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AGRICULTURAL SUPPLY CHAIN MANGO INVENTORY MODEL

MODELO DE INVENTARIOS PARA LA CADENA AGRÍCOLA DEL MANGO♣

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ABSTRACT

The globalization has generated changes in world food consumption, demand for healthy foods as fresh fruits and vegetables have increased. The losses in the perishable fruit supply chains can reach up to 40%, the post-harvest loss in Co-lombia is mainly due to the inadequate planning and execution of the inventory processes. The problem is due to the high perishability of the fruit and its variabil-ity in terms of quality levels, which even under optimal conditions of storage tend to decrease. After reviewing publications in the field of inventory management of perishable goods, there is no research regarding fruit supply chain. Additionally, some models do not cover the entire supply chain, and they only focus in studying one or two actors involved in the chain. This article presents a management mod-el of multi-level inventory for fruit mango chain includes functions decay and own losses of highly perishable fruit, a model nonlinear programming, formulated and evaluated in GAMS, which minimizes the total cost of inventory in the chain formed by a farmer, an agro-industrial company, a wholesaler, a hypermarket, a reseller and a retailer allowing calculate the order quantity and time of optimal re-placement of fruit for each echelon.

Palabras Clave: Inventory Supply Chain, Perishable Fruit, Mango, PNL, Multi-echelon

INTRODUCTION

Controlling inventory is one of the most important logistics operations in agricultural supply chains (Coelho & Laporte, 2014; Qin *et al.,* 2014; Chung *et al.,* 2014; Duan & Liao, 2013; Salin, 1998) especially for products such fruits and vegetables, due to the high rate of perishability of these kinds of goods. In fact, fresh fruits even decrease their quality when they are in motion, and also, fruits offer is seasonal which leads to a volatile demand (Soto-Silva *et al.,* 2016), permitting consumer choice to be influenced by the availability of the fruit at the time of purchasing and the quality thereof, (Yang & Wee, 2003; Akkerman *et al.,* 2010; Van Der Vorst, 2006; Duan & Liao, 2013). Therefore, there are great challenges for obtaining an efficient food supply chain of perishable goods (Batero & Orjuela 2018). Although this has been in the interest of research regarding inventory management in these supply chains, there are not models considering perishable food supply chains, particularly not for fruits.

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Food supply chains are different from other supply chains (Zanoni & Zavanella, 2012), Starting from the harvest time until the delivery to the final consumer, there is variation in the quality of the food, which is susceptible to change even under optimum distribution conditions throughout the entire chain (Sloof *et al.,* 1996; Orjuela *et al.,* 2017), Using integrated planning models in food supply chain is still a subject very limited in terms of studies, especially regarding planning models for fresh fruits supply chains, as existing models in the literature do not incorporate realistic features such lifespan of the product (Manzini & Accorsi, 2013).

Fruits, vegetables, and flowers supply chains may comprise farmers, wholesalers, importers and exporters, retailers and specialty stores, as well as suppliers of goods and services (Van Der Vorst *et al.,* 2007). A close relationship between supply and demand is the key for increasing the competitiveness of such chains (Duan & Liao, 2013). Food supply chains are global complex networks, covering production, processing, distribution, and even elimination of damaged food (Yu & Nagurney, 2013) in which logistics operations become important for agribusiness management, since all of these types of goods are perishable and its short life cycle makes inventory management a critical aspect (Orjuela-Castro *et al.,* 2017).

Inventory management in the supply chain of agricultural goods is not a topic widely studied, however, there are some related studies such RAI *et al.,* (2013) who defined an optimal replenishment time for the retailer in the supply chain, while Pauls-Worm *et al.,* (2013) studied a farmer facing a non-stationary demand with constrained service level, formulating replenishment policies for waste inventory. Law & Wee (2006) studied the transformation of chickens, pigs, and fishes in the supply chain considering a rate of deterioration with a Weibull distribution, as well as discount policies, late deliveries and multiple orders.

Other studies focus on determining planting time, crop size and also the area to be planted, taking into account a stochastic demand in order to reflect a more realistic behavior Lodree & Uzochukwu (2008) consider seasonal sales and the selection of the inventory by the consumer; while Tan & Çömden (2012) intended to match the supply and demand of a fresh fruit-vegetable supply chain; additionally, they compare the system's performance with both, one and multi-suppliers.

After reviewing publications in the field of inventory management of perishable goods, one can say there is a small number of articles related to inventory management models for food supply chain and particularly there is no research regarding fruit supply chain. The complexity of the problem is due to the high perishability of the fruit and its variability in terms of quality levels, that even under optimal conditions of storage and distribution tend to decrease. Additionally, some models do not cover the entire supply chain, and they only focus in studying one or two actors involved in the chain.

As result of reviewing the state of the art, we used as a base for our research the works done by (Rau *et al.,* 2003) and (Wang *et al.,* 2011) who considered the behavior of inventory management for perishables. In this research those studies were supplemented by particular variables in the formulation of a model, for inventory management in the Mango supply chain in Cundinamarca-Bogotá, also we included some constraints not contemplated before, as well as the model covers six echelons of the fruit supply chain, not done before. The model permits to calculate the losses due to the time in inventories elapsed of the different actors, to be accumulated and compared with the life cycle of the fruit, after of harvest.

METHODOLOGY

Before the to design the model, we make a diagnostic about the behavior of the management

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of the inventory by the actors of the mango supply chain in Cundinamarca-Bogotá, Colombia, we use the methodology proposed by (Orjuela-Castro *et al.,* 2016) To the diagnostics were done a survey, by means of non-probabilistic snowball sampling, 24 producers, 20 wholesalers, 42 retailers (marketplaces and shopkeepers), 10 agroindustry and 3 supermarkets were surveyed. In order to include the effect of the seasonality of the fruit harvest, we propose a push system, since production capacity throughout the year is limited and is conditioned to the maximum crop yields of the farmer in the harvest season. This model is characterized by a restricted production rate, which depends on prices and supply-demand. The model calculates both, the cost for each actor independently and the total cost generated in the supply chain. The deterioration rate of the mango was defined based on the estimated average length of time in each link of the chain; the respiration rate in the post-harvest maturing stage was defined according to the stage of life and the properties of the fruit (Figure 1). We estimated the time taken for each actor in the chain, the maximum and minimum lifetime of permanence, which was iterated until reaching a value that converges to the average rate of deterioration of the fruit.

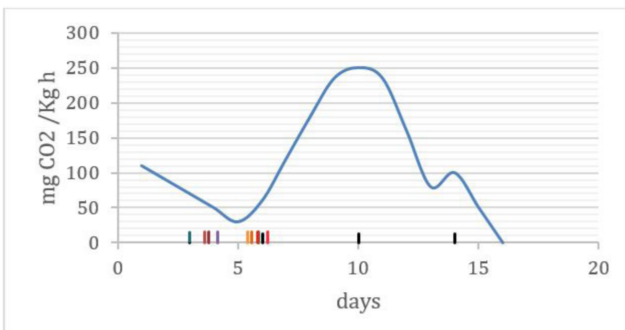

Figure 1. Mango Respiration (Orjuela-Castro *et al.,* 2017).

For the formulation of the models, we established the following assumptions:
One single product is sold through the chain. One replenishment cycle is considered. Replacement of damaged product is not allowed. Replacement rate is instantaneous. The Shortage is not allowed. Demand rate is deterministic. The Planning horizon is determined by the lifetime of the fruit. Ability to receive and send products is unlimited. Production rate is finite and greater than the sum of all demands from buyers. Each actor in the supply chain must meet a minimum demand per cycle.

The rate of deterioration of the product depends on the actor, it’s constant and is also known. This was calculated from the study of the respiration rate of the fruit (Orjuela-Castro *et al.,* 2017).

The following notations are used for the decision variables and the parameters considered in the model.

Notation for the variables used in the model

For the farmer (a)

t_a : Production cycle time.

Q_a: Harvest size of the farmer during t_a

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For the wholesaler (m)
t_m : Replacement cycle time for the wholesaler.
Q_m: Harvest size of the farmer during t_a

For the agribusiness (g)
t_g : Replacement cycle time for agribusiness.
Q_g: Order size for fresh fruit during t_g for the agrobusiness

For the hypermarket (h)
t_h : Replacement cycle time for hypermarket.
Q_h: Order size for fresh fruit during t_h for the hypermarket

For the retailer (r)
t_r : Replacement cycle time for the retailer days (d).
Q_r: Order size for fresh fruit during t_r for the retailer (Kg)

For the reseller (v)
t_v : Replacement cycle time for the reseller.
Q_v: Order size for fresh fruit during t_v for the reseller

Fruit chain
C_T: Total logistics costs generated in the fruit chain

The notation for parameters used in the model can found on the annex one

Inventory model formulation

Figure 2 exhibits the different relationships in terms of generation of orders between the actors in the supply chain, which is composed by the Farmer (Q1) Wholesaler (Q2), Agribusiness (Q3), Hypermarket (Q4), Retailer (Q5), and Resellers (Q6).

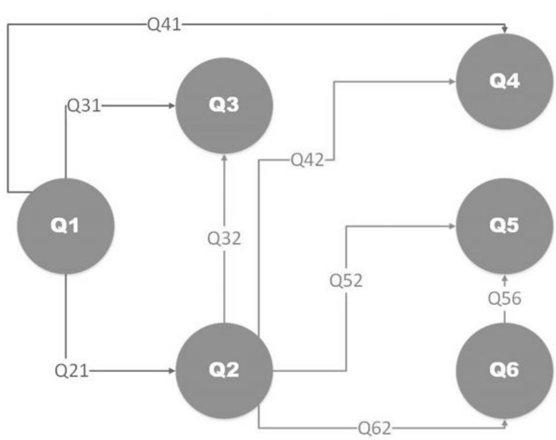

Figure 2. Composition of the agoindustry fruit supply chain

f The total cost of the chain is represented by equation (1), which corresponds to the total sum of the logistics costs generated for each actor in the chain. Equation (2) describes the number of optimal orders that each actor must order to its supplier(s), likewise, equation (3) ensures that the mango order size is greater or equal to the demand exhibited, so that demand can be satisfied.

$$Minimize TC = \sum_{i=1}^{6} CT_i(t_i) \tag{1}$$

Constraints:

$$Q_i = \frac{D_i}{\theta_i} * (e^{\theta_i t_i} - 1) \tag{2}$$

$$Q_i \geq D_i \tag{3}$$

Equations (4) and (5) represent the total cost for the farmer and other actors respectively, corresponding to the sum of the cost of maintaining inventory, deterioration, ordering and losses arising from the imbalance between supply and demand (in the case of the farmer the cost of producing and harvesting is added, and there is no cost of carrying out orders).

$$CT_a(t_a) = CM_a * P_a + (CD_a * P_a * \theta_a) + C_a + C_u * Q_a + L_a * PV \tag{4}$$

$$CT_i(t_i) = CM_i * \frac{(Q_i - (D_i * t_i)}{\theta_i} + CD_i * (Q_i - (D_i * t_i)) + Coi + Li * PV \tag{5}$$

Equations (6) and (7) represent the demands to be met by the farmer and the wholesaler for each of the actors they supply to.

$$D_1 = 1.22 * \sum_2^4 Q_{i1} \tag{6}$$

$$D_2 = 1.22 * \sum_3^6 Q_{i2} \tag{7}$$

Equation (8) represents the maximum time that the fruit can remain in each link of the chain; in order not to exceed the time within the fruit can be consumed. Meanwhile, equation (9) considers that this time must be greater than zero. Where X = 1 when there is flow of fruit and X = 0 when there is not flow.

$$T \geq \sum_1^6 t_i * X_i \tag{8}$$

$$t_i \geq 0 \tag{9}$$

Equation (10) shows the losses in each link of the chain, due to the gaps presented between supply and demand.

$$Pi = \sum_1^2 \sum_2^6 Q_i - Q_j \tag{10}$$

RESULTS - CASE STUDY

Mangos are climacteric fruits exhibiting seasonality in their harvest. This aspect is highly considered when making relevant decisions for inventory management within the actors of the chain (Figure 2).

From surveys conducted during 2015-2016, specifically for the case of Cundinamarca-Bogotá, we set the configuration of the supply chain. Given that mango production is seasonal, the

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agro-industrial supply chain was modeled as a push system. Table 1 shows the results after applying the optimization model. This table exhibits the average inventory to be maintained by each actor in the chain. The wholesaler has the highest storage needs, either in transit or in storage.

Table 1. Tipos de capacidades dinâmicas.

Actor	I_i (kg)
Farmer (a)	
Wholesaler (m)	13,44
Agribusiness (g)	4,76
Hypermarket (h)	6,07
Retailer (r)	4,79
Reseller (v)	5,65

Table 2 shows the main optimal values obtained. There is high production by the farmer because it's harvest time, so the size of the crop is 54,23 kg mango, with a cost of US$10,8 On the other hand, it is evident that the retailer has the minimum time replen-ishment of inventories because it's ordering is a small lot size.

Table 2. Optimal results

Actor	Q_i*(kg)	t_i*(d)	CT_i*(US$)	D_i(kg)	CT*(US$)
Farmer (a)	54,23	-	10,81	-	19,38
Wholesaler (m)	27,34	1	4,15	26	
Agribusiness (g)	8,13	1,16	0,75		
Hypermarket (h)	13,33	0,93	1,51	13,33	
Retailer (r)	10,71	0,92	1,07	10,71	
Reseller (v)	12,5	0,93	1,09	12,50	

Table 3 shows the losses caused by the imbalance between supply and demand, given that the farmer sends a harvest size to the actors downstream the chain hoping that all the fruit is received, however the order size of each actor is different from the expected, therefore, there are declines in shipping, which are supported by the farmer and the wholesaler.

Table 3. Losses associated with the imbalance between supply and demand.

Chain	Parameter	Losses (Kg)
Farmer (a)	7,5%	5,52
	5%	5,42
		5,33
		4,84

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Wholesaler (m)		4,13
	5%	3,45

Consequently, with a rate of decline of 5% there will be a loss of 5,42 and 4,13 kg caused by lack of demand, in the case of the farmer and the wholesaler respectively.

Sensitivity Analysis

Table 4 shows a change in the size of optimal ordering when the rate of deterioration of the mango changes.

Table 4. Effects of the deterioration rate over the cost in the mango supply chain

		Q_i*(kg)	t_i*(d)	CT_i*(US$)	I_i (kg)	D_i(kg/d)	CT* (US$)
	θ_a= 7,5%	55,17		11,10			21,12
(a)	θ_a= 5%	56,36		10,81			19,38
	θ_a= 2,5%	53,31		10,54			17,62
	θ_m= 15%	28,05	1	4,99	13,67	26	21,12
(m)	θ_m=10%	27,34	1	4,15	13,44	26	19,38
	θ_m= 5%	26,66	1	3,35	13,22	26	17,62
	θ_g= 12%	8,27	1,16	0,,84	4,68		21,12
(g)	θ_g= 8%	8,13	1,16	0,75	4,76		19,38
	θ_g= 4%	8,00	1,17	0,66	4,65		17,62
	θ_h= 22,5	13,33	0,90	1,65	5,81	13,3	21,12
(h)	θ_h= 15%	13,33	0,93	1,51	6,07	13,3	19,38
	θ_h= 7,5%	13,33	0,96	1,36	6,35	13,3	17,62
	θ_r= 27%	10,71	0,88	1,27	4,55	10,7	21,12
(r)	θ_r= 18%	10,71	0,92	1,07	4,79	10,7	19,38
	θ_r= 9%	10,71	0,96	0,85	5,05	10,7	17,62
	θ_v= 24%	12,5	0,90	1,29	5,40	12,5	21,12
(v)	θ_v= 16%	12,5	0,93	1,09	5,65	12,5	19,38
	θ_v= 8%	12,5	0,96	0,86	5,93	12,5	17.62

When the rate of decline decreases, the lot size must be less for the farmer and wholesaler, due to losses by deterioration. Also, it is evident that the lower the rate of deterioration the higher the time for replacement of the mango, leading to a longer period of the quality of the mango, which increases the average inventory of every actor.

From all the analyses performed, lower rates of deterioration showed a better performance in terms of costs, cycle times and replenishment quantities, suggesting that with good agricultural practices, cold chains and modified atmospheres may decrease the rate of respiration of fruit, improving performance measures, thus benefiting all the fruit supply chain and reducing inventory costs for every actor.

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CONCLUSIONS

We present a model to management of inventories which aims to minimize the total cost of inventory in the supply chain, considering losses by deterioration, cost of harvest for the farmer, cost of ordering in a fruit perishable supply chain, integrates inventory costs for the farmer, wholesaler, agroindustry, hypermarket, retailer, and reseller all involved within the mango chain. The model presented was done using a push system, taking into account crop conditions. Through the proposed model we obtained optimal results of replenishment times, crop lot size and order size, which allowed improving mango logistics supply chain performance on Cundinamarca-Bogota, Colombia.

We measured the effect of the rate of deterioration of the mango over the decisions for ordering. We found that with lower rates of decline, costs tend to reduce, and an improvement occurs reflected in the cycle times and replenishment quantities, leading to the conclusion that reducing the respiration rate of the fruit, is possible to obtain efficient agricultural chains, with lower costs for each actor involved.
The model for the mango chain was the result of reviewing the state of the art, although we took as pillar studies those developed previously, however, this model contains differences regarding the rate of deterioration which depends on the fruit, the losses due to inventory time in the different actors, novel approach.

FUTURE RESEARCH

For future research, it is important to analyse the impact of stochastic elements presented in the demands for actors such as the hypermarket, retailer and reseller and what its effect on the price of the mango is.

On the other hand, there is evidence from the literature review, that there is the need to develop models that consider more than a logistic process simultaneously, such as location, transfer, routing and inventory and its application in the Colombian context, since replenishment lead times were not taken into account and this is a determining factor because of the conditions of the road infrastructure and fruit collection processes as well for the selection centers owned by the region.

Finally, the development of a dynamic model that considers the number of orders in a finite planning horizon is suggested. On the other hand, one might consider the classical models to model the supply chain even when the products lose their quality and become perishable.

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