Dynamics of the COVID-19 impacts and policies: the case of an Agri-food supply chain

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Abstract. This research aims to analyze the impact generated by the COVID-19 pandemic in an agri-food supply chain (AFSC) case and the associated mitigation policies. We conducted a survey to evaluate the adherence of these impact variables and mitigation policies within an AFSC. Furthermore, we simulated the dynamics of a producer within the AFSC, through System Dynamics modelling. This paper evaluates the inherent sensitivity of supply chains to amplified production costs and disruptions in product delivery, which inevitably hamper the sales pace. It corroborates the anticipated negative repercussions stemming from escalating production costs and delivery inconsistencies. Additionally, the investigation reveals that investments in logistics policies exert a notable influence on sales rates, showcasing a positive correlation between increased investment and enhanced sales performance. The findings highlight the imperative for strategic investments and agile policy formulations tailored to the evolving necessities of agri-food supply chains in navigating crises and sustaining operational efficacy.

Keywords: Supply chain management. Performance management. Disaster response. Disaster Management.

1 Introduction

The COVID-19 pandemic disrupted supply chains (SCs) across different sectors, for example, automotive, healthcare, and food [1-4]. In the agri-food supply chain (AFSC), specifically, activities were disrupted, and blockades were established [5]. Furthermore, the interruptions caused impacts such as reduced productivity, product unavailability, and product price instability [6].

Analyzing the Brazilian context, producers in an AFSC needed to adapt their relationship with consumers. In this sense, some AFSCs adopted social and digital platforms to assist small producers in maintaining and increasing sales, even with supply problems around the world [7]. Due to operational changes like these in

AFSCs, Cordeiro et al. [8] emphasize the need to understand the real impacts of COVID-19 on these chains.

Cardoso et al. [9] argue that there is a gap in the literature regarding how disaster coping strategies, such as mitigation policies, reduce disaster impacts, thereby enhancing SC performance.

That way, this study seeks to clarify the following research question: How does an AFSC behave when addressing the impacts of COVID-19 and implementing mitigation policies? Therefore, this paper aims to analyze the impacts and mitigation policies generated by the COVID-19 pandemic in an AFSC.

In addressing the research question, this paper introduces a case featuring an association of fruit and vegetable producers in Brazil known as Junta Local. Situated in Rio de Janeiro (Brazil), Junta Local organizes a production chain, grouping local food producers to vend their goods in open-air markets as well as via an online platform.

First, the research adopts a survey with producers from the Junta Local to validate the impacts and mitigation policies identified in the literature by Braga et al. [10] to analyze whether these variables accurately represent the reality of the studied AFSC. Then, this paper assesses the effects of COVID-19 impacts and mitigation policies on a producer named Sítio Quaresmeiras. Employing the System Dynamics (SD) method, we conducted simulations of potential operational scenarios involving Sítio Quaresmeiras (the producer) and Junta Local (the distributor) to evaluate the effects and efficacy of the identified mitigation policies in this case.

This study's significance lies in validating data from the literature, adopting surveys and simulations to assess specific COVID-19 impacts and mitigation policies as identified by Braga et al. [10] through a literature review. Such applications are fundamental, allowing empirical observations to be firmly corroborated with theories, factual evidence, variations, and simulations [11].

Following this introduction, Section 2 delineates the employed methodologies. Section 3 details the outcomes of the conducted survey. Section 4 brings the simulation model and its resultant conclusions. Lastly, Section 5 presents the conclusions, limitations, and future research directions.

2 Methods

This section presents the methodologies used in this paper, as well as details how they work in favor of the research objectives.

2.1 Survey

The survey is adopted in this research to assess whether the COVID-19 impacts and mitigation policies identified in the literature by Braga et al. [10] accurately reflect the reality of Junta Local producers. Therefore, this research follows the methodology proposed by Forza [12], encompassing theory alignment, design, pilot testing, data collection and analysis, and reporting stages.

The questionnaire was developed based on the findings of Braga et al. [10]. A pilot test was applied to the producer Sítio Quaresmeiras. Then, the questionnaire was administered to 20 producers from Junta Local, with a 70% response rate, covering the COVID-19 impact and policies based on the literature. We distributed the questionnaire online on May 20, 2021, and collected data via SurveyMonkey® on June 11, 2021. The data was analyzed and represented by a frequency chart based on producers' answers to impacts and policies. These findings are present in the survey results Section.

2.2 System Dynamics (SD)

SD is modelling that involves understanding and representing how complex systems change and evolve [13], aiding in the identification and modification of patterns [14]. It employs Causal Loop Diagrams (CLDs) to illustrate feedback structures [15] and Stock-Flow Diagrams (SFDs) to simulate the accumulation and flow of materials and information [15].

We considered the impact and policies identified by the addressed producer during their COVID-19 response as variables. These variables are employed to model a representative case, developing an SFD. The simulation considers Sítio Quaresmeiras case due to data availability, willingness to participate, and the relevance of data from 2019 to 2020. The Vensim software is utilized for simulation purposes.

Validation tests were performed, following the protocols of Schwaninger and Grösser [16], to ensure the simulation model's reliability. Validation includes tests related to model context (aimed at avoiding inefficient models and inappropriate methods) and model structure assessments (aimed at ensuring alignment with the natural world). We perform two model-related context tests (model fit and adequacy), and we apply the dimensional consistency model structure test by examining units for internal validity and evaluating sensitivity to how parameter variations affect model results, and model structure tests.

3 Survey Results

Figure 1 illustrates the impacts of COVID-19 according to the producers of the Junta Local. Respondents consistently report four impacts: increased production costs, raw material shortages, demand instability, and fluctuation in the price of raw materials. Production costs increase significantly due to vulnerabilities in harvesting, production, raw material supply, transportation, and storage [17]. Raw material shortages were attributed to delays in input acquisition caused by circulation restrictions [17-18]. Demand instability, driven by panic buying during the pandemic, led to increased consumption [18-19]. Circulation restrictions varied demand, hampering the availability of products [18]. Fluctuating in raw material prices resulted from restricted movement and high local demand due to strict regional blockades [20].

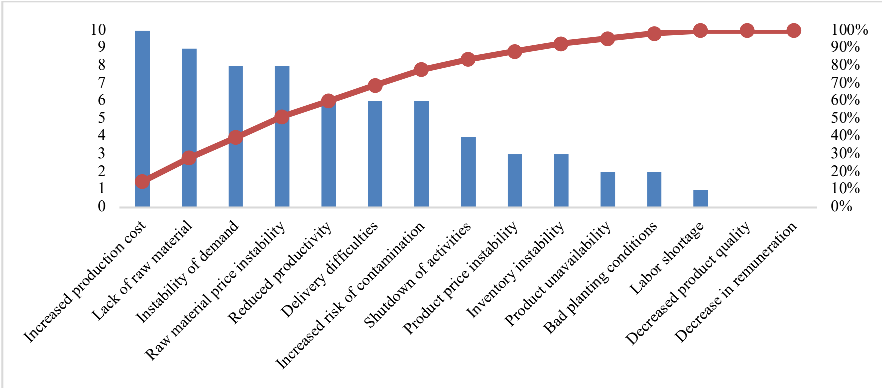

Fig. 1. Impacts identified on survey

Figure 2 reveals the COVID-19 mitigation policies identified in this survey. Academic research investment appears as the primary policy adopted by Junta Local, as supported by the response of the engaged producers. Contingency measures, such as hand hygiene, mask-wearing, alcohol gel use, and social distancing, were the second most mentioned policy, showcasing producer concern for employee well-being and SC continuity, aligning with primary COVID-19 protection guidelines [21]. The third significant policy is digital marketing investment, providing alternative sales avenues like social networks [22]. Logistics investment remains essential to mitigate barriers related to the COVID-19 pandemic [23].

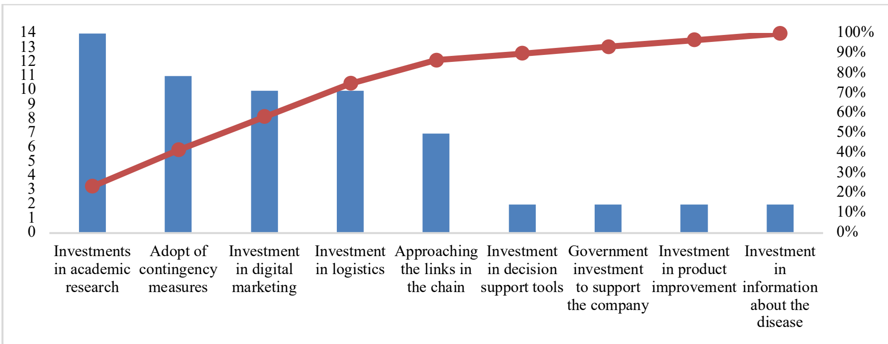

Fig. 2. Mitigation policies on survey

When we analyze the relationship between the literature findings in Braga et al. [10] and the survey conducted in this paper, we conclude that a relationship exists between the results. In the literature [10], the authors identified the three primary impacts of COVID-19 in the AFSC are increased production costs, labor shortages, and demand instability. Conversely, in this survey, the main three impacts are increased production costs, lack of raw materials, and demand instability. Thus, two of the three primary impacts reflect similar outcomes, and this similarity also extends to other types of impacts.

Regarding the policies, the respondents of our survey added two main mitigation policies (investments in academic research and adoption of contingency measures) not previously assessed in the literature [10]. However, when evaluating the three policies following these two in the survey, namely investment in digital marketing, investment in logistics, and approaching the links in the chain, we also find a relationship with the top three policies reported by Braga et al. [10], namely investment in digital marketing, government investment to support the company, and investment in logistics. Thus, two of the main three policies are also identical both in the literature and in the survey. Therefore, previous literature findings partially represent the case studied.

4 Simulation

The simulation in this paper focuses on the relationship between Sítio Quaresmeiras (producer) and Junta Local (distributor). Therefore, the data pertains solely to the interaction between these two links. The model starts with production data, followed by calculations for producer and distributor stocks based on transfer fees and sales rates. Equations I and II illustrate these relationships.

Eq. I $$Producer\ Stock = \int_{to}^{t}[production\ rate - transfer\ fee\ to\ tge\ Junta\ Local - transfer\ fee\ to\ the\ other\ distributors]ds + Producer\ Stock\ (t_0)$$

Eq. II $$Distributor\ Stock = \int_{to}^{t}[transfer\ fee\ to\ the\ other\ distributors - sales\ rate]\ ds\ + Distributor\ Stock\ (t_0)$$

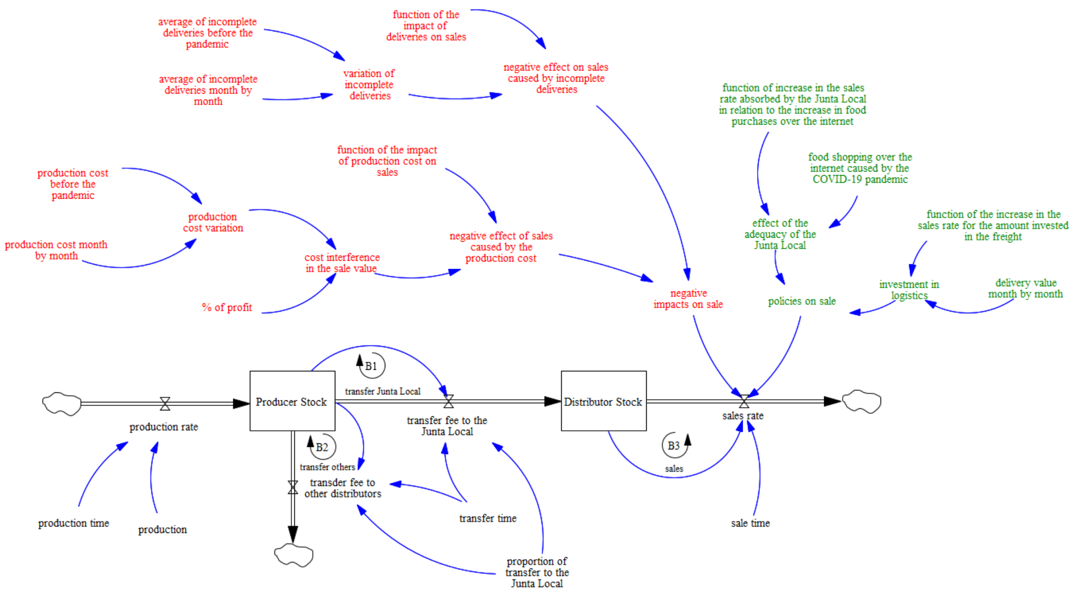

Fig. 3. Simulation model

Sítio Quaresmeiras experienced two noticeable impacts: increased production costs and delivery difficulties. Hence, only these two impacts are modeled in the simulation presented in this section. Additionally, among the mitigation policies, the same producer perceived two policies: investment in digital marketing and investment in logistics. The impacts are modeled and represented (see Figure 3) in this simulation as "negative impacts on sale". Similarly, the policies are depicted as "policies on sale".

The sales rate is negatively impacted by variables associated with costs and incomplete deliveries. The sales rate is also positively affected by variables associated with an investment in logistics and the adequacy effects of the Junta Local. Table 1 presents all the parameters with their names, descriptions, and units.

Table 1. Model variables

Variable	Description	Unit	Source
% of profit	Profit margin on agricultural products	dmnl	Dias (2021)
production cost before the pandemic	Weighted average of production costs in 2019	($) reais	IEA-SP (2020) and Hortfuit Brasil (2020)
production cost month by month	Production cost in 2019 and 2020	($) reais	Sítio Quaresmeiras data, IEA-SP (2020) and Hortfuit Brasil (2020)
effect of the adequacy of the Junta Local	Percentage absorbed by the Junta Local of the increase in the sales rate caused by the behavior of the population to buy online	dmnl	calculated by the model
negative effect on sales caused by incomplete deliveries	Percentage of sales impacted by incomplete deliveries	dmnl	calculated by the model
distributor stock	Junta Local stock level	kg	calculated by the model
producer stock	Inventory level of the analyzed producer	kg	calculated by the model
function of increase in the sales rate absorbed by the Junta Local in relation to the increase in food purchases over the internet	Increase in sales by the Junta Local in relation to the increase in food purchases over the internet in Brazil	dmnl	Junta Local data, Bain & Company (2021) and ABRAS (2020)
function of the increase in the sales rate for the amount invested in the freight	Increase in the sales rate of the Junta Local in relation to the values invested in freight	dmnl	Junta Local data
function of the impact of deliveries on sales	Decrease in sales of the Junta Local in relation to incomplete deliveries	dmnl	calculated by the model
function of the impact of production cost on sales	Decreased sales of the Junta Local in relation to the increase in production cost	dmnl	calculated by the model
negative impacts on sale	Sum of negative effects on sales	dmnl	calculated by the model
investment in logistics	Percentage of sales rate increase caused by investment in logistics	dmnl	calculated by the model
average of incomplete deliveries month by month	Average of incomplete deliveries in 2019 to 2020	dmnl	Dados da Junta Local
policies on sale	Increase in sales by the Junta Local caused by consumer behavior of buying food over the internet	dmnl	calculated by the model
production	Quantity produced month by month in 2019 and 2020	kg	Sítio Quaresmeiras data
proportion of transfer to the Junta Local	Monthly production percentage forwarded to the Junta Local by the producer	dmnl	Sítio Quaresmeiras and Junta Local data
production rate	Quantity produced per month	kg/month	calculated by the model
transfer fee to the Junta Local	Quantity produced forwarded to the Junta Local	kg/month	calculated by the model
transfer fee to other distributors	Quantity produced forwarded to other distributors	kg/month	calculated by the model
sales rate	Quantity sold per month	kg/month	calculated by the model
production time	Production indicator per month	month	calculated by the model
transfer time	Transfer indicator per month	month	calculated by the model
sale time	Sales indicator per month	month	calculated by the model
delivery value month by month	Average shipping value for the month multiplied by the number of orders	dmnl	Junta Local data

Variable	Description	Unit	Source
food shopping over the internet caused by the COVID-19 pandemic	Evolution of the monthly percentage of the population that purchases food over the internet	dmnl	Bain & Company (2021) and ABRAS (2020)
variation of incomplete deliveries	Percentage of incomplete deliveries comparing the 2019 average and the 2020 pandemic year	dmnl	calculated by the model
production cost variation	Percentage of increase in production cost comparison 2019 average and 2020 pandemic year	dmnl	calculated by the model
cost interference in the sale value	Percentage of increase in production cost plus profit margin on agricultural products	dmnl	calculated by the model

The main findings focus on production and sales rates, key performance indicators for producers and distributors. The data from the simulated scenarios for this SD model are listed in Table 2.

Table 2. Simulated scenarios

Scenarios	Production Cost Variation	Incomplete Deliveries	Delivery Value
Scenario A		Real data from 2020	
Scenario B	Increase in production cost by 50% compared to 2020	Percentage of incomplete deliveries month by month 2020	Delivery value month by month invested in 2020
Scenario C	Decrease in production cost by 50% compared to 2020	Percentage of incomplete deliveries month by month 2020	Delivery value month by month invested in 2020
Scenario D	Month-by-month production cost data from 2020	50% increase in the percentage of incomplete deliveries month by month compared to 2020	Delivery value month by month invested in 2020
Scenario E	Month-by-month production cost data from 2020	50% decrease in the percentage of incomplete deliveries month by month compared to 2020	Delivery value month by month invested in 2020
Scenario F	Month-by-month production cost data from 2020	Percentage of incomplete deliveries month by month 2020	Decrease of 50% in the month-to-month delivery value invested compared to the 2020
Scenario G	Month-by-month production cost data from 2020	Percentage of incomplete deliveries month by month 2020	Increase of 50% in the month-to-month delivery value invested compared to the 2020

Figure 4 compares Scenario A with Scenario B, incorporating a 50% increase in production cost to test its sensitivity to production and sales rates. In Scenario B, the production rate (red) resembles Scenario A for periods 1 to 4, but it increases over time. This pattern emerges because production must align with sales, and Sítio Quaresmeiras primarily serves Junta Local. When Junta Local experiences higher demand, Sítio Quaresmeiras prioritizes them. In Scenario B, the sales rate lags the production rate as the producer serves Junta Local but supplies other distributors, as shown in the simulation model.

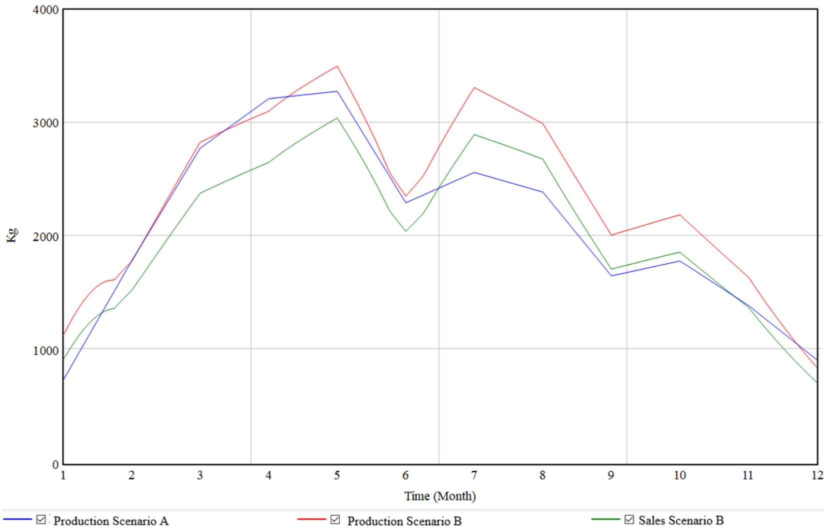

Fig. 4. Scenarios A and B

Scenario C (Figure 5) considers a 50% decrease in production cost instead of an increase. As expected, production and sales rates increase due to decreased costs, as a lower cost reflects a lower price, causing customers to buy more. Comparing the peaks of Figure 4 and Figure 5, increasing the production cost by 50%, the highest production value would be 3498 kg while decreasing the cost by 50%, we have the highest production value of 3924 kg.

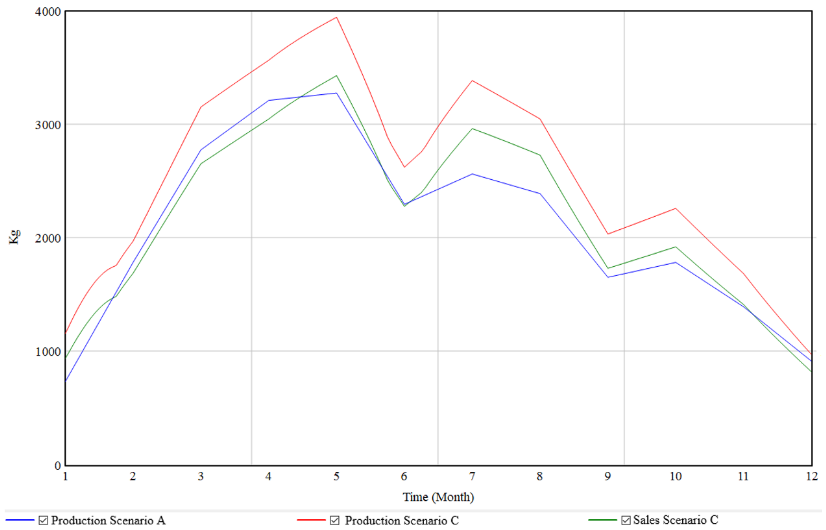

Fig. 5. Scenarios A and C

Scenario D (Figure 6) tests a 50% increase in missed deliveries from month to month, in addition to the other impacts and policies highlighted in Table 2. Figure 6 shows that in addition to decreasing production, an increase in deliveries considerably decreases the sales rate. This occurs because the more products the producer fails to deliver, the fewer products the Junta Local will possess for sales, thus harming its sales revenue.

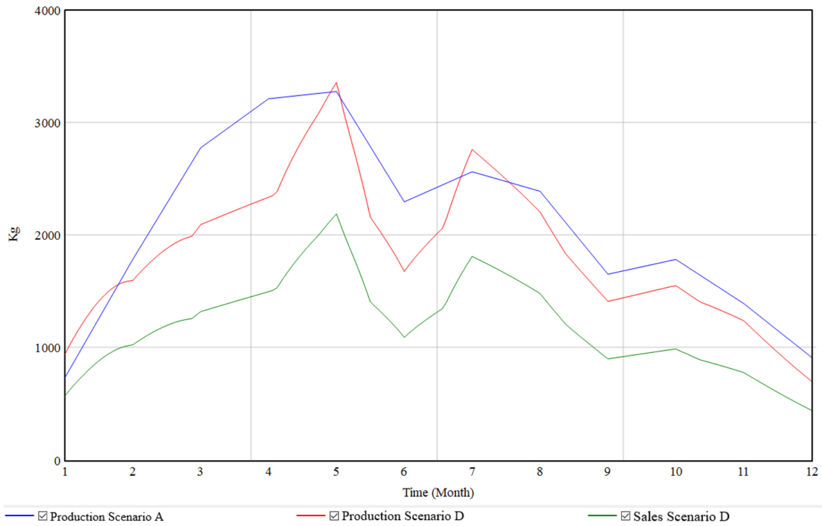

Fig. 6. Scenarios A and D

Scenario E (Figure 7) also tested the variable of deliveries not made month on month. However, product deliveries to Junta Local increased by 50%. Despite the higher production quantities, the sales data from Scenario E show similar behavior to those from Scenario A. This result may indicate that there was no increase in the amount sold despite the rise in the number of deliveries; the Junta Local supply proves to be sufficient to meet its customers' needs.

Comparing the peaks of Figure 6 and Figure 7, increasing the missed deliveries by 50%, the highest production value would be 3357 kg, while reducing missed deliveries by 50% we have the largest production value of 3420 kg.

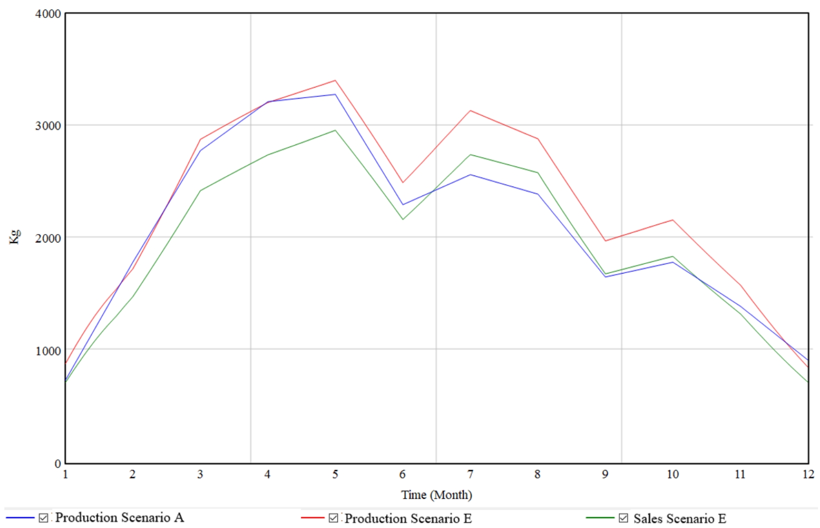

Fig. 7. Scenarios A and E

In Scenario F (Figure 8), a sensitivity analysis assesses the impact of a 50% reduction in freight costs, representing logistics investment, in the simulation. Notably, the production data in Scenario F exhibit behavior similar to Scenario A. This suggests that, even with reduced investment, the production and sales rates are not significantly affected because Junta Local effectively meets customer demands, corroborating the findings in Scenario E.

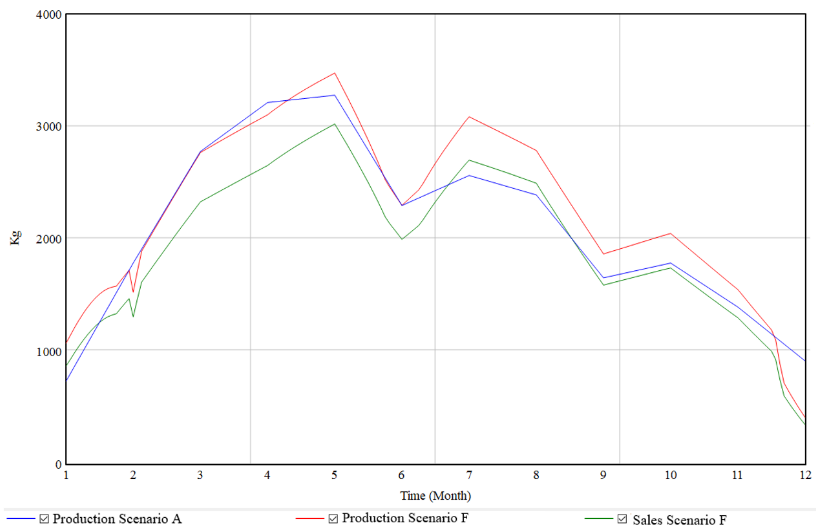

Fig. 8. Scenarios A and F

Unlike Scenario F, Scenario G tests a 50% increase in delivery value, that is, an increase in investment in logistics. The data show that this investment would increase production and sales; that is, Junta Local would be able to sell more by adhering to such a policy.

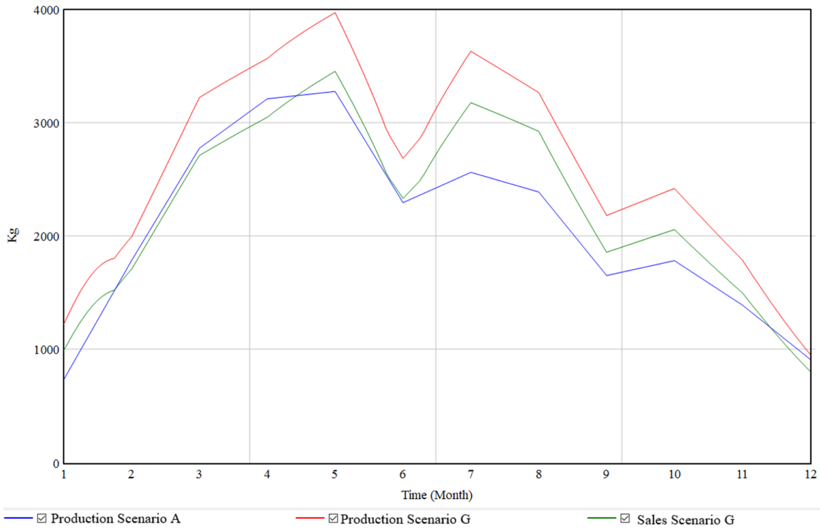

Fig. 9. Scenarios A and G

Comparing the peaks in Figure 8 and Figure 9, increasing the investment in logistics by 50%, the highest production value would be 3972 kg while reducing investment in logistics by 50%, we have the highest production value of 3474 kg.

Production cost variations have minimal effects on the sales rate, while incomplete deliveries directly impact it, decreasing sales as product availability diminishes. Increased logistics investment in delivery, however, boosts the sales rate. The simulation results illustrate how the identified impacts and policies from the literature directly influence the supply chain of Junta Local and Sítio Quaresmeiras. These sensitivity analyses aid decision-makers in choosing optimal policies and impact mitigation strategies to enhance business operations.

5 Conclusion

Encompassing a survey that reached 70% of AFSC producers who are part of the Junta Local, this study yielded results that are partially aligned with the literature, confirming increased production costs and digital marketing as essential policies. Among the variables identified in the relationship between Junta Local and Sítio Quaresmeiras, the primary indicators are the production and sales rates because any change in policy or identified impact is immediately reflected in these indicators.

The simulation findings highlight the importance of strategic investments and policy formulations to the needs of agri-food supply chains in managing crises and sustaining operational efficacy.

This research offers both practical and theoretical contributions. The practical contributions consider the simulation results and the analyses derived from them. The theoretical contributions involve the validation of literature in a specific case, underscoring the importance of revisiting and validating previous research.

However, the research faced some limitations, such as the fact that only Sítio Quaresmeiras agreed to provide inputs for the simulation, which restricted the number of variables evaluated. Nevertheless, the findings remained significant in showcasing how variables interact within a dynamic system when any variation exists.

For future research, we suggest assessing other producers of Junta Local or other AFSC organizations. Additionally, evaluating other SC models may lead to the identification of new impact and mitigation policy variables not only for COVID-19 but also for other diseases, crises, and disasters.

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