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Evaluation of *Bacillus thuringiensis* and *Amblyseius swirskii* for the control of thrips (*Chaetanaphothrips signipennis*) on Cavendish banana (*Musa AAA*) fruit

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ABSTRACT

Banana is one of the primary fruit crops in Ecuador, responsible for the generation of a significant proportion of the country's foreign exchange. Consequently, the fruits must adhere to exacting quality standards in order to satisfy the demands of international marketing. One of the most significant challenges currently facing banana production is the considerable damage caused by infestations of *Chaetanaphothrips signipennis* (Thysanoptera: Thripidae). The damage observed ranged from 35% to 60% of the banana bunches, highlighting the necessity for the development of control alternatives. The impact of two biological control agents, namely the bacterium *Bacillus thuringiensis* and the predatory mite *Amblyseius swirskii*, was assessed in the context of thrips management on Cavendish banana (*Musa* AAA). The experiment employed a completely randomized design, comprising nine treatments, two controls and three replications per treatment. The variables subjected to evaluation included the number of thrips at three application periods (weeks 34, 35, and 36 of the annual calendar), the severity of damage (assessed on a scale), and yield in boxes and kilograms per hectare. Furthermore, an economic analysis of the treatments was conducted. The presence of thrips at weeks 34, 35, and 36 ranged from one to three insects under different doses of *B. thuringiensis* (2, 3, and 5 ml/L water). The results demonstrated a notable decline in the number of thrips. Nevertheless, the extent of damage remained at level 2 on the severity scale, corresponding to 10% damage. The highest benefit-to-cost ratio was observed in T6, with a value of 1.08.

Keywords: agricultural economy, banana, biological control, marketing, thrips.

1. Introduction

In terms of gross production value, banana (*Musa* spp.) is the fourth most important food crop globally, preceded by rice, wheat, and corn (Tripathi et al., 2008). Furthermore, the LAC region accounts for 69% of global banana and plantain exports, with Ecuador representing the largest exporter (28%), followed by Costa Rica (11%) and Colombia (8%) (FAO, 2019). Moreover, bananas are not only a vital export commodity but also a significant source of employment and economic stability. This is exemplified by Ecuador, where approximately 180,336 hectares are dedicated to banana cultivation (FAO, 2019).

Considering the economic importance of banana production and the quality standards demanded

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by international markets, the effective management of insect pests is of paramount importance. Among these, thrips, specifically *Chaetanaphothrips signipennis*, represent a significant challenge due to their ability to infest banana bunches and cause the characteristic reddish discolouration of the fruit pericarp, known as the "red spot" (Bisane et al., 2017). The damage caused by this pest reduces the quality of the fruit, which results in yield losses of between 35% and 60%. This has a severe impact on the incomes of producers (Arias de López et al., 2019; García Sarabia et al., 2015). Although initially observed during the dry season, the pest now causes varying levels of damage throughout the year.

The use of biological control agents, such as pathogens and predators, has gained prominence as a sustainable alternative to synthetic pesticides. The latter often present health risks, environmental contamination, the development of pest resistance, and increased production costs (Ayilara et al., 2023). Among these, *Bacillus thuringiensis* and predatory mites such as *Amblyseius swirskii* have demonstrated efficacy in the control of agricultural pests while simultaneously preserving biodiversity and reducing chemical dependency (Hernández-Trejo et al., 2019).

The objective of this study is to assess the efficacy of two biological control agents, namely *B. thuringiensis* and *A. swirskii*, in regulating *C. signipennis* populations on Cavendish bananas (*Musa* AAA). The research is concerned with the extent of damage, yield outcomes (in boxes and kilograms per hectare) and the economic implications of the treatments applied.

2. Methodology

Study location

The study was conducted on the farm of the engineer. Washington Reinoso is situated at a distance of 1.7 km along the road to Triunfo, Guayas Province, Ecuador (coordinates: 2°15'27.9" S, 79°35'55.9" W; altitude: 19 m above sea level). The farmstead encompasses 140 hectares of land dedicated to the cultivation of bananas.

Experimental design and treatments

The experiment was conducted in accordance with a randomized complete block design (RCBD), comprising nine treatments and five replicates per treatment. Each replicate consisted of three banana plants, with three bunches per plant, resulting in a total of 15 plants per treatment. The following treatments were implemented. *B. thuringiensis* (B.t.) was applied to bunches (2, 3, and 5 mL/L water), B.t. was applied to the entire plant (2, 3, and 5 mL/L water), the release of *A. swirskii* predatory mites, a control involving traditional farm practices, and an untreated control. The evaluations were conducted on a weekly basis during weeks 34, 35, 36, 39, and 40, and continued until week 46, at which point the bunches were harvested.

Application of *Bacillus thuringiensis*

The bioinsecticide PredaBIO®, comprising a minimum of 100 g of *B. thuringiensis* spores and delta toxins, was administered on two occasions: initially at the commencement of bunch formation (prior to sheath placement) and subsequently seven days later. The applications were targeted at the pseudostem and the bunch, respectively, using a motorized backpack sprayer and a 2-L hand sprayer.

Release of *A. swirskii*

Approximately 250 predatory mites (*A. swirskii*) were attached to bunches using toothpicks and covered with pesticide-free bags. The mites were released in sachets, which were commercially available and contained approximately 250 mites each. Evaluations began for seven days post-release and continued weekly through harvest (week 46).

Evaluation protocol

The presence of thrips was monitored at various sites on the plant, including the pseudostem, shoots, and bunch, for the bacterium *B. thuringiensis*. A weekly assessment was conducted on unsheathed bunches to determine the number of affected fingers and to evaluate the overall quality of the fruit. The final evaluations were conducted at the time of harvest (weeks 45–46) in the packing house, where the percentage of stained fruits was calculated. The efficacy of the predatory mite, *A. swirskii*, was evaluated on selected bunches and plants from week 34 to the harvest (week 46), with a primary objective of reducing thrips populations and mitigating damage.

Damage assessment

The extent of thrips damage was quantified by visually inspecting the fingers on each hand of the bunch and classifying the severity using a predefined scale (León, 2018). The evaluations were conducted during weeks 39 and 40 of the study.

Economic analysis

The economic analysis incorporated both fixed and variable costs for each treatment, with the objective of evaluating total production costs and market income. In order to facilitate a comparison of the profitability of the various treatments, both the gross income and the benefit-cost ratio (BCR) were calculated. The BCR formula utilized was as follows: B/C = TI / TC x 100

The B/C ratio is calculated by dividing the total income (TI) by the total cost (TC) and multiplying the result by 100. This analysis permitted an evaluation of the economic feasibility of the treatments under consideration.

Statistical Analysis

The data were analyzed using the non-parametric Friedman test due to the non-normality of the residuals (as indicated by the Shapiro-Wilks test) and the heterogeneity of variances (as indicated by the Levene test). The significance of the observed differences among the treatments was evaluated using Fisher's least significant difference (LSD) test, with a significance level of $\alpha = 0.05$. The statistical analyses were conducted using the R software (R Core Team, 2021).

3. Results and discussion

Population of nymphs and adults of thrips under different treatments

The mean populations of nymphs and adults of thrips observed during weeks 34, 35, and 36 are presented in Table 1 for purposes of analysis. No significant differences were observed among treatments in week 34 ($\chi^2 = 3.64$; df = 8; p = 0.89). The number of thrips ranged between two and three individuals across all concentrations of *B. thuringiensis* applied to the plant and bunch, with the highest mean (3.2 thrips) recorded in *B. thuringiensis*, bunch - 2 mL/L water. In week 35, no significant differences were observed ($\chi^2 = 7.63$; df = 8; p = 0.47). However, the mean number of thrips decreased in plants treated with different concentrations of *B. thuringiensis*, with the lowest numbers observed in *B. thuringiensis*, bunch - 3 mL/L water. Significant differences were observed in week 36 ($\chi^2 = 16.83$; df = 8; p = 0.03), with the lowest mean (1.13 individuals) observed in the *B. thuringiensis*, plant - 5 mL/L water treatment, while the highest mean (4.06 individuals) was observed in the untreated control. These findings suggest that *B. thuringiensis* is an effective method for reducing thrips populations in comparison to untreated controls.

Percentage and severity of thrips damage under the effect of treatments

The damage caused by nymphs and adults of thrips was evaluated during weeks 39 and 40 (Table 2). In week 39, the lowest percentage of damaged banana fingers was observed in the treatment with *B. thuringiensis*, bunch - 3 mL/L water (3.14%), which was significantly lower than in the untreated control ($\chi^2 = 10.45$; df = 8; p = 0.023), where the damage reached 5.41%. In week 40, significant differences were observed among treatments ($\chi^2 = 9.17$; df = 8; p = 0.032), with *B. thuringiensis*, bunch - 2 mL/L water demonstrating the highest percentage of damage (3.20%). In accordance with the damage scale utilized, this equates to 10% of damage, characterized by large reddish spots caused by thrips. These findings illustrate the efficacy of specific *B. thuringiensis* treatments in reducing damage severity in comparison to untreated controls.

Table 1

Mean numbers of nymphs and adults of thrips under experimental treatments

Treatment	Week 34	Week 35	Week 36
B. thuringiensis, bunch - 2 mL/L water	3.20 ± 1.20 a	2.60 ± 0.72 a	2.20 ± 0.67 abc
B. thuringiensis, plant - 2 mL/L water	3.00 ± 0.82 a	2.13 ± 0.55 a	1.66 ± 0.28 bcd
B. thuringiensis, bunch - 3 mL/L water	2.93 ± 0.52 a	1.53 ± 0.27 a	1.20 ± 0.17 bcd
B. thuringiensis, plant - 3 mL/L water	2.87 ± 0.62 a	2.20 ± 0.27 a	2.00 ± 0.25 ab
B. thuringiensis, bunch - 5 mL/L water	2.67 ± 0.83 a	1.66 ± 0.46 a	1.20 ± 0.17 d
B. thuringiensis, plant - 5 mL/L water	2.93 ± 0.88 a	1.86 ± 0.38 a	1.13 ± 0.27 cd
Release of *Amblyseius swirskii*	3.13 ± 1.06 a	2.93 ± 0.68 a	2.40 ± 0.49 ab
Traditional farm practices	1.53 ± 0.31 a	1.66 ± 0.39 a	1.73 ± 0.20 abcd
Untreated control	3.13 ± 0.82 a	3.46 ± 0.88 a	4.06 ± 0.89 a

Means followed by the same letter in the column do not differ significantly according to Fisher's Least Significant Difference (LSD) test ($p \leq 0.05$). Values are expressed as mean ± standard deviation.

Table 2
Mean damage percentages (%) and crop yield (kg) under experimental treatments

Treatment	Damage percentages (%)		Crop yield (Kg) at harvest (Week 46)	
	Week 39	Week 40	Bunch weight	Bunch rachis weight
B. thuringiensis, bunch - 2 mL/L water	3.57 ± 4.05 bc	3.20 ± 4.82 a	35.78 ± 0.40 cd	4.48 ± 0.04 cd
B. thuringiensis, plant - 2 mL/L water	5.13 ± 2.84 ab	3.00 ± 3.22 ab	41.96 ± 1.05 a	4.78 ± 0.08 a
B. thuringiensis, bunch - 3 mL/L water	3.14 ± 2.33 c	2.93 ± 2.78 b	42.51 ± 0.64 a	4.63 ± 0.09 a
B. thuringiensis, plant - 3 mL/L water	4.92 ± 4.33 abc	2.87 ± 4.66 b	41.14 ± 0.74 ab	4.75 ± 0.06 ab
B. thuringiensis, bunch - 5 mL/L water	3.59 ± 2.14 bc	2.67 ± 2.34 ab	40.08 ± 0.93 ab	4.66 ± 0.10 ab
B. thuringiensis, plant - 5 mL/L water	2.69 ± 1.04 cd	2.93 ± 1.68 ab	38.93 ± 0.98 b	4.37 ± 0.08 b
Release of *Amblyseius swirskii*	3.93 ± 4.78 bc	3.13 ± 5.58 ab	38.72 ± 0.74 b	4.69 ± 0.07 b
Traditional farm practices	3.26 ± 2.00 bc	1.53 ± 2.55 c	38.24 ± 1.50 bc	4.57 ± 0.06 bc
Untreated control	5.41 ± 4.44 a	3.13 ± 5.42 ab	35.83 ± 0.44 d	4.65 ± 0.09 d

Means followed by the same letter in the column do not differ significantly according to Fisher's Least Significant Difference (LSD) test ($p \leq 0.05$). Values are expressed as mean ± standard deviation.

Estimation of banana crop yield (kg) at harvest (week 46)

Bunch weight

The data regarding bunch weight at harvest (week 46) (Table 2) revealed statistically significant differences among the various treatments (χ^2 = 25.49; df = 8; p = 0.001). The treatment involving the application of *B. thuringiensis* to the bunch at a concentration of 3 mL/L water resulted in the highest bunch weight (42.51 kg), followed by the application to the plant at 2 mL/L water, which achieved a weight of 41.96 kg. The application of *B. thuringiensis* to the bunch at a concentration of 2 mL/L water resulted in the lowest weight among treated plants, with an observed weight of 35.78 kg. In contrast, the untreated control exhibited the lowest overall weight (35.83 kg). These findings demonstrate the efficacy of *B. thuringiensis* treatments in mitigating yield losses due to thrips damage, thereby enhancing crop productivity.

Bunch rachis weight

Additionally, notable discrepancies were identified in bunch rachis weight (χ^2 = 14.84; df = 8; p = 0.02) (Table 2). The highest rachis weights were recorded in the *B. thuringiensis*, plant - 2 mL/L water and *B. thuringiensis*, plant - 3 mL/L water treatments, with values of 4.78 and 4.75 kg, respectively. The lowest recorded weight was observed in the *B. thuringiensis*, plant - 5 mL/L water treatment, with a weight of 4.37 kg. These findings provide further evidence of the potential of *B. thuringiensis* applications to enhance yield-related parameters in banana cultivation.

Marketing of harvested banana fruits

Table 3 presents the data regarding the number of fruits rejected due to red spot caused by thrips infestations, the number of rejected fruits for non-thrips-related issues, the total number of rejected fruits, and the weight of the accepted fruits.

No statistically significant differences were identified between the treatments (χ^2 = 35.09; df = 8; p = 0.257). However, the treatment with the lowest number of fruits rejected due to red spot was *B. thuringiensis*, plant - 5 mL/L water, with an average of 1.14 fruits. In contrast, the untreated control (which represents the absolute control) exhibited the highest average, with 8.60 fruits rejected.

Significant differences were observed in the number of fruits rejected for non-thrips-related reasons (χ^2 = 30.18; df = 8; p = 0.0001). The lowest number of rejected fruits was observed in the *B. thuringiensis*, bunch - 3 mL/L water treatment, with 0.61 fruits, while the highest number of rejections was recorded in the untreated control (absolute control) treatment, with 3.9 fruits.

The total number of rejected fruits did not demonstrate a statistically significant difference among treatments (χ^2 = 34.24; df = 8; p = 0.367). The lowest mean value was observed in the treatment with *B. thuringiensis*, plant - 5 mL/L water, with a mean of 1.96 fruits, whereas the untreated control exhibited the highest total, with a mean of 12.51 rejected fruits.

Table 3

Mean numbers of rejected fruits, total rejected fruits and accepted fruit weight (kg) under evaluated treatments

Treatment	Number of rejected fruits		Total mean number of rejected fruits	Mean accepted fruit weight (kg)
	Red spot (Thrips infestation)	Fruits rejected for non-thrips-related damage		
B. thuringiensis, bunch - 2 mL/L water	7.04 ± 0.15 ab	0.78 ± 0.06 de	7.82 ± 0.18 b	23.47 ± 0.37 d
B. thuringiensis, plant - 2 mL/L water	6.78 ± 0.25 b	1.48 ± 0.17 bc	8.26 ± 0.29 ab	28.91 ± 0.95 c
B. thuringiensis, bunch - 3 mL/L water	5.56 ± 0.29 c	0.61 ± 0.03 e	6.18 ± 0.31 c	31.69 ± 0.57 ab
B. thuringiensis, plant - 3 mL/L water	4.14 ± 0.39 d	1.00 ± 0.10 cd	5.14 ± 0.46 d	31.25 ± 0.43 ab
B. thuringiensis, bunch - 5 mL/L water	2.99 ± 0.41 d	1.51 ± 0.08 b	4.51 ± 0.46 d	30.91 ± 0.54 bc
B. thuringiensis, plant - 5 mL/L water	1.14 ± 1.16 e	0.82 ± 0.08 de	1.96 ± 0.24 e	32.59 ± 0.83 a
Release of *Amblyseius swirskii*	2.87 ± 0.18 d	1.62 ± 0.10 ab	4.50 ± 0.24 d	29.52 ± 0.56 c
Traditional farm practices	3.47 ± 0.60 d	1.33 ± 0.09 ab	4.80 ± 0.66 d	28.86 ± 0.86 c
Untreated control	8.60 ± 0.45 a	3.90 ± 0.44 a	12.51 ± 0.52 a	18.67 ± 0.52 d

Means followed by the same letter in the column do not differ significantly according to Fisher's Least Significant Difference (LSD) test (p ≤ 0.05). Values are expressed as mean ± standard deviation.

With regard to the weight of marketable fruits, the treatment with *B. thuringiensis* , plant - 5 mL/L water, yielded the highest average weight (32.59 kg), while the untreated control (absolute control) exhibited the lowest average weight (18.67 kg).

Determination of the ratio of box number to bunches and fruit yield (kg ha⁻¹)

The ratio of box number to bunch number was calculated (Table 4), demonstrating notable discrepancies among the treatments evaluated for thrips control ($\chi^2 = 30.29$; df = 8; p = 0.0001). The treatments exhibiting the most favorable ratios were *B. thuringiensis* , applied to the plant at a concentration of 5 mL/L water, and *B. thuringiensis* applied to the bunch at a concentration of 3 mL/L water. These treatments yielded ratios of 1.66 and 1.62, respectively. The lowest ratio was observed in the untreated control, with a value of 0.97.

Significant differences were observed in banana yield (kg ha^{-1}) among the treatments ($\chi^2 = 654$; df = 8; p = 0.04). The highest yield was obtained in the treatment involving *B. thuringiensis* applied to the plant at a ratio of 5 mL/L water, with a yield of 1536.25 kg ha-1. This was followed by the treatment involving *B. thuringiensis* applied to the plant at a ratio of 3 mL/L water, with a yield of 1509.09 kg ha^{-1}, and the treatment involving *B. thuringiensis* applied to the bunch at a ratio of 5 mL/L water, with a yield of 1461.13 kg ha^{-1}. In contrast, the lowest yield was observed in the untreated control, with an average of 882 kg ha^{-1}.

Economic analysis based on yield at harvest time

An economic analysis of yield (kg ha^{-1}) and corresponding benefits was conducted for each treatment, as detailed in Table 5. The application of *B. thuringiensis* at a concentration of 5 mL/L of water resulted in the highest yield (1536.25 kg ha-1), generating a net income of 9985.63 USD with a total cost of 4809.88 USD.

Table 4

Ratio of box number to bunches and banana yield under evaluated treatments

Treatment	Ratio	Yield (kg ha^{-1})
B. thuringiensis, bunch - 2 mL/L water	1.20 ± 0.01 d	1095.60 bc
B. thuringiensis, plant - 2 mL/L water	1.47 ± 0.04 c	1346.10 ab
B. thuringiensis, bunch - 3 mL/L water	1.62 ± 0.02 ab	1367.66 ab
B. thuringiensis, plant - 3 mL/L water	1.59 ± 0.02 ab	1509.09 a
B. thuringiensis, bunch - 5 mL/L water	1.58 ± 0.02 bc	1461.13 a
B. thuringiensis, plant - 5 mL/L water	1.66 ± 0.04 a	1536.25 a
Release of *Amblyseius swirskii*	1.51 ± 0.02 c	1415.53 a
Traditional farm practices	1.47 ± 0.04 c	1324.98 ab
Untreated control	0.95 ± 0.02 d	882.81 c

Means followed by the same letter in the column do not differ significantly according to Fisher's Least Significant Difference (LSD) test (p ≤ 0.05). Values are expressed as mean ± standard deviation.

Table 5
Ratio of box number to bunches and banana yield under evaluated treatments

Treatment	Yield (kg ha^{-1})	Total income (USD)	Total cost (USD)	Benefit (USD)	B/C
B. thuringiensis, bunch - 2 mL/L water	1095.60	7121.40	4709.58	2411.82	0.51
B. thuringiensis, plant - 2 mL/L water	1346.10	8749.65	4749.88	3999.77	0.84
B. thuringiensis, bunch - 3 mL/L water	1367.66	8889.79	4710.78	4179.01	0.89
B. thuringiensis, plant - 3 mL/L water	1509.09	9809.09	4789.88	5019.21	1.05
B. thuringiensis, bunch - 5 mL/L water	1461.13	9497.35	4711.38	4785.97	1.02
B. thuringiensis, plant - 5 mL/L water	1536.25	9985.63	4809.88	5175.75	1.08
Release of *Amblyseius swirskii*	1415.53	9200.95	4722.78	4478.17	0.95
Traditional farm practices	1324.98	8612.37	4690.65	3921.72	0.84
Untreated control	882.81	5738.27	4007.9	1730.37	0.43

B/C: Benefit-Cost ratio.

This treatment yielded a profit of 5175.75 USD and a positive benefit-cost ratio of 1.08. This indicates that for every dollar invested, a profit of 0.08 USD is obtained with *B. thuringiensis*-based applications. Other treatments, such as *B. thuringiensis*, plant - 3 mL/L water (B/C ratio: 1.05) and *B. thuringiensis*, bunch - 5 mL/L water (B/C ratio: 1.02), also demonstrated economic benefits, generating profits of 0.05 and 0.02 USD per dollar invested, respectively.

Discussion

The objective of this study was to evaluate the efficacy of biological control agents, namely *B. thuringiensis* and *A. swirskii*, in managing thrips infestations in banana crops. The findings are of significant importance for the field of banana production, particularly in regard to the impact of thrips infestations, with a particular emphasis on the red spot, which renders fruits unsuitable for marketing.

In the initial stages of crop growth (weeks 34, 35, and 36), thrips infestations were observed on the plant and in the bunch. This finding is consistent with the description provided by (Arias de López et al., 2019), who characterized thrips as pests with piercing and sucking mouthparts, causing damage by feeding or laying eggs on different plant structures. The results demonstrate the efficacy of *B. thuringiensis*, particularly when applied to plants, as it effectively reduced populations thrips during these stages. Despite the common perception that predatory mites are less effective, this study demonstrated that their release inside sheathed bunches provided additional control, achieving up to 93.27% healthy fingers with a minimal investment of 0.98 USD per plant.

In weeks 39 and 40, a notable decline in thrips populations on the plants was discernible, although a residual presence was still evident on the bunches. The degree of severity remained low (grade 2, corresponding to 0–10% infestation), with only slight halo symptoms observed. This finding is consistent with the conclusions of (Grijalba Bernal et al., 2018), who emphasized the effectiveness of *B. thuringiensis* crystal proteins against a range of pests, including Lepidoptera, Diptera, and Hemiptera. Moreover, (Arias de López, 2017) documented near-total pest mortality within 97–109 hours of *B. thuringiensis* application, which aligns with the findings of this study.

The application of *B. thuringiensis* was more effective in controlling the compared thrip populations. The most effective method for combating predatory mites is to target the plant and bunch directly. This strategy led to a notable reduction in the proportion of fruits that were rejected due to red spot infestation, thereby enhancing their marketability. Nevertheless, the release of *A. swirskii* demonstrated additional benefits, including a reduction in damage and an adaptation to Ecuadorian climatic conditions (Carrizo et al., 2017). As observed by San et al. (2021), *A. swirskii* has demonstrated efficacy against a range of pests, including thrips, whiteflies, and mites, in both greenhouse and field settings. Furthermore, the species' life cycle, from egg to adult, under warm and humid conditions (26°C and 70% RH), lends additional support to its use in tropical agriculture.

(Moyón Salazar, 2021) and (Regalado, 2018) similarly reported that the release of *A. swirskii* resulted in the control of red spot infestations in bunches during flowering, with a control efficacy of 90–93%. These findings corroborate the strategy proposed by Arias de López et al., 2020, which involves combining sheathing with the release of predatory mites for effective thrips control. The integration of *B. thuringiensis* and *A. swirskii* illustrates the potential of sustainable pest management practices, reducing reliance on chemical pesticides and promoting environmental health.

The results of this study demonstrate that the application of *B. thuringiensis* at high concen-trations

(5 mL/L water) on plants resulted in significant reductions in thrips populations, particularly during the early stages of crop growth. The degree of severity of damage remained at grade 2 (≤10% infestation), while the benefit-cost ratio (B/C) of 1.08 for *B. thuringiensis*, plant - 5 mL/L water, indicates profitability, with a return of 0.08 USD for every dollar invested. These results not only reflect economic benefits but also underscore the environmental advantages of adopting sustainable pest control practices, which mitigate risks to producers' health and the environment.

4. Conclusions

This study highlights the effectiveness of biological control agents, *B. thuringiensis* and *A. swirskii*, in managing thrips infestations in banana crops. Both agents significantly reduced thrips populations and mitigated red spot damage, thus improving the marketability of Cavendish bananas. Notably, *B. thuringiensis* was particularly effective during early crop growth stages, while *A. swirskii* provided additional control when combined with sheathing, adapting well to Ecuador's climate. The integration of these biological controls demonstrates environmental and economic benefits by reducing dependence on chemical pesticides and promoting sustainable agricultural practices. The favorable benefit-cost ratio of *B. thuringiensis* further supports its use by banana producers.

However, several areas warrant further investigation:

Long-term impact: Future studies should assess the long-term effects of these biological agents on thrips populations and overall ecosystem health.

Broader application: Research could explore the applicability of these agents in diverse climatic regions and on other crops vulnerable to thrips.

Combination strategies: Further investigation into the synergistic effects of combining *B. thuringiensis* and *A. swirskii* with other biological or physical control methods could optimize pest management strategies.

Economic analysis: Detailed economic analyses considering various scales of banana production would help evaluate the broader financial implications of adopting these biological controls.

Overall, this study underscores the importance of adopting integrated pest management strategies that leverage biological control agents to enhance crop resilience and sustainability.

References

Arias de López, M. (2017). El trips de la mancha roja en banano orgánico. Avances de investigaciones para el manejointegrado en Ecuador, Perú y República Dominicana. https://fontagro.org/wp-content/uploads/2017/04/Thrips-INVESTIGACIONES-y-AVANCES-2017-Arias.pdf

Arias de López, M. A., Córózó-Ayovi, R. E., Delgadó, R., Osorio, B., Moyón, D., Rengifo, D., Suarez, P., Paulino, A., Medrano, S., Sanchez, L., Rojas, J. C., Vegas, U., Alburqueque, D., Staver, C., van Tol, R., & Clercx, L. (2020). Red rust thrips in smallholder organic export banana in Latin America and the Caribbean: pathways for control, compatible with organic certification. The International ISHS-Pro*Musa* Symposium, Growing and Marketing Banana under Subtropical Conditions, Acta Horticulturae 1272, ISHS 2020.

Arias de López, M., Corozo Ayoví, R. E., Delgado Arce, R., Osorio Villegas, B., Rojas, J. C., Rengifo, D., & Suárez, P. (2019). Cómo reducir la mancha roja causada por thrips en banano. In Boletín Divulgativo No. 443. El Triunfo, Ecuador: Instituto Nacional de Investigaciones Agropecuarias. Quito, EC: INIAP, Estación Experimental Santa Catalina 2019.

Ayilara, M. S., Adeleke, B. S., Akinola, S. A., Fayose, C. A., Adeyemi, U. T., Gbadegesin, L. A., Omole, R. K., Johnson, R. M., Uthman, Q. O., & Babalola, O. O. (2023). Biopesticides as a promising alternative to synthetic pesticides: A case for microbial pesticides, phytopesticides, and nanobiopesticides. Frontiers in Microbiology, 14. https://doi.org/10.3389/FMICB.2023.1040901

Bisane, K. D., Saxena, S. P., & Naik, B. M. (2017). Management of red rust thrips, Chaetanophothripssignipennis (Bagnall) in banana. Journal of Applied and Natural Science, 9(1), 181–185. https://doi.org/10.31018/JANS.V9I1.1168

Carrizo, B. N., Jaime, A. P., & Macián, A. J. (2017). Primer registro de *Amblyseius swirskii* (Acari: Phytoseiidae) en cultivo de pimiento *(Capsicum annuum* Linneo) en Corrientes, Argentina. Revista Agronómica Del Noroeste Argentino, 37(2), 107–110.

Food & Agriculture Organization of the United Nations (FAO). (2019). Food & Agriculture Organization of the United Nations. (2019). Bananas and Major Tropical Fruits in Latin America and the Caribbean. https://www.fao.org/fileadmin/templates/est/COMM_MARKETS_MONITORING/Tropical_Fruits/Documents/Food_Outlook_May_2019__Tropical_Fruits_Article_.pdf

García Sarabia, M., Mizar Caballero, H., & Sepúlveda Cano, P. (2015). Trips (Thysanoptera) del racimo del banano y sus enemigos naturales en el departamento del Magdalena, Colombia. Temas Agrarios, 20(2), 72–80. https://doi.org/10.21897/RTA.V20I2.760

Grijalba Bernal, E. P., Hurst, M., Ibarra, J. E., Jurat Fuentes, J. L., & Jackson, T. (2018). Bacterias entomopatógenas en el control biológico de insectos. In Capítulos de libros resultado de investigación. Corporación colombiana de investigación agropecuaria - AGROSAVIA.

Hernández-Trejo, A., Drouaillet, B. E., Rodríguez-Herrera, R., Giron, J. M. G., Patiño-Arellano, S. A. A., & Osorio-Hernández, E. (2019). Importancia del control biológico de plagas en maíz (*Zea mays* L.). Revista Mexicana de Ciencias Agrícolas, 10(4), 803–813. https://doi.org/10.29312/REMEXCA.V10I4.1665

Moyón Salazar, D. (2021). Control biológico de Chaetanophothrips signipennis Y Frankliniella parvula en plátano con el ácaro predador *Amblyseius swirskii* [Universidad Agraria del Ecuador]. https://cia.uagraria.edu.ec/Archivos/MOYON%20DAYSI.pdf

Regalado, P. (2018). Efectividad del acaro depredador *A. swirskii* en el control del trips Chaetanophotrips signipennis que causa la mancha roja en banano organico. Cumbre Mundial Del Banano.

San, P. P., Tuda, M., & Takagi, M. (2021). Impact of relative humidity and water availability on the life history of the predatory mite *Amblyseius swirskii*. BioControl, 66(4), 497–510. https://doi.org/10.1007/S10526-021-10081-Y

Tripathi, L., Tripathi, J. N., Tenkouano, A., & Bramel, P. (2008). Banana and Plantain. Compendium of Transgenic Crop Plants, 77–108. https://doi.org/10.1002/9781405181099.K0503.