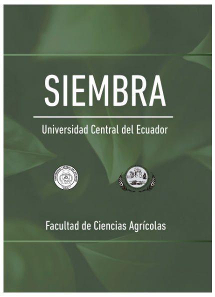
Biological alternatives for the management of Hypothenemus hampei (Ferrari), in Coffea arabica L, Jalapa, Nicaragua

Alternativas biológicas para el manejo de Hypothenemus hampei (Ferrari), en Coffea arabica L, Jalapa, Nicaragua



Sailyng Dayana Siu Palma[1], Edgardo Salvado Jiménez-Martínez[2], Juan Carlos Morán Centeno[3]

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[1] Universidad Nacional Agraria, Facultad de Agronomía. Km 12.5 Carretera panamericana Norte. Managua, Nicaragua.
✉ sdsiupalma87@hotmail.com
https://orcid.org/0000-0003-4466-3730

[2] Universidad Nacional Agraria. Departamento de Protección Agrícola y Forestal. Facultad de Agronomía. Km 12.5 Carretera panamericana Norte. Managua, Nicaragua.
✉ edgardo.jimenez@ci.una.edu.ni
https://orcid.org/0000-0003-1086-7380

[3] Universidad Nacional Agraria. Departamento de Producción Vegetal. Facultad de Agronomía. Km 12.5 Carretera panamericana Norte. Managua, Nicaragua.
✉ juan.moran@ci.una.edu.ni
https://orcid.org/0000-0001-6135-7271

**Corresponding author:*
sdsiupalma87@hotmail.com

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Abstract

The objective of this study was to evaluate biological alternatives for the management of coffee berry borer (*Hypothenemus hampei* Ferrari), on individuals inside brocaded fruits, its effect on the total yield (kg ha^{-1}), economic feasibility of each treatment evaluated. through a partial budget analysis, dominance analysis and marginal rate of return in Jalapa, Nicaragua. A quantitative, applied study was carried out, with a Randomized Complete Block experimental design (BCA), with six treatments and four repetitions, three biological products, one chemical, a combination of chemical-cultural management (trap) and an absolute control, whose variables were subjected to an analysis of variance and separation of means by Tukey test (0.05). It was determined that there was no significant effect of the treatments on the borer control, the pest's affectation increases the fruit develops, causing losses between 20 and 78 % throughout the cycle. The economic analysis showed that all treatments are profitable, having a high marginal rate of return, The Curador® treatment is the one with the highest net benefit, followed by trap plus Curador® and Bea Blue®, constituting alternatives for the biological management of the borer.

Keywords: brocade fruits, fruit dissection, economic analysis, partial budget, biological control

Resumen

El presente estudio tuvo como objetivo evaluar alternativas biológicas para el manejo de la broca de café (*Hypothenemus hampei* Ferrari), sobre la población de individuos dentro de frutos brocados, su efecto en el rendimiento total (kg/ha), factibilidad económica de cada tratamiento evaluado a través de un análisis de presupuesto parcial, análisis de dominancia y tasa de retorno marginal en Jalapa, Nicaragua. Se realizó un estudio de tipo cuantitativo, aplicado, con un diseño experimental de Bloques Completos al Azar (BCA), con seis tratamientos y cuatro repeticiones, tres productos biológicos, un químico, una combinación de químico-manejo cultural (trampa) y un testigo absoluto, cuyas variables fueron sometidas a un análisis de varianza y separación de medias mediante la prueba de Tukey (0,05), se determinó que no hubo efecto significativo de los tratamientos en el control de la broca, las afectaciones de la plaga se incrementan a medida que se desarrolla el fruto provocando pérdidas de entre el 20 y 78 % en todo el ciclo. El análisis económico mostró que todos los tratamientos son rentables, al tener una tasa de retorno marginal alta, el tratamiento Curador® es el de mayor beneficio neto, seguido de trampa más Curador® y Bea Blue®, constituyéndose como alternativas de manejo biológico de la broca.

Palabras clave: frutos brocados, disección de frutos, análisis económico, presupuesto parcial, control biológico

1. Introduction

Coffee (*Coffea arabica* L) is one of the most important agricultural crops in the world (Gasperín-García et al. 2023), it is cultivated in about 80 tropical and subtropical countries and has a high economic impact, especially in developing countries (Villalta-Villalobos & Gatica-Arias, 2019). This crop represents a source of employment for 25 million people around the world, and is also an alternative to reduce the adverse effects of climate change in the agricultural sector (Rodríguez-Del Toro et al., 2023). Coffee is of great importance to Nicaragua, economically, socially and environmentally. It accounts for approximately 25 % of exports and it is one of the main generators of foreign exchange, reaching USD 395.73 million in 2015, equalling 15.6 % of total exports (Centro de Trámites para las Exportaciones [CETREX], 2015). The main coffee producing areas are Jinotega (35 %), Matagalpa (25 %), Nueva Segovia (13 %), and Madriz (8 %) (Instituto Nacional de Información de Desarrollo [INIDE], 2012).

In Nicaragua coffee production systems offers several varieties, with Caturra being the predominant variety with 72 % of the established area at the national level. The remaining percentage corresponds to varieties such as: red Catuaí, yellow, Arabica, Bourbon, Catimor, Super catuaí, Maragogipe, Malaco, Pacamara and Maracaturra (Ministerio Agropecuario y Forestal [MAGFOR], 2019).

In the country, production is based on the use of traditional technologies (use of pesticides) for insect pest management, this means that every year producers invest more economic resources to protect production and that yields are lower (Salazar Hitcher & Jiménez-Martínez, 2022).

The demand for safe agricultural products has forced producers to adopt various pest management strategies (Aristizábal et al., 2016). Biological control, a pest management technique with the use of entomopathogenic fungi, which have proven to be effective for pest control, is currently on the rise (Mishra et al., 2014; Rodríguez et al., 2017). Among the factors that significantly affect production is the incidence of pests, being the coffee berry borer [CBB], *Hypothenemus hampei* (Ferrari, 1867) (Coleoptera: Curculionidae: Scolytinae), the most important (Lima & Cunha, 2021, Morán Centeno & Jiménez-Martínez, 2023). The damage caused by *Hypothenemus hampei* is direct to production, as it lives inside the coffee fruit, reducing the yield in harvest and the quality of the grain (Gómez et al., 2015; Infante, 2018; Laiton et al., 2018). Adult females pierce the cherries through the navel until they reach the kernel, where they feed and develop their reproductive process (Jiménez Martínez & Rodríguez, 2014; Rodríguez et al., 2017; Alba-Alejandre et al., 2018).

According to Gasperín-García et al. (2023), organisms such as *Beauveria bassiana* Bals. have been reported for CBB control and have shown favorable results. Campos Mora et al. (2023) mention that these control techniques have a positive effect on the environment. Due to the importance of the coffee sector in Nicaragua, it is necessary to reevaluate the alternative ways of pest-control, taking into account current research in which biological organisms are implemented. The objective of this study was to evaluate biological alternatives for the management of CBB on the population of CBB individuals inside the fruits and its effect on the total yield (kg ha^{-1}), as well as the economic feasibility of each treatment evaluated through a partial budget analysis, dominance analysis and marginal rate of return. This study contributes to make decisions on the use of viable alternatives in the control of this pest.

2. Materials and Methods

2.1. Location of the study

The study was conducted from October 2022 to January 2023 in the community of La Providencia (coordinates 588717.56 E and 1540085.11 N) in the municipality of Jalapa, department of Nueva Segovia (Nicaragua), in a farm with a total production area of 50.35 ha in coffee (*Coffea arabica* L), Catuaí variety. Production lots were managed with chemicals, establishing a plant distance of 1.25 m, and a distance of 1.67 m between planting rows. Plants were 18 years of age, and had undergone prunning three years before.

2.2. Methodological design

The research was quantitative, longitudinal, applied, with an experimental design of Randomized Complete Blocks (RCB), with six treatments and four replicates, where we carried out the applications of three biological products, chemicals, a combination of chemical and cultural management (trap), and an absolute control.

2.3. Size of experimental plots

Experimental plots were established 12 m wide by 15 m long for a total of 180 m^2 per experimental plot. These were separated by 2 m between plots, with 105 coffee plants per plot, for a total of 2,520 plants. The area of each block was 840 m^2 and the total area was 3,360 m^2.

2.4. Useful plot size and borer sampling

In the useful plot five points were selected at random, distributed in the shape of an "X", and 10 plants included in each point. We selected 50 plants per plot, taking a reproductive bandola (primary branch) from the middle stratum for a total of 1,200 sample plants. The selected bandola was marked with a colored tape to count the variables, and sampling was carried out on a weekly basis.

The National Agricultural Health Service [SENASA, Servicio Nacional de Sanidad Agraria] (2003), in the standard for the execution and submission of information on activities of the integrated pest management program for coffee plants (Directiva General N° 08-2003-AG-SENASA-DGSV-DPF), recommends that 10 fruits from each plant be evaluated for the coffee berry borer in order to determine the incidence of the pest. Twenty coffee cherries were taken for each treatment, 120 cherries per plot for a total of 480 coffee cherries for dissection.

2.5. Treatments evaluated

The treatments evaluated were applied by spraying equipment (knapsack pumps) with a capacity of 20 liters twice during the evaluation period. The first evaluation in October and the second in November 2022, as described below:

- **Treatment 1**: Ecobiol® 300 g, microbiological insecticide, with a concentration of 5 x 109 to 2.5 x 1011 conidia per gram, acts by contact, contains conidia of the entomopathogenic fungus *Beauveria bassiana* obtained naturally from various native strains (isolated from soil, colonized insects), not genetically modified.
- **Treatment 2**: Bea blue®, biological insecticide for agricultural use, isolation of the naturally occurring fungus *Beauveria bassiana* from soil, with a concentration of 1 x 109 spores per gram of product.
- **Treatment 3**: Átropos® WS, active ingredient *Metarhizium anisopliae* and *Beauveria bassiana*, microbiological insecticide formulated based on a consortium of spores of selected strains of endophytic fungi and biological control agents; contains 60 grams of pure spores of *Metarhizium anisopliae* strain BT-Ma. 005 and 60 grams of pure chlamydospores of *Beauveria bassiana* strain BT-Bb. 003 per commercial kilogram, both have a contact mode of action.
- **Treatment 4**: Curador® 70WS, (Imidacloprid), (E)-1-(6-chloro-3-pyridylmethyl)-N-nitroimidazolidin-2-ylideneamine, with molecular formula C9H10CIN5O2, belongs to the Neonicotinoid chemical family, a systemic, contact and ingestion insecticide, effective for the control of sucking insects, thrips and some mites.
- **Treatment 5**: Control, only water was applied.
- **Treatment 6**: Trap + insecticide: coffee berry borer traps (Brocap®) were placed and an application of the insecticide Curador® 70WS was made.

2.6. Variables evaluated

The variables evaluated were:

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- **Number of total fruits and of *bored fruit per plant*:** total fruits per plant, and fruits bored by coffee berry borer were counted in each of the bandolas of the selected trees.
- **Number of adults, pupae, larvae and eggs of *H. hampei* inside fruits**: the fruits collected in the plots for each treatment evaluated were dissected, counting the number of adults, pupae, larvae and eggs on the first three sampling dates.
- **Yield (kg ha^{-1}):** to obtain the yield per hectare, the weight of the mature fruits of the plants selected as the useful plot sampled was transformed into kg ha^{-1}.
- **Economic analysis**: A partial budget economic analysis (average yield data R_X) by treatment, and adjusted yield (R_{ajust} = 25 % of R_X) gross profit were carried out by multiplying R_{ajust} by the field sale price. For the summation of the total varying costs, we estimated the costs of the products evaluated plus the cost of insecticide application. To obtain the net benefit, the total costs (which vary from the gross benefit of each treatment) dominance analysis and marginal rate of return were subtracted, following the methodology proposed by the International Maize and Wheat Improvement Center (CIMMYT, 1988), which considers different costs, yields and benefits.

2.7. Statistical analysis of data

The data were ordered by variables, statistical analyses were carried out with the R 4.3.0 program (R Core Team, 2023), analysis of variance was performed to determine the significance between treatments, and Tukey's test (p = 0.05) to compare means between treatments.

To determine the profitability of the treatments, the benefit-cost ratio, dominance analysis, marginal rate of return (equation [1]), and an economic analysis was carried out following the CIMMYT methodology (1988).

$$\text{MRR} = \frac{\text{Marginal benefit}}{\text{Marginal cost}} * 100 \qquad [1]$$

3. Results and Discussion

3.1. Number of total and brocade fruits by H. hampei

When analyzing, for each treatment evaluated, the amount of fruit counted on the first sampling date (November 4), in each sampling a constant reduction in the range of 10 to 20 % was recorded. At the end of the evaluation period (January 20, 2023) less than 20 % of the initial production was left, being the Trampa + Curador® treatment and the control the ones showing the lowest percentage of fruit to harvest, 9 and 13 %, respectively (Figure 1). Lima and Cunha (2021) refer that the use of biological alternatives can control between 15 and 65% of CBB. While Gasperín-García et al. (2023) state that the success of coffee production systems is directly related to the volume of production that is put on sale in the market; therefore, the losses caused by pest organisms directly affect the economy of the producer and their families and, therefore, the economy of the nation. Likewise, Santiago-Hernández et al. (2023) report that the combination of natural attractants and handmade traps constitute a low-cost and locally available alternative for CBB management.

The percentage of infestation per tree is high, considering that for every 1 % increase in the level of infestation, the number of beans that fall without ripening increases by 0.26 % to 0.47 %; and, in infestations of 10 % to 15 %, there are losses of 5,087 kg per quintal of parchment coffee (46 kg) (Barrera Gaytán, 2017).

Figure 2 shows that CBB infestation occurred in highest percentage during the second data collection, when infestation was in the range of 20 to 78 %, being the control and Átropos® the most affected, with considerable damage caused by the plague on all evaluated sampling dates. Biological products based on *Beauveria bassiana* cause greater mortality of the plague when the strain used, if is adequate the concentration of spores, the virulence of the pathogen, the efficiency of the application, the microclimate of the coffee plantation and the moment of attack when the CBB is found (Castillo-Arévalo et al., 2023; León Romero, 2015; Lima & Cunha, 2021). In addition, good coverage should be ensured, verifying that the attacked fruits are well sprayed, so that this, as well as the cultural control practices might have an impact on the efficient control of the pathogen. Mendoza-Cervantes et al. (2023) indicate that the months from September to November are the most

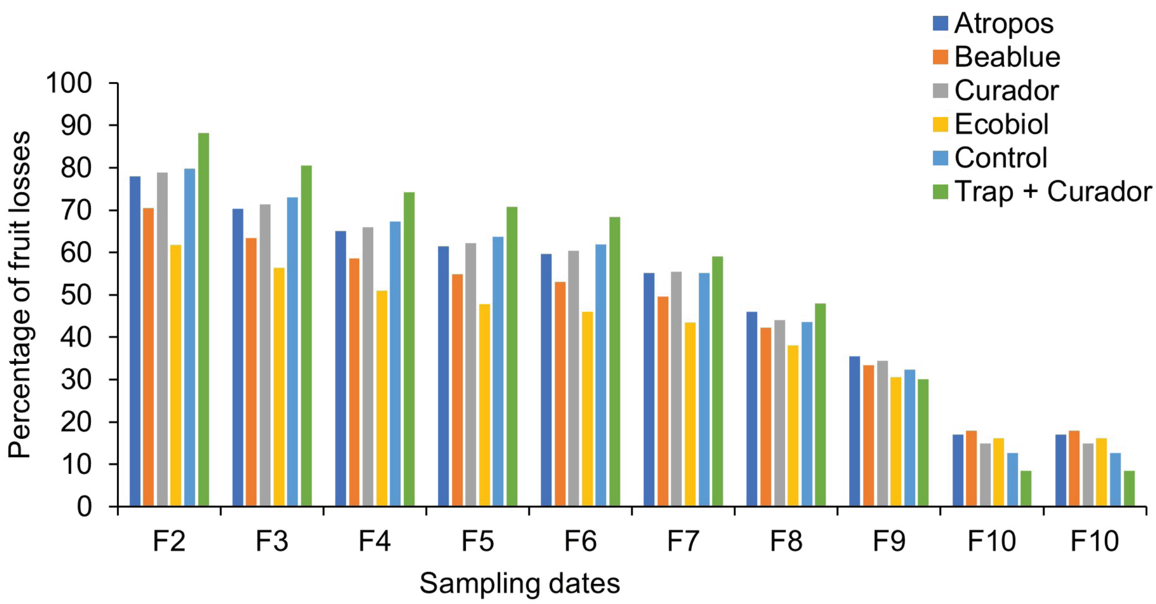

Figure 1. Percentage of fruit losses due to borer damage on the different sampling dates in the treatments under study.

affected by CBB, with up to 100 individuals per count, which represents the real problem for coffee growers. In a study by Rodríguez-Del Toro et al. (2023), the authors argue that the coffee berry borer is an insect that affects coffee production, regardless of altitude and variety, where management is a determining factor to keep populations under control.

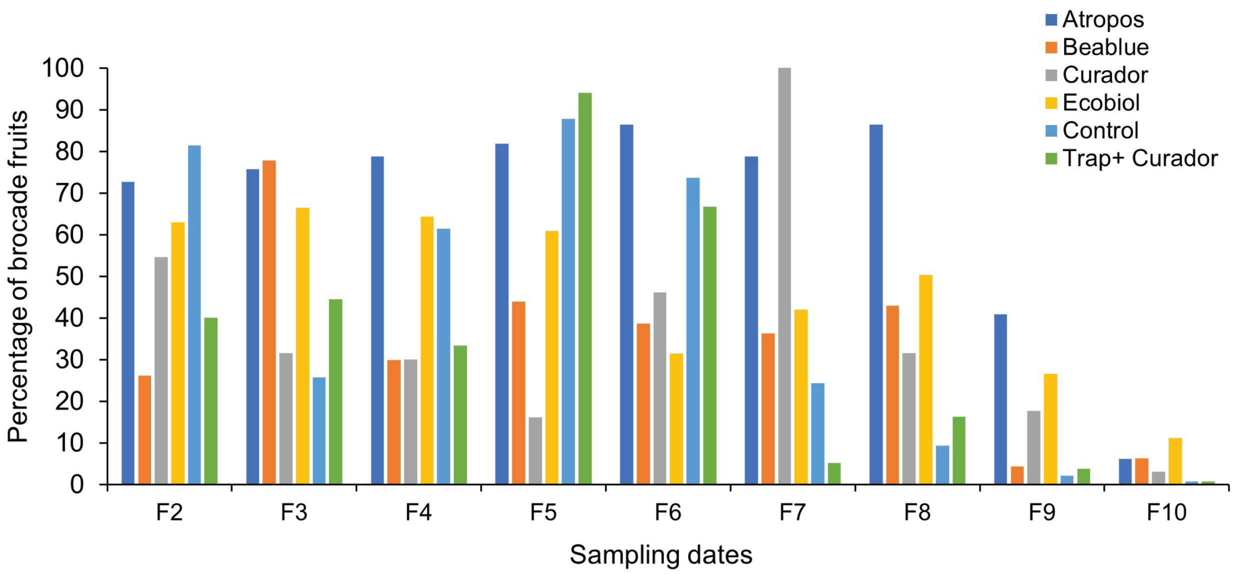

Figure 2. Borer damage behavior on different sampling dates in the treatments under study.

The analysis of variance for total fruit per bandola showed a significant difference between treatments (p = 0.0001), observing that the highest total number of fruit was found in the Ecobiol® treatment, with an average of 1,740.88 fruits; and the lowest number was found in the trap + curador® treatment, with an average of 1,455.05 fruits. When analyzing the quantity of sprouted fruit, the analysis of variance showed no significant differences between treatments (p = 0.3945) (Table 1).

In a study conducted in two coffee growing areas of Nicaragua, Pineda Méndez and Blandón Siles (2009) found that the highest percentage of sprouted fruit occurred in the months of October, November and December. Results that coincide with this study where the highest number of sprouted fruits was observed on the sampling dates in November, this can be attributed to the fact that this month presents optimal conditions for the development of the pest, such as light intensity, temperature, rain, condition of the fruit, physiology of the insect (López-Guillén

Table 1. Average of total fruits and brocades per treatment and sampling date (Tukey α: 0,05), in the coffee crop in Jalapa Nueva Segovia during the period 2022-2023.*

	Total number of fruits		Total number of borer fruits	
	μ±SE		μ±SE	
Treatments				
Átropos®	1.594,70±94,34	bc	16,10± 2,58	A
Bea Blue®	1.660,00±102,38	b	21,03± 3,24	A
Curador®	1.561,65±95,83	c	16,23± 2,86	A
Ecobiol®	1.740,88±120,04	a	18,45± 2,11	A
Control	1.524,73±97,23	cd	16,83±3,01	A
Trap + Curador®	1.455,05±97,26	d	13,90± 2,39	A
N	240		240	
CV	7,69		87,84	
Pr = 0.05	0,0001		0.3945	
Sampling dates				
F1 (04/Nov/2022)	2.811,63±86,73	a	34,21±3,57	a
F2 (11/Nov/2022)	2.109,88±10,59	b	20,46±3,48	b
F3 (25/Nov/2022)	1.915,71±9,25	c	18,46±3,07	b
F4 (02/Dec/2022)	1.762,17±6,20	d	21,38±3,12	ab
F5 (09/Dec/2022)	1.663,13±4,03	de	22,21±2,39	ab
F6 (16/Dec/2022)	1.610,17±3,40	e	19,79±2,79	b
F7 (23/Dec/2022)	1.469,54±12,39	f	16,13±3,93	bc
F8 (06/Jan/2023)	1.216,13±18,37	g	12,25±3,65	bcd
F9 (13/Jan/2023)	918,92±26,99	h	4,38±1,17	cd
F10 (20/Jan/2023)	417,75±27,79	i	1,63±0,74	d
N	240		240	
CV	7,69		87,84	
Pr = 0,05	0,0001		0,0001	

*μ: Average, SE: standard error, Tukey (alpha: 0,05, N: number of data used in data analysis), CV: coefficient of variation, Pr: probability according to Tukey.

et al., 2011). Another aspect to take into account is that in these months the fruits have reached the optimum degree for colonization, with the availability of food and shelter to develop and reproduce (Bacca et al., 2021).

In both variables, it was found that CBB damage varies according to the stage of development of the coffee fruits, which is why constant monitoring of the pest should be carried out to reduce the effects on yields, with the first dates being the ones where the damage was greatest. Pérez Constantino et al. (2023) mentioned that during the months of September to November, the greatest damage by this insect occurs in the coffee crop, confirming the findings of this study.

3.2. Number of adults, pupae, larvae and eggs of H. hampei in bored fruits

As to the different stages of development of the pest, no significant differences were found among the treatments evaluated; however, sampling dates one and three showed the highest average population of pupae, larvae and eggs (Table 2). This leads to higher populations of adults in subsequent samplings, causing a higher percentage of damage to the developing fruit.

The population of *H. hampei* was recorded by dissection of the sprouted fruits, showing variability of the different stages of the pest among treatments and sampling dates (Table 2), showing that the Curador® treatment presented the lowest number of biological stages (Table 3).

Table 2. Population of adults, pupae, larvae and eggs in brocaded fruits per treatments and sampling dates (Tukey α: 0,05), in coffee cultivation in Jalapa Nueva Segovia during the period 2022-2023.*

	Adult		Chrysalis		Larvae		Eggs	
	µ±SE		µ±SE		µ±SE		µ±SE	
Treatments								
Átropos®	0,73±0,08	a	0,74±0,08	a	0,77±0,09	a	0,27±0,07	a
Bea Blue®	0,66±0,06	a	0,89±0,09	a	0,79±0,10	a	0,25±0,06	a
Curador®	0,62±0,06	a	0,80±0,08	a	0,61±0,08	a	0,22±0,05	a
Ecobiol®	0,60±0,06	a	0,90±0,09	a	0,65±0,09	a	0,24±0,05	a
Control	0,65±0,07	a	0,86±0,09	a	0,73±0,09	a	0,23±0,06	a
Trap+Curador®	0,58±0,06	a	0,84±0,09	a	0,70±0,08	a	0,32±0,07	a
N	480		480		480		480	
CV	158,06		160,96		188,13		354,35	
Pr = 0,05	0,6315		0,8050		0, 6828		0,8767	
Sampling dates								
F1	0,75±0,05	b	0,86±0,06	a	0,94±0,07	b	0,66±0,07	b
F2	0,51±0,04	a	0,79±0,06	a	0,59±0,06	a	0,09±0,02	a
F3	0,66±0,05	ab	0,86±0,06	a	0,59±0,06	a	0,01±0,01	a
N	480		480		480		480	
CV	158,06		160,96		188,13		354,35	
Pr = 0,05	0,0011		0,6540		0,0001		0,0001	

*µ: Average, SE: standard error, Tukey (alpha: 0,05, N: number of data used in data analysis), CV: coefficient of variation, Pr: probability according to Tukey.

3.3. Yield (kg ha^{-1})

The highest coffee yield was obtained with Curador® applications, and the lowest yield for the control (Figure 3). This shows that the use of chemical substances reduces CBB infestations and, therefore, higher yields are obtained. In the study conducted by Matus Miranda and Jiménez-Martínez (2020), they found that the Galil treatment based on imidacloprid followed by Cormoran and Ecobiol produced the highest yields in kilograms per hectare.

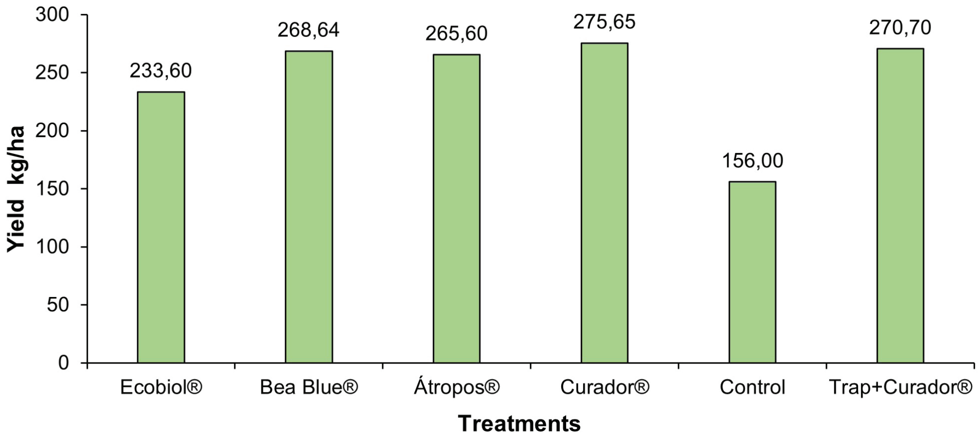

Figure 3. Yield (kg ha^{-1}) per treatments evaluated in the coffee crop in Jalapa, Nueva Segovia during the period 2022-2023.

3.4. Economic analysis of the evaluated treatments

In the analysis of the partial budget, the value of the daily wage was established at 10.4 US dollars (US$), and the sale price in the field was US$ 4.84 per kg of coffee. The highest variable cost was obtained by the trap plus

Curador® treatment with US$164.4 ha^{-1}, and the lowest costs were Ecobiol® and Control with US$23.6 and US$15.6 ha^{-1}, respectively. The treatment that obtained the highest net benefit was Curador® with 956.21 US$ ha^{-1}, and the lowest net benefit corresponded to the control with 550.68 US$ ha^{-1} (Table 4).

Table 4. Partial budget in dollars (US$) for treatments evaluated in the coffee crop in Jalapa, Nueva Segovia during the period 2022-2023.

Treatments	Adjusted yield (US$)*	Gross Benefit	Variable cost	Net Benefit
Ecobiol®	175,2	848,00	23,6	824,37
Bea Blue®	201,48	975,20	35,63	939,53
Átropos®	199,2	964,13	39,6	924,53
Curador®	206,73	1000,57	44,4	956,21
Control	117,00	566,3	15,6	550,68
Trap+Curador®	203,02	982,62	164,4	818,24

* Official price of the dollar: 36.00 Nicaraguan córdobas.

The results were subjected to a dominance analysis, where the partial budget analysis was taken into account. The result of the dominance analysis indicates that the treatments are not dominated by the control. Therefore, all were included in the marginal rate of return analysis (Table 5).

Table 5. Dominance analysis for the treatments evaluated in the coffee crop in Jalapa, Nueva Segovia, period 2022-2023.

Treatments	Variable cost (US$/ha)	Net Benefit (US$/ha)	Observation	
Control	15,6	550,68	Control	---
Ecobiol®	23,6	824,37	From Control to Ecobiol®	ND
Bea Blue®	35,63	939,53	From Ecobiol® to Bea Blue®	ND
Átropos®	39,6	924,53	From Bea Blue® to Atropos®	ND
Curador®	44,4	956,21	From Átropos® to Curador®	ND
Trap+Curador®	164,4	818,24	From Curador® to Trampa+Curador®	ND

ND= Not dominated

3.5. Marginal Rate of Return (MRR) Analysis

The analysis of the marginal rate of return reflects that all treatments are viable; however, Atropos® obtained the highest marginal rate of return, followed by Curador, Trap + Curador®®, Bea Blue® and Ecobiol® since, for every dollar invested, the producer obtains a high marginal rate of return (Table 6).

Table 6. Analysis of the marginal rate of return for treatments evaluated in the coffee crop in Jalapa, Nueva Segovia during the period 2022-2023.

Treatments	Variable cost (US$ ha^{-1})	Net Benefit (US$ ha^{-1})	IMBN*	IMCV**	Marginal Rate of Return %
Curador®	44,4	956,21	16,68	4,80	347,5
Bea Blue®	35,63	939,53	15,00	12,03	124,69
Átropos®	39,6	924,53	100,16	3,97	2.522,92
Ecobiol®	23,6	824,37	6,13	8	76,62
Trap+Curador®	164,4	818,24	267,56	120	222,97

* IMBN = Difference in the net benefit of the treatments. / ** IMCV = Difference in the variable costs of the treatments.

Considering the importance of coffee cultivation, this study could provide an alternative for the management of coffee borer in tropical climates production systems.

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4. Conclusions

The results obtained in the study determine that the impact per drill bit was high in all treatments and sampling dates, reducing yields in a range of 20 to 78 %. This is due to the fact that as time goes by, the effects are greater, the first dates being when the damage was significant. When analyzing the different stages of the insect's life cycle, it was determined that there were no significant differences in the treatments, as well as in the variable brocade fruits.

The economic analysis showed that the Healer treatment yielded higher returns, hence higher net profit, followed by Trap plus Healer®® and Bea Blue®. All treatments showed a high marginal rate of return, indicating that they are cost-effective for the control of the coffee borer (*Hypothenemus hampei*).

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Contributor Roles

- Sailyng Dayana Siu Palma: conceptualization, investigation, methodology, resources, data curation, writing – original draft.
- Edgardo Salvado Jiménez Martínez: supervision, writing – review & editing.
- Juan Carlos Morán Centeno: data curation, formal analysis, writing – review & editing.

Ethical Issues

Ethics approval Not applicable.

Conflict of interest

The authors declare that they have no affiliation with any organization with a direct or indirect financial interest that could have appeared to influence the work reported.

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