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An Appraisal of Traceability Systems for Food Supply Chains in Colombia

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ABSTRACT

Traceability systems have improved significantly in the last few years in relation to safeguarding food safety and quality. Although traceability is considered to be an effective tool in supporting quality control, the adoption of different traceability systems along the supply chain can bring the drawback of information asymmetry, which affects inventory management. This paper explores adoption alternatives that may facilitate the blend of traceability technologies in the food industry of developing countries. The analysis is based on a simulation model that represents the behaviour of inventory and food quality in the case of the mango supply chain in Colombia. The results show the asymmetries between traceability systems along the supply chain as well as their effects on inventory and food quality.

Keywords: food industry; supply chain; traceability system; performance; food quality; system dynamics

1 Introduction

Traceability systems are an essential aspect of tracking the source of a food and its components in the supply chain (SC). In addition to this, traceability systems are of great importance in highlighting food quality drawbacks (Zhang et al. 2011; Qian et al. 2020). However, the complexity of food production and consumption brings new challenges for traceability which need to be analysed as a dynamic capacity of the chain (Cetindamar et al. 2009; Becerra et al. 2016; Pappa et al. 2018). In other words, the tracking technology can influence the set-up time and the processing time of the chain (Basole and Nowak 2016). For instance, in a continuous processing of mango-based liquid food it is difficult to identify the source of the raw material in the mixture, which brings new challenges and opportunities in terms of analysis of a suitable traceability system (Skoglund and Dejmek 2007).

Due to customers' growing concerns regarding food quality and safety, the acquisition and implementation of traceability systems have gained more attention. The adoption of traceability systems involves formulating a technological capacity strategy for the food industry in the long-term, which in turn requires an appropriate policy to be implemented (Orjuela-Castro and Herrera-Ramírez 2014; Herrera-Ramírez et al. 2017). A traceability system needs strong investment for its adoption in the SC, which restricts the implementation of the entire system (Heyder et al. 2012; Pappa et al. 2018). In this regard, the policy of investment and the selection of appropriate technology play an important role in the food industry (Heyder et al. 2010; Corallo et al. 2020).

The capacity for tracking in the food supply chain entails a profound analysis regarding the potential impacts on performance (Bosona and Gebresenbet 2013; Saak 2016; Pappa et al. 2018; Cho and Choi 2019). On the one hand, the traditional processes of traceability use manual checking for each item of a product, which influences the response time of the supply chain (Rincón et al. 2017; Shankar et al. 2018). On the other hand, inspection has a control effect before purchase, while information traceability has a control effect after purchase, resulting in different quality levels (Cheng et al. 2013). This situation occurs when different traceability systems are adopted. In other words, one consequence of the adoption of isolated traceability systems is that this provokes asymmetric information affecting the stakeholders' performance: purchase, processing, inventory and delivery. Though the traceability systems benefit food safety and quality, the adoption of different unconnected systems along the SC may cause data loss.

In this context, the adoption of traceability systems is one of the critical competitive factors in the food supply chain (Zúñiga-Arias et al. 2009). Thus, the objective of this paper is to appraise the adoption alternatives for different traceability systems in terms of inventory and food quality, particularly in the case of the mango supply chain.

Traditionally, simulations have been used as a tool to model alternatives and run them repeatedly under varying experimental conditions to obtain results. In this sense, system dynamics (SD) is particularly applicable in order to assess alternatives under simulation scenarios (Forrester 1997; Sterman 2000). Earlier studies reported models based on SD which show the implication of technological adoption in the long-term (Stavredes 2001; Wolstenholme 2003; Chen 2011; De Marco et al. 2012; Herrera and Orjuela 2014; Herrera et al. 2018). Although some studies have modelled the impacts of traceability technology on operations (e.g. inventory), there do not appear to have been any studies that examined the long-term effects considering the adoption isolated systems of traceability. Besides, prior simulation models that were used in order to evaluate traceability technologies showed a simplifying level or a very specific level (Wolstenholme 2003), which do not take into account the entire supply chain behaviour. In this sense, the novelty of this present research is the dynamic perspective that it proposes for the evaluation of a traceability system that is heterogeneous among actors, and its effects on the inventory of perishable food in SC and its relationship with food quality.

This article is organized as follows. The adoption of traceability systems and traceability systems modelling is further described in Section 2, while Section 3 shows the modelling approach taken in this paper. Section 4 presents the results of the simulation model in terms of the performance measures for the mango supply chain. In Section 5, the findings are discussed, the research limitations are highlighted, and future directions are suggested. Finally, the conclusions of the research are presented.

2 Background

2.1 The adoption of traceability systems

In order to carry out the traceability process the adoption of technologies is necessary for the tracking and tracing of products in the supply chain. The traceability systems support the food supply chain through recording a great quantity of data – information management (Tamayo et al. 2009). The aim of these systems is to record the history and location of the different products along the SC (Dabbene and Gay 2011; Aung and Chang 2014). Thus, the traceability systems identify the amount of a product that may be discarded and recovered. However, the adoption of traceability technology involves an analysis and evaluation in terms of investment according to physical and information flows (Tsao et al. 2017). In addition to this, the implementation of traceability systems requires the integration of other technology systems supporting production operations, in order to make strategic decisions (Mohan et al. 2008).

A suitable adoption of the traceability systems contribute to formulating different strategies that improve the product flow as well as inventory control (Folinas et al. 2006; Canavari et al. 2010). Numerous studies about the traceability systems show how the adoption of traceability systems relieve response times of logistics operations (e.g. picking and packing) (Lin 2009; Barchetti et al. 2010; Angulo et al. 2013; Bosona and Gebresenbet 2013; Jung and Lee 2015; Bibi et al. 2017). However, the standardisation of traceability processes and interfaces does not have a joint platform, but is independent, which limits the conditions of operation. In this sense, earlier studies have affirmed the need for the integral adoption of traceability systems between trading partners (Zúñiga-Arias et al. 2009; Zhang and Li 2012; Rincón et al. 2017), and so this paper aims to fill this gap.

Traceability systems have had a significant increase in countries such as the United States, Italy, France, Portugal and Norway, with applications in nuclear control, inventory, traceability of flights, and manufacture (Bibi et al. 2017). However, food loss and waste in developing countries is often highest at post-harvest stages, due to technical and infrastructure constraints (Chaboud and Moustier 2020). In the Colombian case, the adopted traceability systems may differ at each stage of the food supply chain (Castañeda and Orjuela 2012; Herrera and Orjuela 2014). The diversity of traceability technology used by the food supply chain dampening the coordination and integration between actors. This situation involves food loss and waste affecting the performance of the food industry (e.g. inventory shortages).

2.2 Modelling of traceability systems

Technological changes are continuously creating new challenges and opportunities related with the supply chain management including the selection of an appropriate technology. The changes of technology may be modelled from different perspectives, such as technological forecasting, road-mapping and technology intelligence (Caetano and Amaral 2011; Trappey et al. 2011; Cho and Daim 2013). In addition to this, optimization models have also been used, to evaluate the adoption of traceability systems to improve the quality control and information (Tamayo et al. 2009; Dabbene and Gay 2011). However, these modelling perspectives do not take into account the dynamics capacity of the supply chain in the long-term.

Simulation plays an essential role to support making decisions within uncertain environments (Balfaqih et al. 2016). In this sense, SD modelling has been used to analyse the behaviour of technology adoption when there is a complex causality and timing in the supply chain (De Marco et al. 2012; Ferreira et al. 2016). Although there are simulation models that report the effects of traceability systems adoption on retail inventory (Chen 2011; De Marco et al. 2012), these models do not take into account how the adoption influences the food quality along supply chain.

In this context, the traceability systems may be analysed through SD to achieve a better understanding of the behaviour of technological changes. Besides this, the use of SD allows the evaluation of policy alternatives to improve performance of the supply chain (Wolstenholme 2003).

3 Materials and methods

3.1 Model description

The simulation model was developed using Vensim software. The modelling process starts with the outline of the model and definition of the variables. From this, a simulation model that involved the use of differential equations was proposed. The validation model was supported by historical data and statistical tests. The simulation model was also validated by experts, which allowed it to be used as a decision-making support tool for the fruit sector.

3.2 Dynamic hypothesis

Firstly, this paper worked on understanding, structuring and analysing the food supply chain with regard to the investment of technology in terms of production and the traceability system adopted, food quality and inventory. In this way, the relationships between variables are represented through a causal loop diagram, as shown in Figure 1. The reinforcing loop (R2) is a representation of the effects of demand and investment on the installed capacity of production. The demand for food affects the investment in production capacity; hence this generates an impact in the total installed capacity of production. Additionally, the installed capacity of production is related with the food inventory and its features of quality. Food quality depends on storage time, which affects the average life of food as well as its demand. Thus, the inventory is related with the demand of food and its quality, creating the balancing loop B1. The reinforcing loop (R1) represents the dynamics of the effect of investment on the traceability system and food quality. In this sense, the investment has an effect on the adoption of new technologies for the production and traceability systems caused by the food demand. Therefore, this situation impacts on the adopted traceability system, which affects the quality control and food demand in the supply chain. The balancing loop (B2) represents the effect of quality control on the quality improvement programs applied in the traceability systems. This effect is determined by the loss of quality between the desired product quality and current product quality.

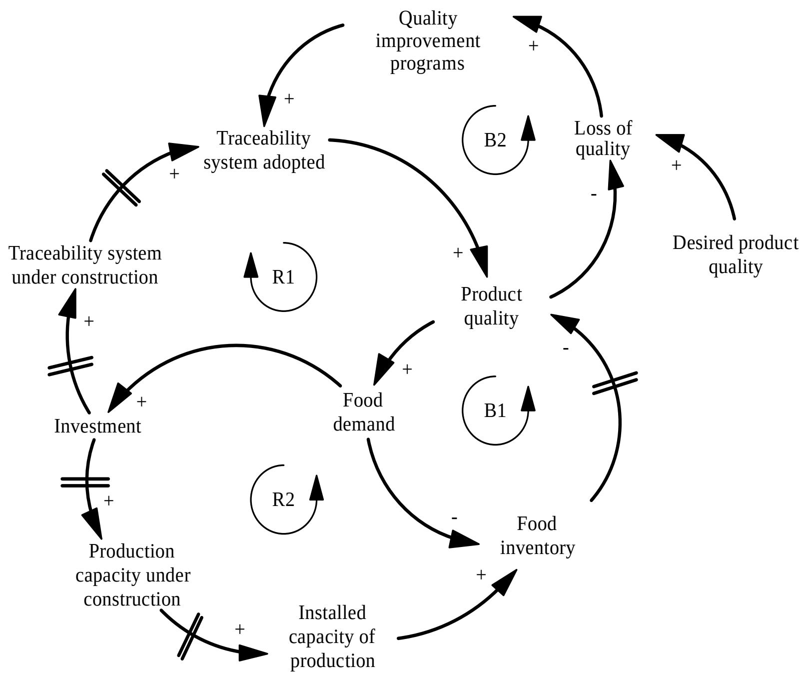

Figure 1. Main feedback loops interacting in the traceability system and quality control of food supply chain

3.3 Simulation model

The simulation model is represented by the stock and flow diagram, as illustrated in Figure 2. This model presents the traceability system and quality control of the food supply chain. The stock and flow diagram include three subsystems to assess the adoption of the traceability system and quality control in the mango supply chain. The first subsystem is related to the effects of quality improvement programs on the adoption of the traceability system, which generates an impact on food quality. Equations (1) and (2) calculate the loss of quality and the percentage of quality product controlled by the capacity of the traceability system, respectively. The second subsystem represents the effects of food demand on the technologies' investment of production and traceability. The expected demand for food is calculated as observed in Equations (3) and (4). The final subsystem includes the impact on the product quality generated by the estimated life cycle of the mango regarding the amount of product on the inventory.

$$Loss\ of\ quality = desired\ product\ quality - product\ quality\ \ [\%] \tag{1}$$

$$Product\ quality = tsa * effect\ \ of\ life\ cycle\ \ \ [\%] \tag{2}$$

$$EFD(t) = EFD(t-dt) + \int_{t=o}^{T}[Change\ of\ demand(s)]ds \qquad [Tn] \tag{3}$$

$$Change\ of\ demand = EFD * product\ quality\ \ \ [Tn/Year] \tag{4}$$

Where,

EFD: Expected food demand

tsa: Traceability system adopted

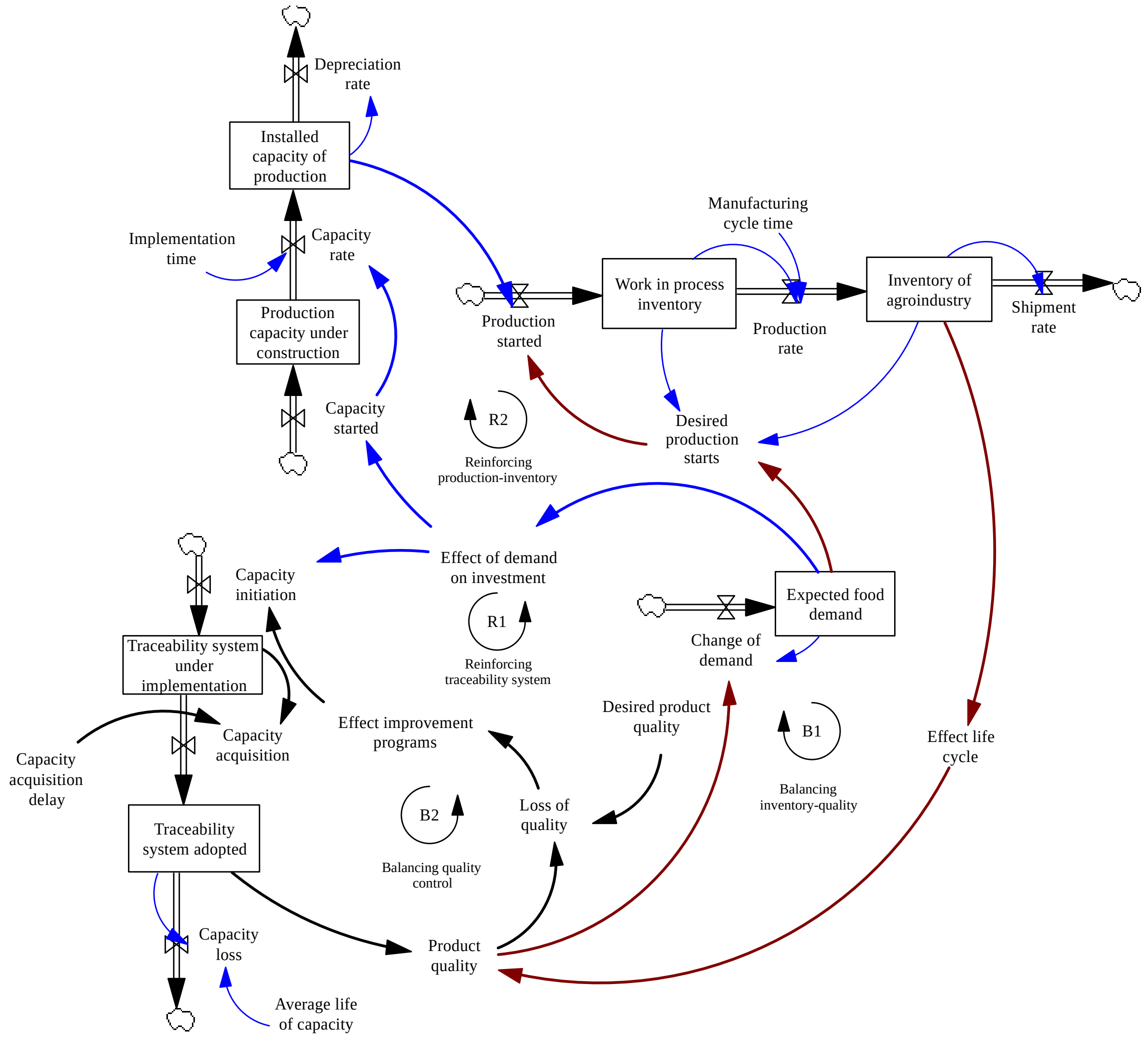

Figure 2. Stock and flow diagram of traceability system and product quality

The base simulation experiment was done based on assumed initial simulation parameters. A synthesis of the main assumptions for the simulation model as well as some input data are presented below:

a) Given the dynamics of change in the traceability systems, the simulation horizon was set at 25 years.
b) The initial parameters are associated with the mango demand in Colombia reported by the Ministry of Agriculture (2018). In this sense, all the data is indexed to the base year, 2016.
c) Regarding the mango demand, the simulation model assumed an increase of 4% per year (FAO 2016).
d) The percentages of the traceability system for each player of the supply chain were considered (Herrera and Orjuela 2014).

e) The model was presented to a panel of experts from the association of mango producers in Colombia to evaluate the findings (Universidad Piloto de Colombia 2017).
f) For the estimation of inventories, the study elaborated by Herrera and Orjuela (2014) was used in the model.

3.4 Model validation

The validation process generates confidence in the usefulness of a simulation model (Oliva 2003; Qudrat-Ullah and Seong 2010). The structure of such a model involves an evaluation through statistical tests for simulation system behaviour in comparison with the actual system. For behavioural validity, the simulation model was exposed to the tests proposed by Sterman (2000) and Oliva (2003). Figure 3 shows the test of trend comparison between the inventory of the agri-food chain and the model-generated data. This test displays the historical and simulated data from 2005 to 2016. These plots suggest that the validated model adequately captures the history of the agri-food industry inventory. In addition, the mean absolute per cent error (MAPE) for the simulation model is 3.24% and correlation coefficient (R^2) equal to 0.94 for the validation periods. Therefore, the results show that the simulation model has the ability to capture trends and replicate historical data (see details in Appendix A).

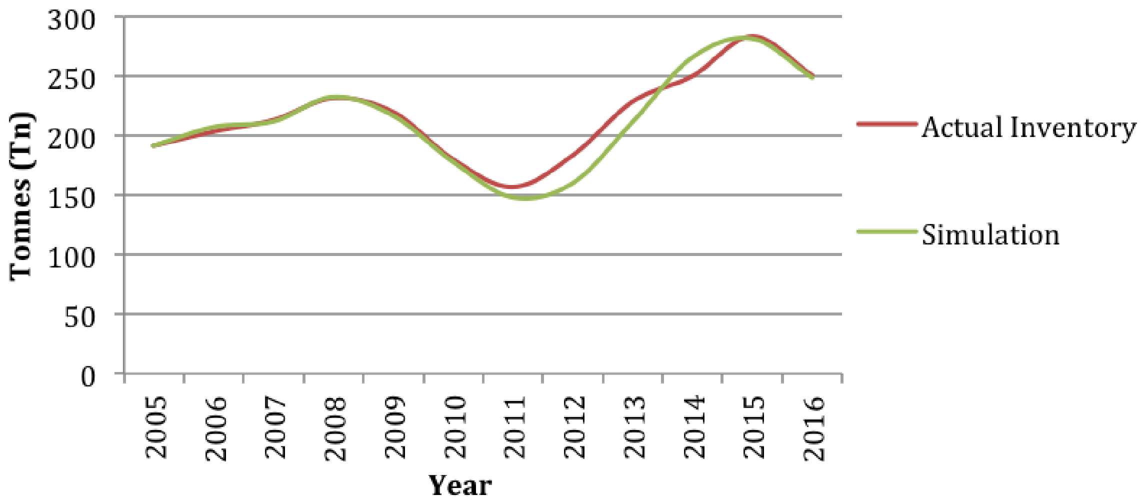

Figure 3. Historical and simulated inventory behaviour of the mango supply chain

3.5 Unique features of the simulation model

The simulation model provided important results due to its structural formation which correlated with the food supply chain and traceability system. The model possesses the following distinctive features:

- It has been extensively validated through different tests including historical fit, as well as structural and behavioural validity (Sterman 2000; Oliva 2003).
- It captures the asymmetry of the mango supply chain in Colombia in terms of the traceability system adopted. This model also considers the food demand, production capacity and inventory.
- It considers a co-flow structure, which allows behavioural changes in the SC to be represented.
- It evaluates the acquisition delays of a new traceability system for food quality control along the SC.

4 Results

4.1 Asymmetries of the inventories in the mango supply chain

The proposed model has been simulated from 2017 to 2042 in order to better understand the asymmetry in inventories, traceability systems and loss of quality along the mango supply chain. The results of asymmetries among producers, the agri-food industry, wholesalers and retail traders related with the inventories are shown in Figure 4. This behaviour of asymmetries in the inventories of the supply chain was addressed and analysed by Sterman (1989, 2000) through a simulation model. Sterman's studies presented the effects of time delays in the shipments on inventories among the stakeholders of supply chain. In our simulation model, the asymmetries in the mango supply chain affect the food quality due the delays in the adoption of different traceability systems. The results of the simulation show that there is a considerable difference between producers' inventories and retail trader, which generates difficulties for the quality control of the traceability system. That is, there is a strong inter-dependence between the actors along the supply chain. Thus, these results can be deeper when the traceability system is heterogeneous.

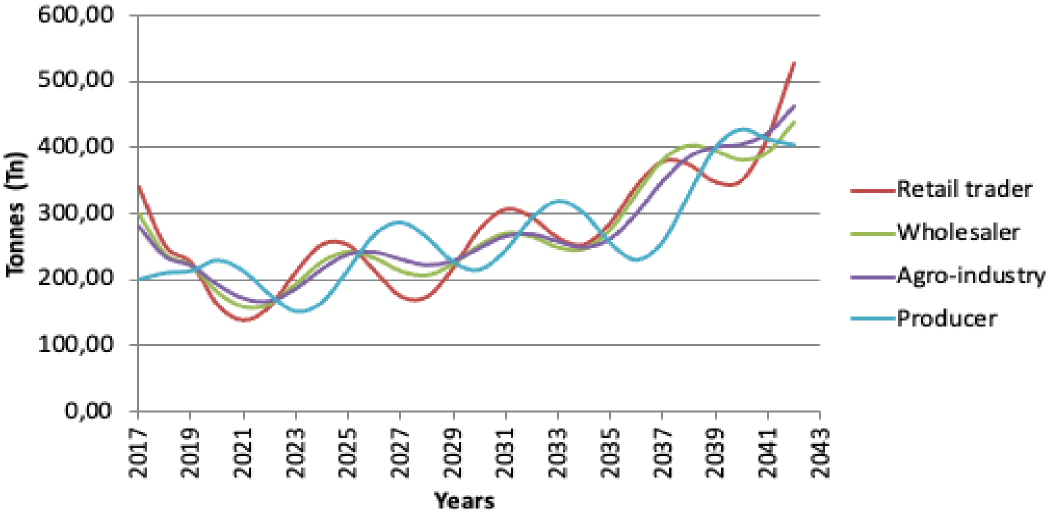

Figure 4. Asymmetry of the inventories in the mango supply chain

Based on the simulation model, the paper presents the seasonal inventory average for each player in the supply chain, as shown in Table 1. The results reveal an increase in the seasonal inventory in retail trading caused by an accumulation of the finished product inventory. This situation is associated with uncertainty in the mango suppliers' seasonal production, as a result of changes in climate. Consequently, this asymmetry may affect the quality of the finished product in the SC.

Table 1.
Seasonal inventory average of the mango supply chain

	Retail trader	Wholesaler	Agro-industry	Producer
Seasonal inventory average	635.74	623.07	622.30	600.53

4.2 Asymmetries of traceability system and its impacts on product quality and inventory

An important aspect that directly impacts customers is the loss of quality caused by the accumulated inventory of perishable food. The different traceability systems adopted by actors in the SC affect the quality control of products. For instance, suppliers have adopted a barcode, while agribusinesses have a radio frequency identification (RFID) system. This situation causes problems with product quality and a lack of control of inventory (Büyüközkan and Göçer 2018; Alfian et al. 2020).

Figure 5 show the asymmetry of traceability systems and its effects on inventory and food quality in the case of the retail trade. This condition occurs due to the lack of coordinated policies and strategies among actors regarding technology management, which affects the response time to customer demand in terms of product quality (Caracciolo and Cembalo 2011; Orjuela and Adarme 2017). In this sense, the behaviour of inventories is correlated with the loss of quality caused by the accumulation of perishable products along the SC. Consequently, the asymmetry could generate an impact on the holding costs of inventories (Sterman 1989).

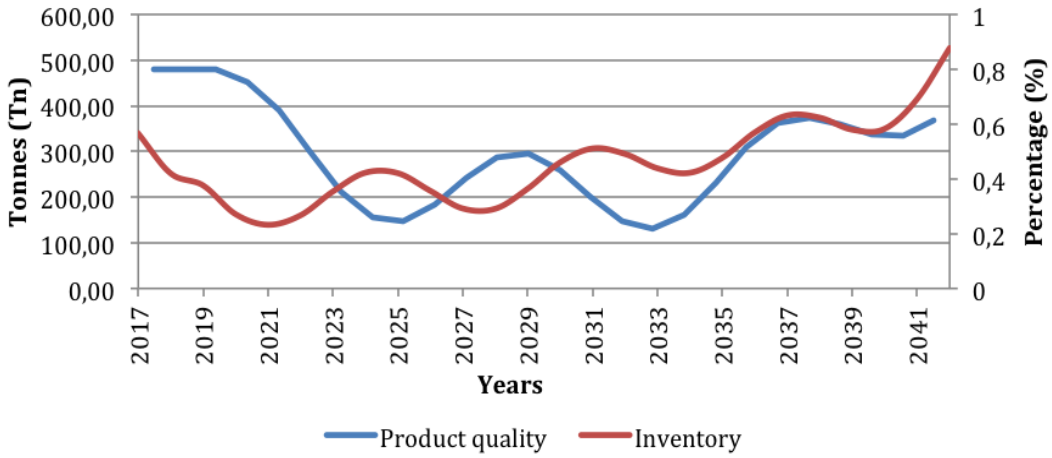

Figure 5. Asymmetry of the inventories and percentage of food quality in the case of retail trade

Figure 6 (a) shows a graph representing the loss of quality generated by the adoption of different traceability systems according to implementation times for each actor in the SC. These results shown how the percentage of the adoption of a traceability system involve a loss of quality for each actor in the long term. This situation is caused by the different traceability technologies of each actor as well as the time delays of implementation that are involved in the adoption of new systems.

Figure 6 (b) presents the asymmetries in terms of the percentage of adoption of a traceability system for each actor. The adoption of new systems of traceability is associated with times of implementation and financial resources. In this case, the simulation results show that the delays for implementation of new systems affect the producers of the mango supply chain. Therefore, the adoption of a traceability system for producers is characterized by delays that may be associated with the learning curve. In this sense, the adoption of different technologies requires a coordination of technology policies for the actors along the food supply chain.

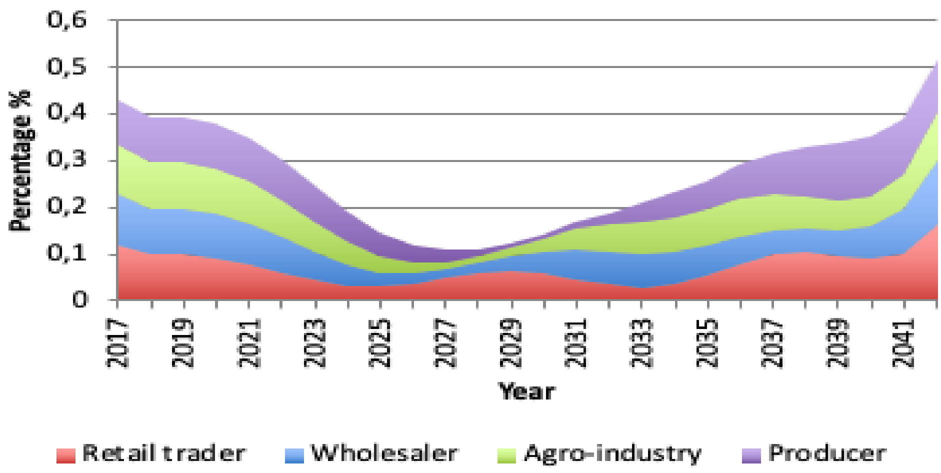

Figure 6a. Accumulated loss of quality affecting the actors in the mango supply chain.

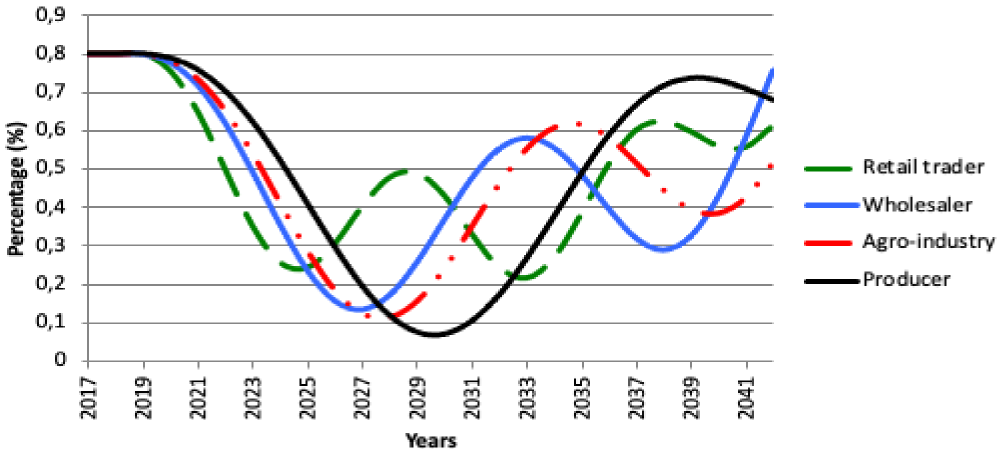

Figure 6b. Percentage of adoption of traceability system in the mango supply chain

4.3 Assessing symmetries of traceability systems in the mango supply chain

According to De Marco et al. (2012), the adoption of RFID technology can contribute to sales growth because of its capacity to improve inventory management. However, when different traceability technologies exist along the supply chain this can produce an asymmetric effect on inventories and food quality. This condition affects the performance of the supply chain (seasonal inventory average and product quality). In the present research, different experiments were considered in order to assess some possible combinations for the traceability systems adopted by the SC. Table 2 presents the results of experiments based on the simulation model that evaluated the adoption of different traceability technologies used by the actors in the mango supply chain. The experiments presented the symmetries and asymmetries in the SC through the performance measure associated with seasonal inventories and food quality. The results show that a better performance in terms of inventory and product quality is obtained when traceability technologies are homogeneous. The selection of RFID technology demonstrates a better performance regarding the seasonal inventory average, as shown in experiment 2. In addition, experiment 1 proves that a common selection of traceability technologies is associated with a better performance in the product quality average. Therefore, the model estimates symmetries when similar traceability technology is used by each player in the SC.

Table 2.
Analysis of symmetries and asymmetries according to the traceability system adopted by the mango supply chain

Nº	Retail	Wholesaler	Agribusiness	Producer	Seasonal	Product quality
1	B	B	B	B	258.15	97.14
2	R	R	R	R	256.23	97.08
3	B	R	B	R	258.39	97.10
4	R	R	B	B	257.01	97.12
5	B	B	R	R	257.37	97.10
6	R	B	R	B	257.02	97.12
7	B	R	R	B	257.35	97.12
8	R	B	B	R	257.03	97.11

B = barcode R = RFID

5 Discussion

Traceability systems allow inventory management and food quality along the SC. In this sense, De Marco et al. (2012) provide a study that illustrates the adoption of RFID technology in retail operations. In contrast, the present study has evaluated the adoption of traceability technologies (RFID and barcode) along the supply chain as well as their asymmetries in terms of inventory and product quality. Orjuela-Castro et al. (2017) illustrate an analysis of asymmetries in the inventories and transport in a supply chain. However, the present paper has conducted an in-depth study on the adoption of traceability technology and its effects on the inventories and product quality. Likewise, the delays of adoption in traceability technology are taken into account for the asymmetry analysis.

Novel conceptual frameworks for food supply chain assessment have been proposed by Manzini and Accorsi (2013), Badia-Melis et al. (2015) and Rincón et al. (2017). These conceptual frameworks show the levels of quality and efficiency that involve a traceability system adopted by the food supply chain. The quality and nutritional characteristics of raw materials and food products may be altered along the supply chain (Manzini and Accorsi 2013). In this sense, the traceability system of the food supply chain should consider the tracking of product history information in the food supply chain, as illustrated by Bosona and Gebresenbet (2013). Based on this, the developed simulation model proposed an analysis of this issue and its implications in the food quality and traceability systems.

The developed model includes the sectors of producer, agri-food industry, wholesale and retail trades in the mango supply chain. The asymmetry analysis through the model allows the selection and comparison of technologies of traceability in the SC, taking into account inventory level and food quality. The developed model can be adapted to other food supply chains.

An increasing concern of food industry and government agencies is that of food crisis management, particularly the loss of food (Dabbene et al. 2014). As a consequence, traceability systems provide strategic information that allows the risk assessment of a process. Therefore, a performance measure is directly associated with its ability to control the loss of food. In this sense, the determination of use requirements for the traceability systems is needed for their implementation (Hu et al. 2013). For this reason, the evaluation and selection of a suitable traceability system along the SC is needed.

Intelligent food logistics are needed, in order to reduce perishable waste and improve the SC (Badia-Melis et al. 2015). The development of intelligent traceability involves a novel strategic approach to assess the adoption of these traceability technologies. As not many studies have assessed food traceability performance (Bosona and Gebresenbet 2013), this research has aimed to achieve a better understanding of the different drivers of food traceability systems related with inventory and food quality.

It is believed that the simulation model presented in this paper will prove useful to assess the design and management of traceability technology as from supply chain structure.

6 Conclusion

A simulation model to evaluate the adoption of different traceability systems into the food supply chain was developed. The simulation model considered the combination of two traceability systems (RFID and bar code) to analyse the uncertainty associated with seasonal inventory and food quality in the mango supply chain. In this way, the developed model offers an ample perspective of the problem at hand. However, although the implementation of a simulation model can assist decision-making, the adoption of traceability systems can vary considerably from one supply chain to another.

The results suggest that the adoption of traceability systems in the food supply chain have an impact on the flow of material and information but should be carefully synchronised when expanding the capacity of the system in the long-term. In this sense, the decision to change and the implementation of traceability technologies in the food supply chain require comprehensive analysis-oriented models of relationships and flows between actors in the chain.

Lastly, further research could explore how the homogeneous traceability system may contribute towards reducing food quality costs in the long-term while at the same time fostering food safety and quality.

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.17632/jvzztzj9fv.1

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