) time-deliveryconstraints after processing, to cite a few.

Due to such features, the firm is highly motivated to (i) improve the operations of their SC by processing and distribution sides, (ii) define suitable models for their SC, and within these models define the potential improvements points, and (iii) demonstrate, in real time, the origin of the product to avoid potential frauds by the suppliers.

Several authors have addressed the main benefits of RFID applications in SC [42,43], and the roles of RFID have been clearly highlighted by others [26,35]. Yet, the review of the literature revealed that there are not enough investigations on the potential use and the impact of RFID technologies within the value chain.

Under this framework, the first research question (RQ1) investigated the potential role of the RFID within the value chain as follows:

- RQ1: How can the fresh food SC be configured using the RFID and VCOR model?

The benefits of RFID application in agri-food are widely demonstrated through empirical approaches [24]. In particular, the SC supply chain of chestnuts includes both the fruit supply and the delivery operations to large retailers. Farmers deliver fresh fruits to the producer, who processes them, and in turn delivers them to the distribution channels. Furthermore, for such fruit, some restrictions in the distribution exist with respect to features such as size and weight, that involve an additional selection process to be carried out before processing. In fact, the selection and identification of the batch is mainly based on size and weight. Yet, the chestnuts sector has no practical approach for SC management with IT solutions, and this lack has motivated our research.

The second research question (RQ2) explores the quantitative impacts of RFID on the food-value chain as follows:

- RQ2: Within this SC, what can the impact of RFID technology on warehousing capability be?

4. Materials and Methods

This research was conducted within an SC of chestnuts considering supply, production and distribution operations.

The proposed case study regards a firm that processes and supplies fresh and cooked chestnuts to a firm producing seasonal sweets and operating within qclarge international distribution. After being receive, the fruits are delivered either to (i) distributors or (ii) to multinational firms belonging to the seasonal sweets and cakes sector.

The retailer is registered to the EU with a Protected Geographic Indication. For this reason, some restrictions regarding specific selection parameters (fruits size and weight) impose additional manual selection/calibrating process on fruits.

The SC operations begin with the supply of fresh fruit from the growers to the company. Then, the fruit is selected and dried. The processor pack and deliver the fruit to the sweets' producers or serve their local distribution channels (supermarkets and shops) after shelling, drying and cooking within two parallel ovens. The ovens, propelled by wood pellets, work for 8 h a day.

Based on the processes described, the configuration of the SC includes two types of customers: the multinational cakes industries, and the local clients made of small shops and supermarkets.

The firm produces three main varieties of chestnuts: (i) cooked, (ii) fresh and (iii) dried, where the first two account for more than 77% of the orders. Around 65% of these orders regards fresh ones, while the remaining 35% are cooked ones. The production process decreases the weight to about one-third for fresh fruits and two-thirds for cooked fruits.

Cooked fruits and fresh fruits are packaged in bags of 5 kg and 10 kg, respectively. Each pallet of cooked/fresh fruits contains 30 and 20 bags, as reported in Table 3, which also sums up the volumes of fruits processed during the harvesting season.

Table 3. Material flow in the observed chestnut SC.

SC Phase	Material Flow	
Receiving	895.4 tons	
Quality selection (% scrapes)	10%	
Treatment	Cooked 676 tons	Fresh 138 tons

Figure 1 gives the synoptic of the processing and distribution tasks, with the relative material flows for cooked and fresh fruits.

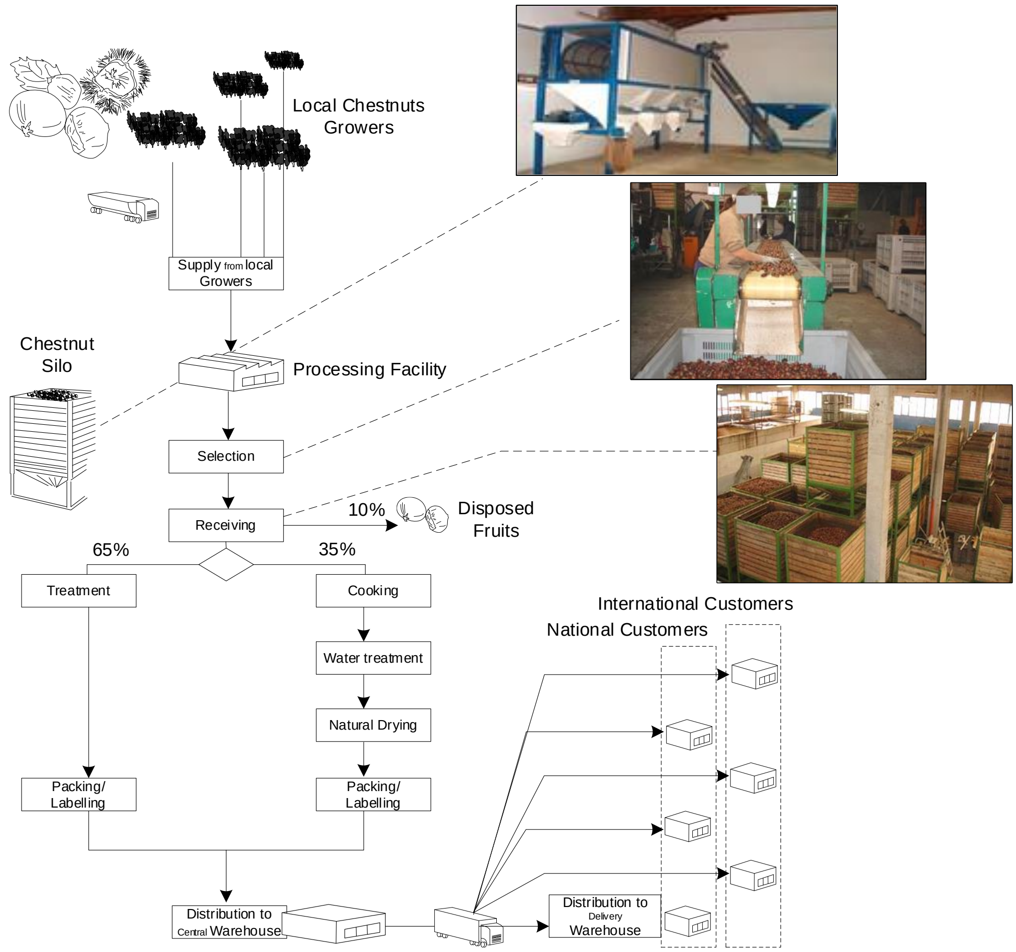

Figure 1. The chestnuts supply chain operations.

From Figure 1, we can see that after the supply of the fresh fruits from local growers, during the selection phase the fruits are separated based on their dimension and weight. The receiving and stocking process is organized into bulky wood silos. In this phase, a first selection of fruits is carried out based on size and destination.

The firm can (i) package the fruits for the main multinational firms, or (ii) make additional shelling, cooking, and packaging processes to serve national distribution centres. The VCOR modelling was developed based on the processing and distribution of chestnuts for the first six customers (in terms of volume), composed of three multinational firms and three national distributors, which together accounted for 70% of fresh and 55% of the cooked fruits processed, respectively.

Value Chain Configuration

This SC can be intended as a three-tiered configuration, in which the firm receives products from the suppliers, then it processes and store them for the distribution phase. The VCOR configuration of the SC proposed by [7], provides the supplier with the fulfill block, and the customer with the acquire block. Table 4 gives the VCOR configuration and the quantities processed at each block. In this table, the modules Acquire, Build, and Fullfill of the VCOR model are involved in the acquiring of the fruits, and in their processing/delivering to the final customers.

Table 4. VCOR configuration and quantities processed.

Supplier Fullfill		Plan Production Company						Final Customer Fullfill			
		Acquire		Build							
Shipping		Receiving		Treatment/Drying/ Cooking *		Packaging		Shipping			
Supplier ID	Fruits [tons]	Scraps	Acquired [tons]	Fresh [tons]	Cooked [tons]	Fresh	Cooked	Multinational Firms Fresh (70%)		National Distributors Cooked (55%)	
								id	[tons]	id	[tons]
1	500	1%	495								
2	745	2%	730.1			#Packages 67,600					
3	210	1%	207.9				#Packages 27,600	1	250	1	75
4	750	2%	735	676	138	#Pallets					
5	400	1%	396				#Pallets1380	2	225	2	53
6	680	2%	666.4			2103					
7	250	1%	247.5					3	201	3	26

* the values consider the loss of weights relative to the drying and cooking processes.

Based on the literature review regarding the possible benefits of RFID application, this study focuses on the following main improvements:

- Cycle time: the number of overall processes may be reduced by the automation of quantities and documents reading/writing, including data entry, verification, and reporting in the receiving, packaging, and shipping process [9];
- Service quality: Accurate inventory information, enabling efficiency measurements in real time [44];
- Process improvement: reduction of errors, fast checking of quantities, documents matching, zero paperwork [17].

Table 5 summarizes the results of this step by showing the analysis of process requirements at each stage of the logistic processes.

Table 5. Process requirements identification.

Process	Requirement	Error Detected
Fruits storage	Inventory level	+7%
Fruits Identification	Quantities identification based on processes (Fresh/Cooked)	−11%
Fresh packaging	Quantity of bags Quantity of pallets Inventory level updating	−8%
Cooked packaging	Quantity of bags Quantity of pallets Inventory level updating	−4%
Storage	Sorting pallets Pallets identification Inventory level updating	-
Fresh shipping	Quantity definition	−5%
	Pallets picking	
	Finished products inventory level updating	−6%
	Invoice emission	
	Shipping identification (customer)	5
Cooked shipping	Quantity definition	−2%
	Pallets picking	
	Finished products inventory level updating	+1%
	Invoice emission	
	Shipping identification (customer)	9

From Table 5, it can be argued that the main issue of the company lies in product identification and the management of inventory levels at the origin of the SC, where the fruits are separated with regard to fresh/cooking processes. The proper and accurate control at this phase contributes towards avoiding mistakes in updating the inventory level, that may yield bullwhip effects and errors in the other SC processes.

Table 6 shows how the shipping identification errors are double for fresh fruits than for cooked ones. This may be due to the manual counting errors resulting from packages overlapped on the unit load. By process analysis, some basic key performance indicators (KPI) were identified and linked to (i) the blocks of the VCOR and (ii) to the basic specifications of the RFID system.

Table 6. Devices locations and KPI definition.

VCOR Block	RFID Tags Location	Reading System	KPI
Acquire	Receiving warehouse	Flash card in laptop	Fruits inventory level time - For fresh process - For cooking process
Build	Central warehouse	Hand reader	Silos location time Inventory Level time (number of bags) - Fresh - Cooked Packaging time Warehouse cycle - Palletizing time - Transportation and sorting time - Quantity registering - Inventory updating
Fulfill	Shipping warehouse	RFID portal	Warehouse cycle - Quantity check - Picking, Sorting and transportation - Docs issuing - Inventory updating

In this phase, different types of RFID tags and reading systems have been investigated toward the definition of tailored solutions for each VCOR block and process.

The adoption of active RFID tags with localization system might affect such SC operations with impact on the KPI of the fulfill block of VCOR.

Nevertheless, the benefits of RFID technology may be affected by the operational and organizational procedures and the training of operators. Thus, the use of new technologies in certain SCs may imply additional procedures or changes to appraise, in full, the relative benefits.

5. Supply Chain Operations with RFID

The RFID operational environment required replacing and upgrading the traditional Electronic Data Interchange (EDI) system in both facilities (processing and distribution). Before the introduction of the RFID technology, the EDI system was not present in the processing facility, but it was working via a wired LAN in the distribution facility.

The introduction of RFID systems implemented the EDI over a wireless LAN connected with the facility management system. In this phase, traditional batch checking and paper notes are shifted into a paperless communication.

Then, the re-engineering of warehousing operations was conducted. The additional requirements by the side of the operators regarded and additional training on the use of the new technology and for the new packaging and palletizing procedure, in particular the additional training have been made for:

- All operators on the use of the laptop RFID location interface for the processing facility;
- Operators of the central warehouse for the RFID sticking and bags packaging;
- EDI employee on RFID management and maintenance.

Figure 2 shows the inbound process at the receiving warehouse. The procedure is similar for outbound operations. In Figure 2, the continuous and dashed lines indicate material and information flow, respectively, while blue dashed lines indicate the new RFID information flow.

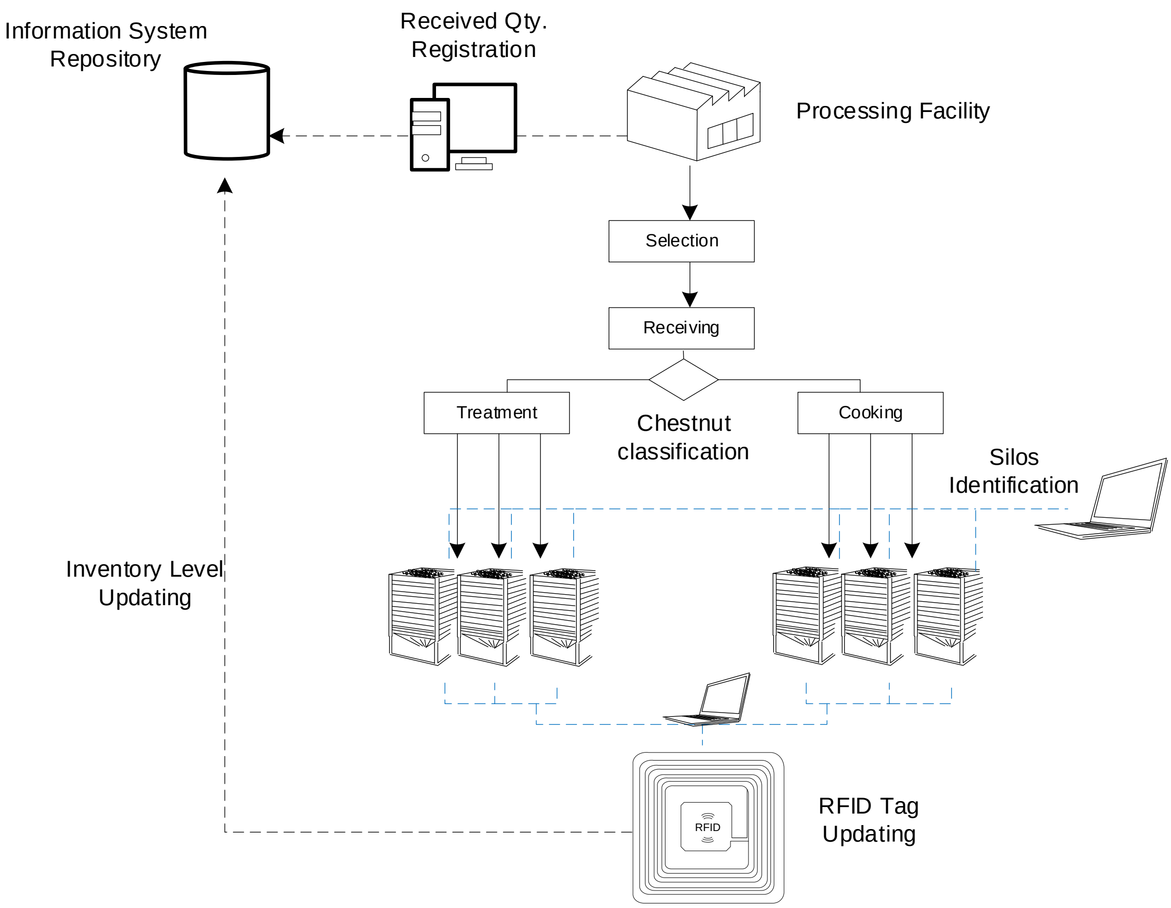

Figure 2. Receiving process with RFID.

The introduction of the RFID technology affects the receiving tasks under operators' perspective. The new procedure includes the following steps:

- Fruits arrive to the processing facility;
- The quantity is checked and registered into the information system;
- The operator moves the fruits to the selection/manual checking area;
- The selectors verify the quality of chestnuts and classify them according to the process to perform (fresh treatment/cooking);
- The warehouse operator identifies the silos where to store the fruits through the software installed on a laptop;
- The silos are then mechanically filled;
- The operator updates the RFID labelling the silos and the inventory level in real time.

Figure 3 shows how the implementation of the RFID system affects the operations within the central warehouse or distribution facility. This warehouse is typically managed according to a push approach. Due to the uncertainty of the fruit-selection process, the quantities of the two types of fruits available at the receiving warehouse may vary with the season and the supplier. As a consequence, processing operations and the shipping to the central warehouse are push-managed with regard to silo availability.

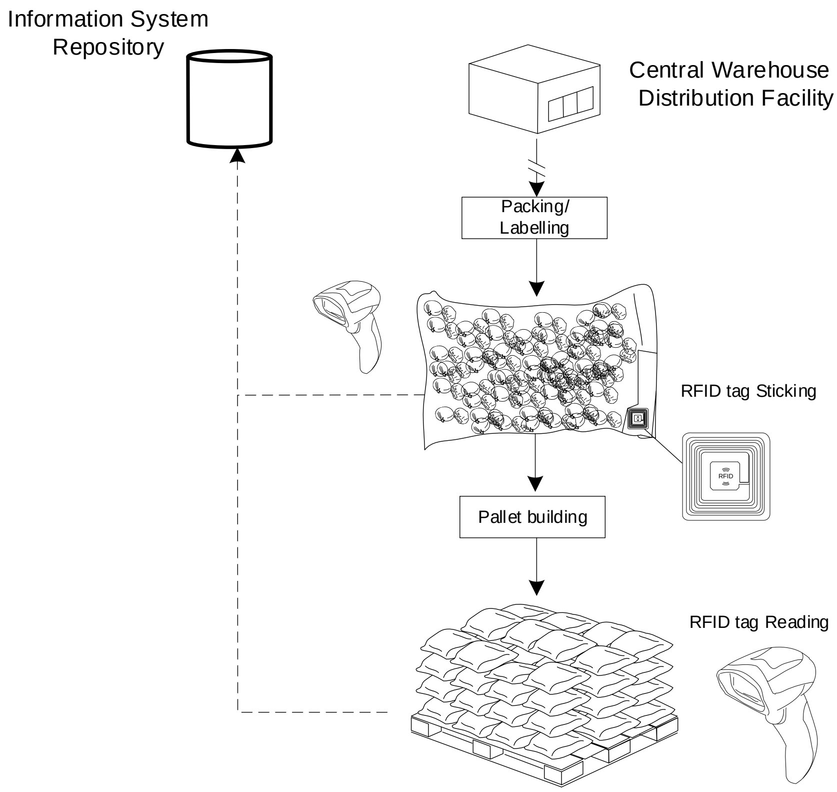

Figure 3. Central warehouse operations.

The warehousing operations are managed as follows:

- Warehouse operators pack the products according to the arrivals;
- An RFID is stuck on each package;
- The warehouse inventory level is updated through an RFID handy reader;
- The operator receives the order list, in which the quantities for each type of product are detailed;
- The operator composes the handling unit (HU);
- Each HU is handled and acquired through the RFID gate;
- The warehouse inventory is then updated, transportation documents printed;
- HUs are lastly loaded and shipped.

Figure 4 shows the revised procedures at the delivery warehouse, which operates following a pull approach and performs picking operations accordingly.

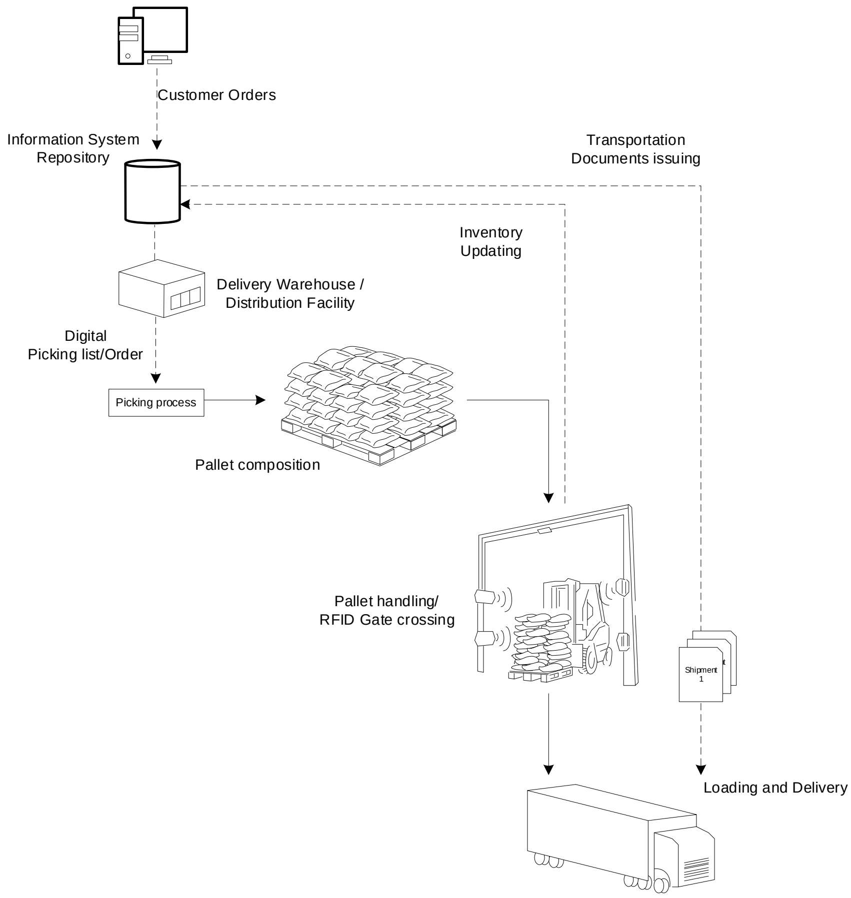

Figure 4. Shipping warehouse operations.

According to this configuration, the central warehouse can be merely intended as a buffer to front the availability uncertainties that characterize the processing activities.

RFID Testing

Under an operations management perspective, it is worth noting how RFID technology may influence: (i) the processing facility, through silos tracing and real-time inventory updating; and (ii) the delivery warehouse, where the real-time issuing of documents and the inventory levels are updated. An experimental campaign of the RFID reading test was conducted. The data in this portion of the study were also used for a preliminary assessment and quantification of the KPIs. During this phase, different locations of tags were tested to enhance the reading rate and avoid the shield effect. This issue was faced by sticking the RFID tag at the top of each bag after it was closed as shown in the Figure 5.

Figure 5. Examples of tagged packages and pallets.

Due to the passive tag stuck on the bags, the company defined new procedures describing ways to lock packages, attach the RFID tag, and to pick/load packages on the pallet.

In the processing facility, the assessment was conducted on five fruit supplies through 40 trails in the central warehouse on 25 fresh bags and 15 cooked bags, on 60 trails in the delivery warehouse on 20 pallets of fresh and 40 of cooked fruits.

The assessment resulted in an identification accuracy of 99.4% for bags and 98.7% for pallets.

6. Technology Specifications

Two types of RFID systems were used in this case study: an active tag for the receiving warehouse and a passive tag for bags and pallets identification in the central and shipping warehouses. The use of the passive tags for the last two blocks was encouraged by the low investment required (less than €0.90 each) for the purchasing of the tags. These tags are often lost or damaged during de-palletizing and the de-packaging processes. RFID tags include an RFID Chip that stores small amounts of data; the RFID antenna that sends and receives radio waves, allowing the tag to communicate with an RFID reader and the substrate to protect the chip and antenna from damage.

Passive tags do not have a built-in power source and rely on the energy transmitted by the RFID reader to function. The RFID reader sends out a radio wave which excites the tag and powers it. The tag uses this energy to transmit its signal to the reader.

This technology is called inductive coupling. The distance between the tag and the reader determines how much power is transferred to the tag. If the tag is too far away, it will not receive enough power to operate. Passive RFID tags are more cost effective than active tags and require no maintenance.

Therefore, passive tags were used for the last two blocks in our study. These tags are often lost or damaged during the de-palletizing and the de-packaging processes and the choice was encouraged by the low investment required (less than €0.90 each) to purchase the tags. The two warehouses were also provided with a wireless network to allow for the communication of the controller with the handy RFID readers and with the information-system repository.

6.1. Active Tag

The active RFID has a transponder embedding a position-marker technology, that is able to identify the proper silos in the receiving warehouse. This feature is necessary to avoid errors made by pickers in choosing between the fruits for the fresh/cooking process. The main features and data for the active tag are reported in Table 7.

Table 7. Main features of the transponder and the active tag.

Feature/Parameter	Value
Frequency	125 kHz
Modulation	100% AM
Range (adjustable)	up to 3.5 m
Position Data	16 bits
Loop Current	max. 6 App
Loop area	Integrated
Number of Loops	1

For the reader device, a flashcard type i-CARD M 350 has been used, with a laptop in a bundle of localization software. This card is able to receive data at distances of up to 500 m with a receiving capacity of around 700 concurrent tags.

The tracking data include location of silos, process type, class and size of fruits, actual quantity (weight) of fruits, dates, or last picking/feeding and related quantities.

6.2. *Passive Tags*

These tags are used for product identification and track is single package (i.e., bag).

For the specific case a roll RFID is adopted. To comply with the ISO 15963 [45] RFID tags in the range of high frequency 13.56–900 MHz were adopted with a short reading range maximum of approximately 30 cm (12 inches) to 1.5 m.

The data-transmission speed is around 106 bits per second. The antennas are made of aluminium coils. Table 8 lists the other parameters of the tags.

Table 8. Main features of the passive tag.

Feature/Parameter	Value
Frequency	13.56–900 MHz
Chip	I code SLI
Range (adjustable)	1–1.5 m
Memory	12 bytes
Dimension	86 × 54 mm

For the reader device, two commercial systems have been used for the experimental campaign (PDA HP2140 + Reader SDiD1020 beta version), and for the final installation (device PSION work about with reader HF Feig), respectively.

The reading system, compliant with the standards ISO 15693 and 14443A/B [46] and installed into the central warehouse, has been made of two couples of RFID antennas-paddles type-installed at the inbound and outbound docks of the facility.

7. Results

The assessment of the results was conducted in two steps. The first step concerned the comparison of the resulting errors in quantities evaluation and shipments before and after the introduction of the RFID technology. Table 9 reports the requirement for each process and the mean error detected with respect to the previous harvesting season.

Table 9. Improvements evaluations for warehouse management.

Process	Requirement	Mean Error	Difference before and after the RFID Technology.
Fruits storage	Inventory level	+1%	−6%
Fruits Identification	Quantities identification in warehouse based on processes (Fresh/Cooked)	−0.5%	+10.5%
Fresh packaging	Quantity of bags Quantity of pallets Inventory level updating	−0.5%	7.5%
Cooked packaging	Quantity of bags Quantity of pallets Inventory level updating	0%	+4%
Fresh shipping	Quantity definition	−0.3%	+4.7%
	Finished products inventory level updating	0%	+6%
	Shipping identification (customer)	0	2
Cooked shipping	Quantity definition	0%	+2%
	Finished products inventory level updating	0%	+1%
	Shipping identification (customer)	0	5

A set of KPIs was quantified during the as-is configuration and compared to the values tracked during the experimental campaign, the values of which are summarized in Table 9.

From the data of Table 10, we may see an increase of the packaging/palletizing phase time, which is in contrast to the shorter times of inventory updating and documents issuing. From an on-filed analysis, it emerged how such an increase was mainly due to the inexperience of workers when performing the new procedures of package closing, RFID sticking and palletizing. Transportation time was almost constant because the SC re-engineering did not involve warehouses re-layout.

Table 10. KPI of the SC model.

VCOR Block	Quantities		KPI	Values (Avg. Times [min])	
				As-Is	To-Be (RFID)
Acquire	5 conveyances [290]		Fruits inventory level time		
			- For fresh process	50	10
			- For cooking process	30	10
			Silos location time	12	4
Build	[0.32] Number of bags		Inventory Level time (number of bags)		
			- Fresh	90	2
			- Cooked	40	2
			Packaging time (per bag)	4	6
	Fresh	Cooked	Warehouse cycle		
			Palletizing time	11	13
	25	15	Transportation time	8	8
			Inventory updating	12	0
Fulfill	[8] Number of bags		Warehouse cycle		
	Fresh	Cooked	Quantity check	25	5
			Picking, Sorting and transportation time	30	30
	20	40	Docs issuing	12	2
			Inventory updating	16	0

8. Discussion

The empirical results of Table 6 answer to the RQ1 by providing the list of RFID devices and their roles/locations with regard to the VCOR blocks. While the VCOR framework typically provides generic KPIs [46], the empirical finding of Table 6 is the first attempt at defining tailored performance indicators for chestnut SC.

The whole development, implementation, and testing of the RFID technology for this SC may provide multiple answers to RQ2. The results showed that the practical solutions, in terms of operational procedures, complementary to RFID implementation, can highly affect the success of the introduction of this technology. Some of these solutions include the reengineering of packaging and palletizing operations with new procedures. Further evidence lies in the lack of general-purpose technological solutions for any SC environment and operation. The specificity of the SC application and the associated operational and infrastructural constraints are the main aspects to consider when choosing which traceability technology to adopt.

RQ2 is also addressed by Table 10. The RFID system mainly impacts on the Acquire and Fulfill blocks, wherein product tracking and identification affects operations, inventory updating and reading accuracy. Furthermore, palletizing tasks and silo-tracking could be further improved by operator training and practices.

By answering to RQ2, the following technological and managerial considerations can be made: (i) with food products stored in bulk and with different quality parameters, the active RFID technology with a localization system is more suitable for value chain analysis; (ii) for certain SCs, the positive impacts of the RFID technology is affected by the operational procedures and the training of operators in these; (iii) the use of new technologies in SC management may imply additional procedures or changes in traditional procedures to appraise in full the relative benefits.

9. Conclusions

This focused-on-practice research examined a chestnuts SC within a VCOR framework, in which a practical implementation of RFID was implemented and assessed. The SC analysis was driven towards: (i) the RFID implementation by the adoption of different types of tags and tracking methods with respect to the blocks of the VCOR model and (ii) the evaluation of the relative KPIs. The test campaign resulted in a general improvement of inventor level accuracy and updating times. Both the technology deployment and on-field tests also provided clear evidence of the basic needs for such an SC when adopting these technologies.

At the time of this study, the possibilities of fully appraising the benefits of RFID systems in some food SC niches, such as the one explored, had still to be assessed. Thus, we believe that this study can be used not only as a practical guide for RFID implementation in these SCs, but also as a guide for practitioners for the careful analysis of the specific requirements and procedures needed to make a successful application of these technologies. In this regard, one of the main lessons learned is that just well-designed IT solutions may be not sufficient for the success of these projects. In contrast, a manifold tool for the concurrent economic and efficiency analysis and the correct formation and motivation of workers, may be also basic elements that allow these technologies to be as successful as they are expected to be.

Within this study, the following main limitations are reported. First, the KPI analysis concerned a limited material flow and must be further developed. It was conducted with workers not completely trained for RFID use. This may have caused some bias in KPI values, that should be measured with a larger test campaign. Second, the study did not consider economic analysis for this implementation, such as return on investments (ROI) and/or Payback Periods (PBP). Third, the study did not consider the re-engineering of the warehouses layouts and operations that would have improved the other KPIs, such as transportation, sorting and picking.

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