ISSN 1870-4069

Dynamic Simulation to the Beekeeping Supply Chain in the Region of Vichada, Colombia

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Abstract. The purpose of this article is to model beekeeping production in the region of Vichada in. The beekeeping chain was chosen as the objective of the study because it is a sector of economic importance in the mentioned region with the highest indices of multidimensional poverty in Colombia, but also one of the places with the greatest conservation of its biodiversity. A systems dynamics approach is used from a causal diagram to explain the interactions among bee rearing, wax production, honey production and transformation, and then simulations were performed to determine the behavior of inventories with respect to the production and demand. This model highlights the dynamics of the system and the management of the supply chain and is presented as a useful tool to predict production-demand scenarios in the beekeeping sector where similar studies are scarce. As future research, it is recommended to include the economic nature of the products in this kind of models so that scenarios can be proposed to help beekeepers make production decisions according to demand and develop inventory policies.

Keywords: Honey, wax, system dynamics, product diversification.

1 Introduction

The beekeeping supply chain involves the rearing of bees, the products derived from the hive and their relationship with the demand, in which many participants are linked. The science of caring for bees considers the production environment with the availability of honey flora and agents that can cause mortality in bees, as well as the productive purpose of the beekeeper for which hives are used which are made of wooden boxes with frames. They contain wax cells built by bees and are used to store food made up of honey and ¿pollen.

All these elements that combine within the hive are used by the beekeeper to extract and market them, and even the same bees are sold as biological packages, although keeping a minimum population of bees within the hive to avoid an imbalance. Vichada

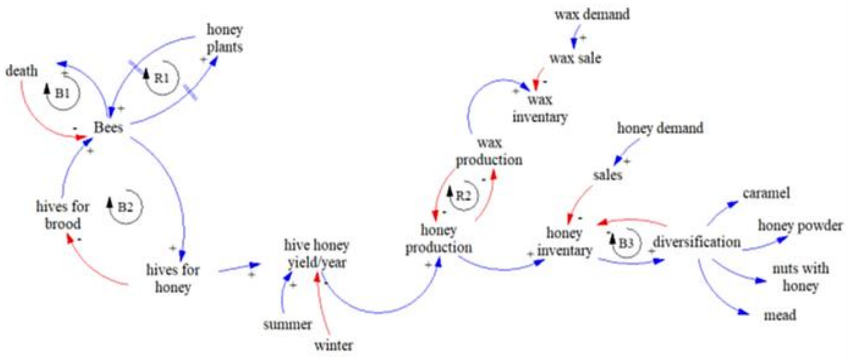

Fig. 1. Causal diagram of Beekeeping production.

has about 95.940 forest hectares within which are plantations of Acacia mangium that provides nectar for bees (El Espectador 2020). In this region, the river Bita basin, with a Ramsar wetland declaration that preserves a natural landscape, contains 1.474 specimens of plants, belonging to 103 families, 278 genera and 424 plant species

(Trujillo and Lasso 2017) and at the same time it provides clean water and food for bees and an adequate environment for the development of the beekeeping chain.

For regions with a tropical climate such as Vichada, honey is the main product of the hive. Vichada has an approximate production of 140,000 kg of honey with yields of 40 kg / hive-year. Beekeeping is prioritized as one of the productive bets of the region (Comisión Regional de Competitividad e Innovación de Vichada 2019) due to the apicultural potential given by the environmental conditions and botanical resources for the development of the activity (Castro 2018).

However, nowadays this sector presents the need for investigating at a higher extent the bee chain, its products and innovative uses to generate value (Ministerio de Agricultura y Desarrollo Rural 2018). This coincides with the low competitiveness of bee honey production in Vichada, which influences the inappropriate existing inventory.

Therefore, it is intended to evaluate honey production in terms of its dynamic demand, and it seems convenient to establish production systems that consider other kinds of products such as bees for breeding, and by-products derived from honey, and wax. The latter one, has an interesting demand by beekeepers and pharmaceutical industry mainly and also bees have a demand related to recover degraded agroecological systems or support agricultural productions that require the pollination service provided by bees.

In this sense, system dynamics is presented as a useful tool to represent problems and provide solutions to a given situation, through a relationship of variables and simulation of the built model. When conducting a preliminary review using the Scopus database considering English written articles relating system dynamics and the word honey, only 12 articles were found that were reviewed and some limitations were found in the form that authors face the system dynamics modeling in a beekeeping context.

Carlevaro et al. (2004) present a conceptualization and simulation with system dynamics of the behavior of the Argentine honey chain with an export profile and analyze climatic, economic, and technological scenarios.

However they do not present a Forrester model that allows readers to replicate the model. Ward and Boynton (2010) used an econometric model to analyze the honey demand and showed the impact of its generic promotion, and Rusell et al. (2013) evaluated the factors that may have the greatest influence on the growth and survival of the colonies but the products of the hive were not considered.

Therefore, there are few known studies of system dynamics in bees or in honey production in the Colombian and Vichada context that lead to having a model that considers productive factors of the hive and its by-products that opens the possibility of evaluate a wider range of decisions in the beekeeping chain. This aspect reflects the innovative component of this article which aims to develop a dynamic simulation model to evaluate beekeeping production in Vichada.

2 Methodology

The case study was the beekeeping production model in the region of Vichada, Colombia. The conception and construction of the model was carried out in Vensim PLE.

2.1. Causal Diagram

The Figure 1 presents the causal diagram that indicates the cause-and-effect processes originated in the dynamic behavior of beekeeping contexts, and this is based on the literature review and on the knowledge of beekeeping experts in Vichada. The arrows in the diagram are used to link the causal elements and the sign used symbolizes the direction of the effect generated by the cause. Feedback loops are also employed, with a reinforcing or compensating nature. Figure 1 contains two reinforcement loops and three compensation loops.

During the visit of the bees to the plants in search of nectar, they carry out pollination, which would cause the growth of more honey and nectariferous flora, that is, R1 has double delay. For the R2 loop, as wax production increases, honey production decreases.

In addition to the nectar supply, the reproduction of bees is influenced by mortality, loop B1, and if this mortality of bees is high then the population of bees decreases significantly. The compensation loop B2, means that if the number of bees in a hive increases significantly, then the beekeeper can increase the boxes, vertically in the same hive for honey production, but at the same time reduces the possibility of dividing colonies of bees for breeding (Jimenez 2017). However, the number of bees continues to increase. Regarding the B3 loop, as the diversification of products from honey increases, the inventory of honey decreases. By having honey-producing hives, the hive / year yield increases, expressed in kg of honey / hive, which is mainly influenced by the harvest season (Medina et al. 2014).

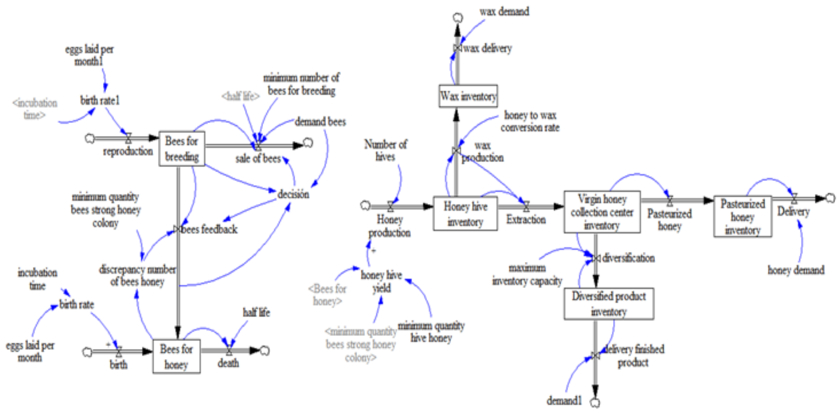

Fig. 2. Forrester diagram of the beekeeping production in Vichada.

If the honey yield increases, so will the honey production in the hive. Although here it can be presented that the honey is converted by the bees into wax, if there is a demand for wax, it increases sales and therefore the inventory of honey decreases. Honey production can be extracted from the hive and ante resultant inventory is affected by sales which are influenced by demand. The beekeeper, then, can follow a line of product diversification based on honey. In the context of Vichada, honey is used as raw material for the production of alcoholic beverage mead (Hernández et al. 2016), and it is also used as a coating for cashew nuts, and it is marketed in doypack bags and in glass containers with dispensers, as a strategy to reduce honey inventory.

2.2. Data for the Model

In addition to the loops already presented, relevant information to the model was obtained for testing: it was considered a minimum number of bees for breeding, a weight of 1 kg of bees which implies between 10.000 and 12.000 bees. However, a strong and healthy colony has at least 5 kg of bees, with an incubation time of the bee in the breeding cell on average of 21 days, and it is estimated that a queen bee on average has a posture of 500 eggs/day in winter season and up to 1500 eggs per day in summer.

The half-life of the queen bee is 3 years and of the worker bees with beekeeping of up to 25 days in winter, and 19 days in summer which is the time when the flowers expel nectar and provide pollen and therefore the bees work harder in winter to collect and store food. In the harvest season the beekeeper visits the hive and extracts hive boxes with honey, but they should leave a minimum amount of honey for internal food of the bees, which is about of 5 hive boxes with honey, 6 kg of honey (Director técnico Apícola de Inverbosques S.A.S, Manuel Bernal, Puerto Carreño-Vichada, comunicación personal, 2020).

As for the conversion rate of honey into wax, it is necessary 8 kg of honey to produce 1 kg of wax, and this occurs in the wax glands of the abdomen of bees (Monreal 2019).

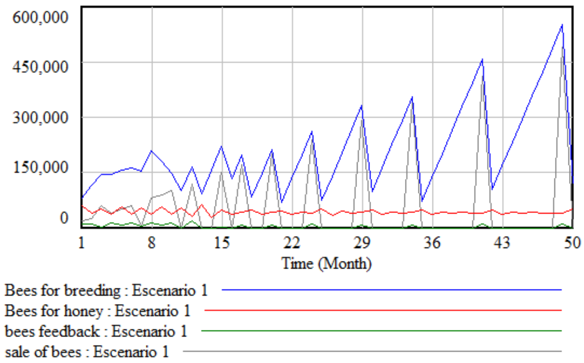

Fig. 3. Comparison between bee levels and feedback and sales outs flows.

Although wax is an indispensable input for developing beekeeping activity and therefore has a commercial demand, the demand for wax is not known for certainty and in this article is considered a behavior of a uniform distribution between 10 and 1000 kg. For the demand of pasteurized honey, the consumption culture of 0.83 g honey per person in Colombia is accounted for (Ministerio de Agricultura y Desarrollo Rural 2019), and we assume a behavior of a normal distribution of 6.500 to 7.778 kg of pasteurized honey/month.

It is also taken into account that the quality of the product of Vichada's extrafloral honey is supported by studies of the physicochemical composition and known sensory and bioactive attributes, and the extraction process is carried out in compliance with good handling practices (Castro 2018).

With regard to the products diversification from honey as a raw material or input, we assume that there is a qualified workforce in the region, equipment and inputs are available to transform the products, and also storage capabilities are available for the processed products. It is considered to have a demand with normal distribution behavior of 2.500 to 2.121 kg of diversified product/month. The system dynamics model includes level variables, flow variables, and auxiliary variables represented in Figure 2.

3 Results

The interpretation of the model expressed in the Forrester diagram is presented from left to right. A first scenario (Figure 3) was analyzed that corresponds to the breeding of bees and hives for honey in summer season where the half-life of the bees is 19 days because there is flowering in the plants and the worker bees leave the hive to perform pecoreo work, and this process is performed from 4:30 am to 6:30 pm approximately in Vichada.

It is also considered an impact on hives from attacks by animals such as the Plain Ocarro or Armadillo which consume bee and honey larvae, as well as the burning of Vichada savannahs that reach forest plantations and cause the escape of bees

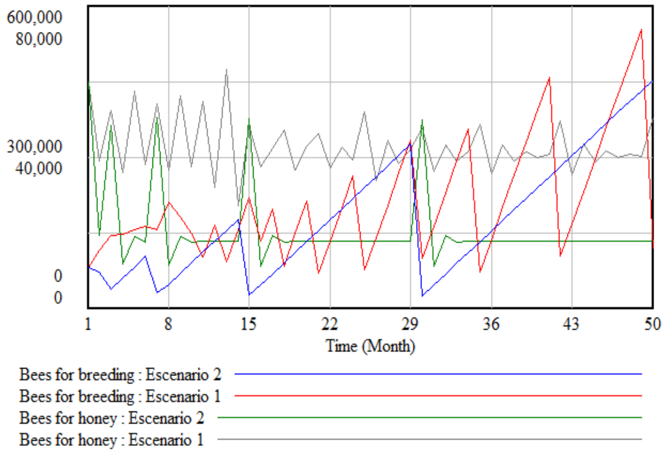

Fig. 4. Behavior at the level of bees for breeding and honey bees in two scenarios.

(Asociación de Apicultores y Meliponicultores de Vichada, comunicación personal 2020).

Other factors are considered in a lesser proportion, based on the literature, such as exposure to pesticides (Klein et al. 2017), malnutrition of the colony (Naug 2009; Montoya et al. 2016), diseases and parasites (Potts et al. 2010),which according to the reviewed literature, these are important factors in the mortality of bees. Likewise, the queen bee is considered to increase its egg posture to try to compensate for the bee population.

Figure 3 shows the behavior of the "Bees for breeding" and "bees for honey" inventories and the variables "sales of bees" and "bees feedback", where there is a slight increase in bee reproduction until the eighth month and then a decrease that coincides with the behavior of salts of bees.

It also shows a fluctuation in the amounts of bees for breeding that follows typical inventory behavior based on the sale of bees and the bee dispatching for feedback of honey hives, without affecting the minimum number of bees that must be in a breeding hive. As for honey hives, they have a stable bee population because they continually receive feedback from the inventory of bees for breeding.

Figure 4 exhibits a comparison between Scenario 1 and Scenario 2. The scenario 2 is based on beekeeping behavior in the winter season where bee posture decreases to 500 eggs per day and the half-life of bees increases to 25 days. The population of breeding bees and honey bees tends to be lower in the winter (blue line) compared to the summer (red line).

Figure 5 presents the production of honey in the hive that generates an inventory of honey which fluctuates according to the output of hive boxes with honey for extraction and to the production of wax that occurs internally in the hive, but which decreases the inventory of honey.

Figure 6 shows the behavior of the "virgin honey collection center inventory" from which comes a flow of honey to pasteurize and honey to be transformed into other

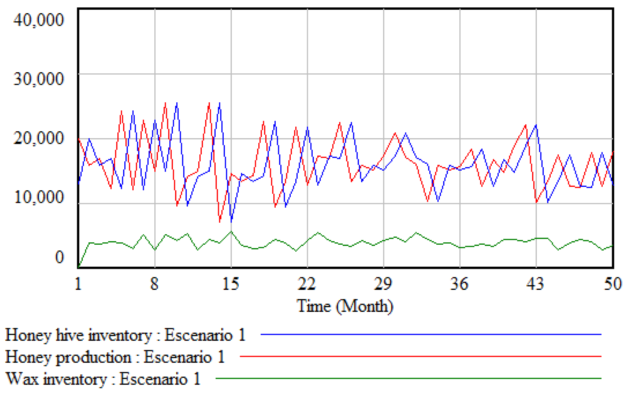

Fig. 5. Behavior in the honey inventory of the hive and wax inventory, and honey production.

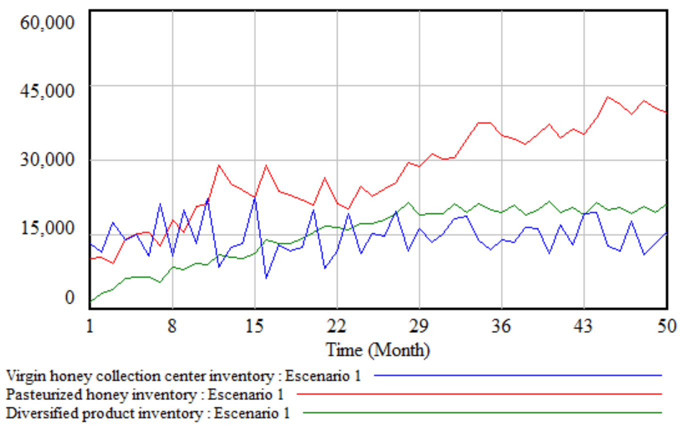

Fig. 6. Inventory behavior of pasteurized honey, collection center honey and diversified product inventory.

products, that is "diversification", in a ratio of 80:20. Virgin honey inventory fluctuates each month because there is an input from the apiaries and an output to the pasteurization and diversification processes, where pasteurization inventory presents a build-up based on demand that is not enough to maintain a stable inventory, and the same is true for diversification where the product diversification order depends on the storage capacity of the inventory.

4 Conclusions

The production of bee honey and wax depends directly on the performance of the hive which in turn is influenced by the half-life that is strongly related to the degree of health, the bee population, and the clean environment where the bees are located. Product diversification is a strategy to help reduce virgin honey inventory when low demand for honey is presented for direct consumption.

It is important to have clarity on the demand for pasteurized honey, diversified product, wax, and bees for breeding to establish production conditions and not have some accumulated inventories, while other inventories are low. It is recommended to introduce into the analysis the production costs, sales prices, and profitability of each analyzed product in this model of beekeeping production, in order to have a sustainable approach and to be able to make decisions regarding production.

Acknowledgments. Lizeth Castro thanks to the Ministerio de Ciencia, Tecnología e Innovación-Minciencias funding received in doctoral training in Engineering. Emphasis Industrial Engineering on Universidad del Valle.

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