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Research Article

Operational Risk Assessment for the Pollination Service with *Apis mellifera* Bees in Cashew Crops in Vichada, Colombia

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The cashew tree relies heavily on the presence of pollinators during the peak receptivity of its flower to facilitate the transfer of pollen from the stamen to the stigma and ensure successful fruit production. Apis mellifera bees play a crucial role as intermediaries in the pollination process of the fruit, simultaneously extracting nectar and pollen from the flowers. The pollination service (PS) is susceptible to various risk factors that, if realized, could impact both the beekeeping industry and cashew production. This article aims to assess the operational risks associated with pollination service for *Anacardium occidentale* production in Vichada, Colombia, as a strategic measure to safeguard the business's value. Drawing on expert opinions and relevant literature, nineteen risks were identified, encompassing threats such as fires, thefts, attacks by wild animals, unexpected rains, etc. Following the application of Failure Mode and Effects Analysis (FMEA), four risks were prioritized based on their severity and occurrence. Subsequently, Value at Risk (VaR) was employed for risk evaluation. The anticipated loss for the pollination service, resulting from these prioritized risks: 1, 9, 12 and 13, was quantified at \$226674 ± \$19096 per year for an 8000-hectare margin with a confidence level of 95%. The economic loss for 16000 hectares was \$453348 ± \$38192. This substantial value is of great significance to the beekeeping sector, translating to a loss of \$27.3 per hectare per year and directly impacting the estimated \$437824 loss in the cashew sector. Such losses have far-reaching consequences, affecting the livelihoods of peasant beekeepers in the region and potentially discouraging the maintenance of bee colonies and forests.

1. Introduction

The cashew (*Anacardium occidentale* L) produces both apples and nuts, considered of a significant socioeconomic value for the cashew chain [1]. This chain operates collaboratively and complementarily with the beekeeping chain, as bees play a crucial role in pollinating the crop while collecting nectar to bring back to the hive, contributing to the production of honey and other hive products [2, 3]. Cashew cultivation requires a robust rainfall regime, well-drained soils, and distinct dry periods. It thrives in warm semihumid climates with an average temperature of 28°C, sunlight exposure, and specific iron nutritional requirements, with a base content greater than 35%. In Vichada, a department in Colombia, cultivation takes place in soils with high aluminum saturation, strong acid reaction, low salt content, and very low natural fertility, necessitating base correction. Due to these agroclimatic conditions, the crop yields 900 kg/ha of nuts per year, a significantly higher output compared to other plantations in Colombia, ranging between 50 and 300 kg/ha of nuts per year [1], partially due to its status as an endemic crop. Therefore, it is considered one of the primary productive chains for driving development in Vichada, encompassing millions of hectares suitable for cashew planting.

Reports indicate that cashew is primarily pollinated by insects, with approximately 40 species from 13 families of three insect orders involved in this process [4]. The sticky texture of the pollen and the stamen measurements make self-pollination difficult, creating favorable conditions for crosspollination by insects such as flies, moths, and bees. Although the cashew flower has a single ovule that could be manually pollinated, a high nut yield necessitates a substantial number of pollinator visits during the peak period of stigma receptivity to achieve optimal nut yields [5].

The pollination service in crops is estimated to cost between 18 and 185 dollars/hive, with an economic value ranging from approximately 233 to 577 billion dollars per year [6, 7], excluding the conservation value of plant species [2]. Pollination involves the transfer of pollen from the stamens to the receptive part of flowers (stigma), initiating germination and fertilization of the flower's ovules, enabling seed and fruit production. In nature, 90% of pollination is performed by insects, while 10% relies on wind action the total in nature, and 10% depends on the action of the wind on the flowers. 95% of pollination is done through cross-pollination, and only 5% of crops are self-pollinated [4].

Throughout the collaboration between the cashew production and beekeeping chains, benefits and risks are shared. Like any operational activity, there is an exposure to risk factors that, if they realized, can negatively impact company objectives. Risks stem from the probability of adverse events occurring at any stage of the supply chain, causing physical damage, delays, or operational, tactical, and strategy failures [8, 9]. According to the authors in [10], supply chain risks are categorized into two main types: disruptive and operational. Disruptive risks are primarily associated with natural and man-made disasters, such as floods, avalanches, currency devaluation, roadblocks, and terrorist attacks, among others. Operational risks occur during the activities of the supply chain and result from uncertainties in market demand, supply, price, cost, management errors, or failures in processes, equipment, or facilities [8].

Several reports have evaluated pollination conditions with bees in cashew crops [5, 11–14]. However, there is limited information available regarding the identification, prioritization, and mitigation of operational risks in the cashew pollination process with bees. Therefore, addressing operational risk management in cashew pollination is crucial for enhancing productivity and optimizing the interaction between the cashew and the beekeeping chain. This is particularly relevant in the Vichada region, the main cashew producer in Colombia, where there is an existing planting of 8000 hectares [1], expected to be expanded to 16000 hectares or more in the next 10 years, generating a growing interest in crop technological development [15].

2. Literature Review

In the realm of risk management methodologies, the International Standard (2019) published by the International Organization for Standardization (ISO) provides a comprehensive list. Each tool and technique from this list finds application in various risk assessment contexts. In this paper, the Failure Mode and Effects Analysis (FMEA) emerges prominently as a tool featuring a structured approach to identify prominently as a tool featuring a structured approach to identify and prioritize failure modes. It assesses detection (D), occurrence (O), and severity (S), culminating in a Risk Priority Number (RPN) [16]. FMEA is considered an organized analysis tool that aids in the identification, evaluation, and prioritization of failure modes using the RPN. Consequently, a higher RPN value signals a greater associated risk that warrants close attention, while a lower RPN value indicates a lower associated risk [17].

Value at Risk (VaR) stands out as a popular method employed in operational risk assessments [18]. VaR is a statistical technique that facilitates the measurement of the worst expected loss over a specific period at a defined confidence level [19]. Despite the simplicity of the VaR concept, its calculation is not straightforward. Various methodologies, often referred to as standard models, have been developed for VaR calculation. The Monte Carlo simulation, a semiparametric method, is among these methodologies. VaR's main advantages lie in its simplicity, broad applicability, and universality [20].

The Monte Carlo simulation, commonly used to assess the impact of risk/uncertainty in project management, forecasting models, and financial costs, involves developing a model with data from field experience or historical data to estimate an expected value. In this case, the probability distribution employed was the Program Evaluation and Review Technique (PERT), which considers a minimum value, a maximum value, and a most probable value. This type of estimation inherently carries risk and uncertainty as it is an estimate of an unknown value. In certain situations, a range of values will likely be estimated [21]. Specifically, the PERT distribution can be utilized to identify risks in projects and is designed to generate a distribution that closely resembles realistic probability distributions. While the PERT can provide a close fit to normal or lognormal distributions, it constructs a smooth curve that places progressively more emphasis on values around the most likely value [22].

To address the aforementioned problem, a risk assessment was implemented by integrating FMEA with Value at Risk (VaR) through a Monte Carlo simulation using the PERT distribution.

3. Methodology

3.1. Sample. The information regarding the 8000 and 16000 hectares of cashews in Vichada [16] was gathered through a literature review [4, 12, 23, 24] and surveys conducted with farmers and beekeepers. Five surveys were distributed in person, and fifteen surveys were sent via e-mail, resulting in eight responses, including five from beekeepers and three from farmers. On average, these professionals have about 50 beehives, while farmers cultivate an average of 2500 hectares of cashew plantations.

3.2. Induced Pollination Service Process. The process commences with an agreement between the farmer and the beekeeper for the induced pollination service in cashew crops. Subsequently, an appropriate location must be selected, considering factors such as water conditions, flat terrain, easy access, distance from hoses and highways, and light wind currents. Following this, groups of hives are strategically installed to create an apiary within the crop, and the rate of bee visits to the flowers is monitored [14]. Finally, during the cashew harvest, the yield of cashew nuts per hectare is calculated and the agreement is concluded with the payment for pollination.

3.3. Risk Identification. The information for identifying risks was gathered through a combination of literature review and consultations with experts. In the literature review, searches were conducted in the Scopus database using keywords such as "cashew," "pollination," and "risk." The Scopus database was chosen for its extensive collection of reviewed articles, academic journals, and book chapters. Initially, 74 documents were identified, and based on the relevance of the articles, 33 documents published between 1994 and 2022 were selected. Following a more in-depth review, 12 documents were finally chosen for identifying risks associated with the pollination service in cashews.

To validate elements of risk, a semistructured interview was conducted with a group of experts. This group comprised nine members, including professionals and academics. The selected professionals had over five years of experience in cashew cultivation and with Apis mellifera bees. The expert panel consisted of three beekeepers and six cashew farmers, all with substantial experience in Vichada.

3.4. Risk Prioritization. FMEA was utilized for prioritization. The four steps of traditional FMEA are described as follows: first, identify all failure modes in the process. Second, assign a numeric value between 1 and 10 to S, O, and D, respectively (Table 1). Then, calculate the risk priority number (RPN) by multiplying the three risk factors ($S \times O \times D$) with the assessment results. Finally, ranking the failure modes involves taking corrective actions [25].

The dispersion was plotted, and the risks from the upper quadrant were selected (Figure 1).

3.5. Risk Evaluation. For risk quantification, two scenarios were considered: one with a total of 8000 hectares and another with 16000 hectares of cashew planted in the department of Vichada. Each hectare accommodates 125 trees, resulting in a total of 1000000 cashew trees and 2000000 capable of pollination. It is estimated that one tree produces approximately 6 kg of nuts per harvest, equivalent to 750 kg of cashew nuts per hectare, totaling 6000000 tons per harvest (according to the experts).

In this scenario, a beekeeper installs four beehives per hectare of cashew and sets a service cost of $146 per hectare for pollination or charges a percentage of 8% of the sales value obtained by the cashew grower. With the inclusion of bees, it is estimated that the crop experiences a 40% increase in walnut production compared to production without bees [14].

3.6. Risk Quantification Analysis Using @Risk Simulator. The @Risk Simulator software package was employed to conduct risk analysis through Monte Carlo simulation, displaying multiple potential outcomes in an Excel spreadsheet model. A total of 5000 interactions were performed.

The structure of the model is given "i" as the index associated with the relevant risks, 1, 9, 12, and 13, and the calculation of the frequency events for a possible total is performed using the following equation:

$$\widetilde{F}_i = \text{probability} * (750 * \text{crop}) * \text{hp}_i, \quad (1)$$

where probability means a probability of occurrences which is assigned as follows: 15% for risk 1, 5% for risk 9, 10% for risk 12, and 10% for risk 13. The number "750" represents the amount of kilograms of nuts produced per hectare. Crop refers to the total hectares of cashew (per hectare). hp_i denotes the historical probability of impact in the event of the risk materializing, considered information provided by experts: 50% for risk 1, 30% for risk 9, 80% for risk 12, and 10% for risk 13.

The economic loss for the cashew pollination service was quantified using the expected value. Equation (2) calculates the cashew nut loss per crop.

$$\text{loss of nut per harvest}_i = \widetilde{F}_i * \widetilde{\text{price}}_i, \quad (2)$$

where $\widetilde{\text{price}}_i$ is the unit price of a nut (dollar/kg nut): minimum: 0.7, most likely: 0.9, and maximum: 1.2 (PERT distribution). $\widetilde{F}_i$ is the frequency of events of a possible total (kg nut/harvest).

Loss per unit i is an input variable to the PERT distribution. The values are as follows:

(1) Risk 1: minimum: 0.2, most likely: 0.3, and maximum: 0.35.
(2) Risk 9: minimum: 0.8, most likely: 0.9, and maximum: 1.
(3) Risk 12: minimum: 0.06, most likely: 0.1, and maximum: 0.15.
(4) Risk 13: minimum: 0.05, most likely: 0.08, and maximum: 0.09.

The expected value of the output forecast data (equation (3)) is calculated as follows:

$$\text{Expected value} = \sum_i \left(\text{loss of nut per harvest}_i * \text{loss per unit}_i\right). \quad (3)$$

Table 1: Scale used to apply FMEA.

Range	Occurrence		Severity	Detection
	Possible failure rate	Failure probability	Effect	
10	≥1 in 2	Extremely high	Dangerous	There is no known or available detection method that provides an early alert, enough for doing contingency planning
9	1 in 3	Very high	Serious	
8	1 in 8	Repeated failure	Extreme	The detection method is untested or unreliable
7	1 in 20	High	High	
6	1 in 80	Moderately high	Significative	The detection method has a medium level of effectiveness
5	1 in 400	Moderated	Moderated	
4	1 in 2000	Relatively low	Low	The detection method has a moderately high effectiveness
3	1 in 15000	Low	Very low	
2	1 in 150000	Remote	Insignificant	The detection method is highly effective
1	≤1 in 1500000	Almost impossible	None	

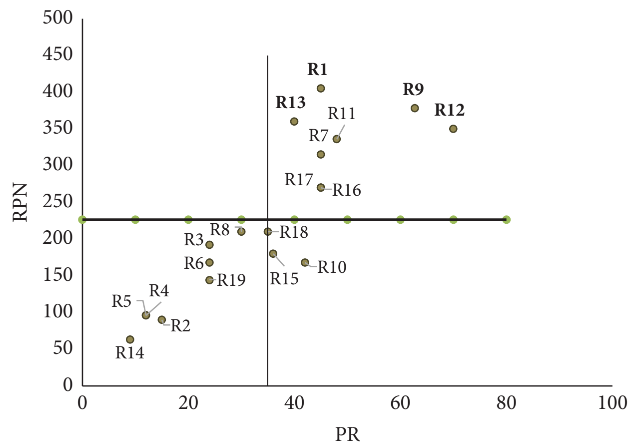

Figure 1: Scatter plot of FMEA scores.

Table 2: Identified risks and prioritization values using the FMEA scale.

#	Risk	•RPN
1	*Loss of cashew productivity during harvest due to unexpected rains with intensity greater than 2 days during flowering	**405**
2	**Loss of cashew productivity due to low visit of pollinators to the cashew during flowering	90
3	***Economic losses due to noncompliance with the pollination service (over 10% service)	192
4	***Economic loss due to a decrease in the price of cashew nuts below $0.80 per kg	96
5	***Economic loss due to an increase in prices of beekeeping supplies	96
6	*Productivity losses due to disease dissipation in cultivation, with the bee acting as a vehicle for crosscontamination	168
7	*Economic losses due to theft of hives with bees	315
8	****Decrease of the pollination service contract due to competition with other pollinators	210
9	**Economic loss of the beekeeper due to a decrease in the population of bees caused by diseases and pests in the hive	**378**
10	*Loss of hives due to attack by bush animals	168
11	*Economic losses due to incompatibility of bees with crop management activities	336
12	*Economic losses due to burns of the cashew crop (greater than 10% burns)	**350**
13	*Economic losses due to theft of cashew	**360**
14	**Loss of bees due to exposure to agrochemicals	63
15	*****Economic losses of cashew due to yields less than 20% with the pollination service included	180
16	*Economic losses due to hiring inexperienced personnel in bee management and pollination	270
17	*Reduction of the service contract due to lack of education in management and reaction to bee attacks	270
18	*Decrease in the service contract due to a bad image of the business due to aggressive bees	210
19	*Loss of bees due to little floral diversity to feed bees	144

•RPN = risk factor. Source: *Experts, **[4], ***[23], ****[11, 24], *****[12, 23]. The values in bold are the risks prioritized for having higher scores.

4. Results and Discussion

Nineteen risks were identified for the pollination service in cashew crops for walnut production (Table 2). The risks highlighted by experts are associated with local cashew production conditions, encompassing factors such as burning, theft, and attacks by wild animals. Conversely, risks identified from the literature are linked to fluctuations in the prices, the impact of pests on beehives, and the dynamics of bee visits to cashew flowers.

This tree is endemic to a region characterized by a distinct intense rainy season and a dry season with temperatures reaching 40°C. These conditions, combined with air currents flowing through the plain of the territory, increase the likelihood of forest fires spreading. Apart from affecting the forests, the fires also reach the beehives [26].

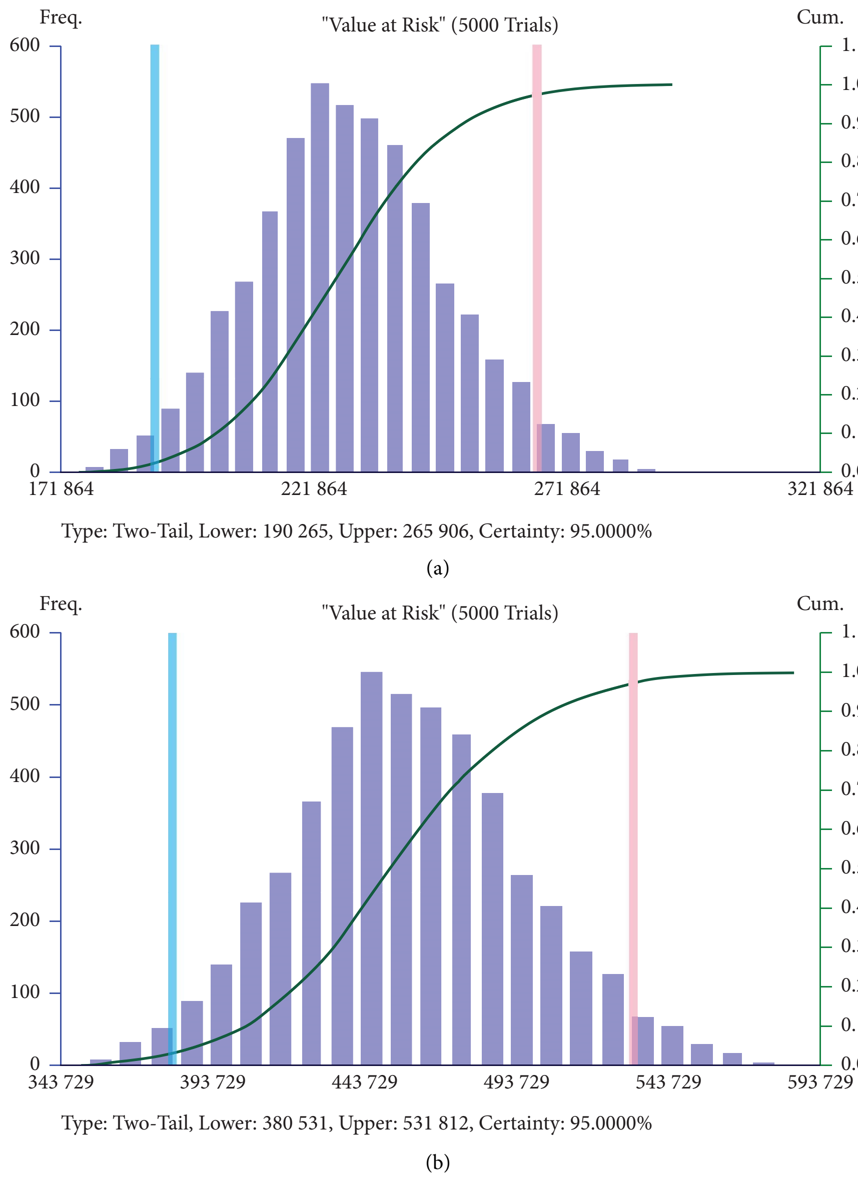

Figure 2: PERT distribution with a 95% probability to 8000 hectares (a) and (b) 16000 hectares.

According to the FMEA values, the risks with the highest values require the most attention. Four risks colored in red were selected for the quantification (Figure 1).

According to Figure 2(a), the total estimated loss for the cashew pollination service in 8000 hectares was $226674 ± $19096, with a 95% confidence margin. In comparison, the economic loss for 16000 hectares was $453348 ± $38192 (Figure 2(b)). This represents a significant value for the beekeeping sector, as this loss is contingent upon the estimated value in the cashew sector, totaling around $437824. This corresponds to a loss of $27.3 per hectare per year. For risks with higher scores, probabilities were established and the PERT distribution was applied to calculate the expected value of the total estimated loss for the cashew pollution service.

In this case, if the prioritized risks are not addressed as the activity expands in its development, the expected value of the loss will also increase. For this study, if the number of trees affected by burning is reduced by 3%, the losses would be −$29200 instead of −$129600, representing a recovery of $103680. This is achievable by understanding the dynamics of fire, conducting controlled burning, and creating firebreaks around the crops, while also raising awareness in the community about proper fire management [27].

If cashew theft is reduced by 5%, the losses would be −4532 dollars instead of −$9064, with a gross recovery of $4532. This could be facilitated by establishing an antitheft network in collaboration with military authorities of the region. If the death of bees due to diseases in the hive is reduced by 2%, the losses would be −$46656 instead of −$116640, representing a recovery of 69984 dollars. Finally, the risk with the highest incidence is the loss of cashew productivity due to unexpected rains, which is challenging to avoid due to climatic conditions. However, stakeholders can respond by applying products to prevent fungi in the trees [28] and enhancing the presence of bees in the crop to improve fertilization and prevent the fall of fertilized flowers. If the risk is reduced by 2%, the losses would be −$210600 instead of −$243000, representing a recovery of $32400.

Now, decision-makers must quantify the cost of the strategy against the recovery value and establish a margin of acceptance of the risk or recognize the importance of facing and managing the corresponding risk.

This demonstrates how collaborative cashew and honey chains can share benefits and risks in their operations. In fact, in the northeastern part of Brazil, beekeepers and cashew farmers have integrated management elements to produce cashew apples, walnuts, and honey, simultaneously increasing the yield of both foods and sharing risk management activities that affect the chains [13].

5. Conclusions and Recommendations

The induced pollination service contributes to the conservation of bees, improves the quality of the fruit and the yield per harvest, and increases the profitability of the business. Therefore, intervening in it from the operational risk approach positively impacts the cashew and beekeeping chains by understanding the worst loss, valued at $437824 per year for 16000 hectares, if the prioritized risks materialize.

This research employs a combination of traditional methods. FMEA is utilized to prioritize risks with the greatest impact, severity, and occurrence through the participation of experts who respond based on scales. Quantifying the risk is a fundamental phase in its management because the impact of the risk is measured in economic terms. VaR demonstrated that it is a standardized risk measure that groups risk into one number and can be compared because it is likely used. According to the obtained graphs, they were adjusted to the PERT distribution for the Monte Carlo simulation, which has proven to be useful in risk analysis because it considers the most probable value.

The quantification of risk for two collaborative chains in the growth phase is an opportunity for managers to measure the economic impacts on the business in the event that any of the prioritized operational risks materialize. Likewise, decision-makers can propose mitigation strategies that can be shared between the cashew and honey chains.

As a recommendation, it is suggested that the risk assessment study for the pollination service in cashew production includes more information from historical records to provide greater precision to the results, as this research could only achieve results through expert interviews.

Data Availability

The data used to support the study are available from the corresponding author upon request.

Disclosure

This work is part of the doctoral project of the lead author. The authors thank for the presentation of the abstract of the manuscript at (The EII present at the 29th International Annual Conference-EurOMA 2022).

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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