

Determination of the Whitefly (Hemiptera: Aleyrodidae) Damage Index in a White Cargamanto Bean Crop (*Phaseolus Vulgaris*, Fabaceae), in Antioquia, Colombia

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ABSTRACT

The whitefly is a prevalent pest in bean crops. Although it feeds on sap and can transmit phytopathogenic viruses, many farmers and existing literature do not fully acknowledge its potential harm to bean crops. To address this, it is crucial to quantify the Damage Index (DI), Economic Injury Level (EIL), and Economic Threshold (ET) to aid in decision-making and prevent economic losses. This study aimed to quantify the DI of whiteflies in a bean crop under field conditions. A bean plot was established with three treatments: Buffer Zone, Chemical Control, and No Control. Whitefly adults per leaflet were monitored every 14 days throughout the crop cycle. Yield per plant for each treatment was estimated and related to whitefly populations using linear regressions. The EIL and ET were calculated based on the region's socioeconomic

context. The estimated DI was 3.52 grams of dry beans per plant (47 kg per hectare) for each whitefly adult found per leaflet. Consequently, the EIL and ET were 14 and 8 adult whiteflies per leaflet, respectively. Whitefly populations can significantly reduce yields and result in economic losses for local farmers if not properly managed.

Keywords: Crops, economic injury level (EIL), economic threshold (ET), integrated pest management (IPM), monitoring

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INTRODUCTION

The common bean (*Phaseolus vulgaris*, Fabaceae) is one of the most important crops for the rural economy across the American continent. Belonging to the genus *Phaseolus*, which includes about 70 species, the bean has historically contributed to human well-being in Mesoamerica and the Andean regions of South America (Acosta-Gallegos et al., 2007). Its ability to adapt to various environments and climatic conditions, owing to its tropical and subtropical origins, sets it apart from other crops (Ligarreto & Gustavo, 2013). Common bean is the predominant legume crop globally, accounting for approximately 85% of total bean production worldwide (Machiani et al., 2019). With an annual global output exceeding 27 million tons, this crop is cultivated across 29 million hectares (Gepts et al., 2008). In Colombia, per capita consumption ranges between 3 and 4 kg annually. The regions with the highest production are Santander, Antioquia, Huila, and Nariño, yielding an average of 1.24 tons per hectare. Beyond its role in food security, the bean crop provides rural employment and income, with approximately 120,000 small-scale farmers cultivating 92,412 hectares and producing 114,408 tons annually (Ministerio de Agricultura y Desarrollo Rural, 2020).

However, the bean is also one of the crops most affected by insect pests, which can cause significant losses or result in excessive insecticide use during the production process. Whiteflies (Hemiptera: Aleyrodidae) are among the most damaging pests worldwide, affecting beans and many other crops. These sap-sucking insects cause damage in two ways: by directly feeding on the plant's sap, which weakens the plant, induces chlorosis, deforms foliage, and reduces crop productivity; and by transmitting leafroll viruses in the early stages of leaf development (Otzoy-Rosales & Rodas-Rodríguez, 2003). Additionally, whiteflies indirectly cause harm by excreting sugary honeydew, which promotes the growth of sooty mold (*Capnodium fungus*) (Rebolledo-Martínez et al., 2013). While this fungus does not damage plant tissues, it impairs photosynthesis by obstructing light penetration, reducing the marketable value of leaves, flowers, fruits, and other parts (Nombela & Muñiz, 2010). Thus, whitefly infestations can severely impact bean production. Furthermore, whiteflies have a broad geographic distribution and a wide range of host plants, increasing their economic impact. Although substantial research exists, some studies have misled bean growers, suggesting that whitefly infestations do not significantly reduce yields under field conditions (Bueno et al., 2005). Consequently, many bean producers in Eastern Antioquia appear unconcerned about the losses caused by whiteflies, possibly due to a lack of accurate population and yield quantification.

The technical term for the relationship between pest populations and crop yields is the Damage Index (DI), which represents the amount of damage (e.g., kilograms/plant, tons/hectare) per unit of pest population (individual or percentage unit) (Pedigo et al., 1986). For instance, Bueno et al. (2005) evaluated the DI of the whitefly *Trialeurodes vaporariorum* (Westwood) in snap bean crops in Valle del Cauca, Colombia, finding that

2.25 nymphs/leaflet/cm² led to losses of 158.4 kg per hectare. The DI is crucial in estimating the Economic Injury Level (EIL), which marks the pest population level where economic loss equals the cost of control measures. The EIL helps determine the Economic Threshold (ET), or the pest population level that requires intervention to avoid financial loss. These indices are vital for developing Integrated Pest Management (IPM) programs. However, no published data are available on yield losses in beans under field conditions caused by whitefly infestations.

Therefore, quantifying production losses due to whitefly in bean crops and assessing the economic impact of pest control measures are crucial for decision-making processes. This study aims to estimate the whitefly Damage Index in bean crops under field conditions, based on the hypothesis that plants with the highest whitefly populations will exhibit the lowest yields across various production parameters. Specifically, the study seeks to answer the following questions: 1) How much production loss do whiteflies cause in bean crops when populations are left uncontrolled? 2) What is the net economic profit margin in systems with and without whitefly control? 3) What are the Economic Injury Level and Economic Threshold for the growing conditions in this region?

MATERIAL AND METHODS

Location

The experiment was conducted in the municipality of San Vicente Ferrer, in the Alto de la Compañía area, on the “Curazaos” farm, Antioquia department, Colombia (6°15'56"N; -75°20'24"E), at an elevation of 2,201 meters above sea level (masl). The average temperature was 17°C, with a maximum of 25°C and a minimum of 13°C, and relative humidity of 70%.

Crop Establishment, Cultural Practices, and Harvest

A plot of approximately 500 m² was established. Land preparation involved plowing, row hilling, and the application of a soil conditioner (60 kg of dolomitic lime one month before planting). A total of 440 bean plants were sown at a spacing of 1.50 m between rows and 0.5 m between plants, with two seeds per site. A subplot of 220 sites (hereafter referred to as plants) was marked off, consisting of 11 rows of 20 plants each, to minimize edge effects. In the third week after sowing (WAS), 100 g of organic matter was applied to each plant, followed by staking and wiring in the fourth week. During the sixth week, weeding was performed, and each plant received 40 g of granular fertilizer, consisting of a 1:1 mixture of diammonium phosphate and micronutrients. In the tenth week, a second round of weeding and fertilization was performed, with each plant receiving 50 g of a granular mixture of 10-20-30 and potassium chloride in a 1:0.5 ratio.

The dry bean harvest was carried out in the 18th week, with pods from 15 plants per treatment being individually counted. The harvested pods were separated, placed into labeled plastic bags, and weighed before and after shelling. Total production for each row was recorded, based on the individual yields of the 45 plants across the three treatments.

Experimental Design

The experiment consisted of three treatments: buffer zone (BZ), chemical control (CC), and no control (NC). The BZ comprised 100 plants, arranged in five rows of 20 plants each, situated between the CC and NC treatments to mitigate drift from the CC applications. No whitefly control measures were implemented in the BZ. The CC treatment consisted of 60 bean plants, arranged in three rows of 20 plants, placed between the NC and BZ treatments. These plants were treated with a rotation of chemically synthesized insecticides traditionally used by local farmers for whitefly control: Malathion (1B), Sulfoxaflor (4C), and Lambda-cyhalothrin (3A), applied every 14 days. The NC treatment also included 60 plants, distributed in three rows of 20, located between the CC and BZ treatments, with no whitefly control applied.

In all three treatments, fungicide applications were performed every 14 days using the following active ingredients: Difenoconazole and Flutriafol (G1), Azoxystrobin (C3), and Chlorothalonil (M05), for Lepidoptera larvae management *Bacillus turigensis* var *kursaki* (Dipel®) was applied, every 15 days. All applications followed the dosages recommended by the manufacturers.

Whitefly Monitoring

The first whiteflies appeared during the third week (WAS). Adult and nymph samples were collected and sent to the “Instituto Colombiano Agropecuario” (ICA) for identification (sample number M4021M0004094). Monitoring began in the sixth week (WAS) and was conducted every 14 days. To count whiteflies while avoiding underestimation due to adult escape, six leaflets per plant from 15 randomly selected plants per treatment were photographed. The images were taken on the underside of the leaves using a mobile device camera with 13 megapixels of resolution, capturing two leaflets from the upper, middle, and lower parts of the plant to assess spatial distribution. The images were processed to count adults, and the data were recorded in spreadsheets. Images also allowed to confirm or discard the presence of any other pest insect species.

After each monitoring event, whitefly control measures were applied only in the CC treatment. Disease control was carried out across the entire plot. A total of six monitoring events were conducted, with the final one occurring in week 16, two weeks prior to harvest.

Data Analysis and Statistical Modeling

The analysis of production parameters and losses due to whitefly infestation was conducted by comparing treatments using box and whisker plots (Tukey, 1977). Whitefly population data and production outcomes (three and six parameters, respectively) were used to calculate the Damage Index (DI) via linear regression analysis (Pedigo et al., 1986). Confidence intervals were generated for each regression using 9,999 bootstrap pseudo-replicates. All analyses were performed using the PAST software, version 4.08 (Hammer et al., 2001).

Economic Injury Level (EIL) and Economic Thresholds (ET)

With the calculated DI and the control costs for whitefly management (including labor, insecticide costs, and equipment depreciation), the EIL was calculated using the formula:

$$\text{EIL} = \frac{\$ \text{ CONTROL/HA}}{\$ \text{ SALE KG} * \text{DI} * \% \text{ CONTROL EFFECTIVENESS}}$$

To determine this, economic calculations were made for chemically synthesized insecticide applications, and the sale price was estimated based on the monthly average for beans from the nearest local market.

RESULTS

The whitefly species identified was *Trialeurodes vaporariorum* Westwood (1856). A total of 8,108 individuals were recorded throughout the experiment: 1,658 in the Chemical Control (CC) treatment, 5,519 in the No Control (NC) treatment, and 931 in the Buffer Zone (BZ). The highest abundance of whiteflies occurred during week 12, with an average of 50 adults per leaflet in the NC treatment. By week 16, the population had decreased, coinciding with the onset of plant senescence. The average number of adults per plant across the entire growth cycle was 3.20 in the CC treatment, 10.80 in the NC treatment, and 3.80 in the BZ.

In the BZ, the upper leaflets exhibited an average of 6.77 adults per leaflet over the entire crop cycle, compared to 4.00 in the middle section and 0.79 in the lower section. A similar pattern was observed in the NC treatment, where the averages were 2.43, 0.88, and 0.33 adults per leaflet for the upper, middle, and lower sections, respectively. The CC treatment showed a higher whitefly distribution, with 18.50 adults per leaflet in the upper section, 7.81 in the middle, and 0.61 in the lower section, indicating a concentration of the pest in the middle and upper parts of the plants (Figure 1).

Total production of shelled dry beans was 16,354 g, with the CC treatment yielding 6,585 g (109.76 g/plant), the BZ treatment yielding 5,924 g (59.24 g/plant), and the NC treatment producing 3,845 g (64.8 g/plant). Individual measurements from the 15 plants sampled (Table 1) were 132.3 g ($\pm$ 30.12) per plant for CC, 95 g ($\pm$ 35.04) for BZ, and 82.8 g ($\pm$ 33.89) for NC. The average unshelled weight per plant, calculated from the entire

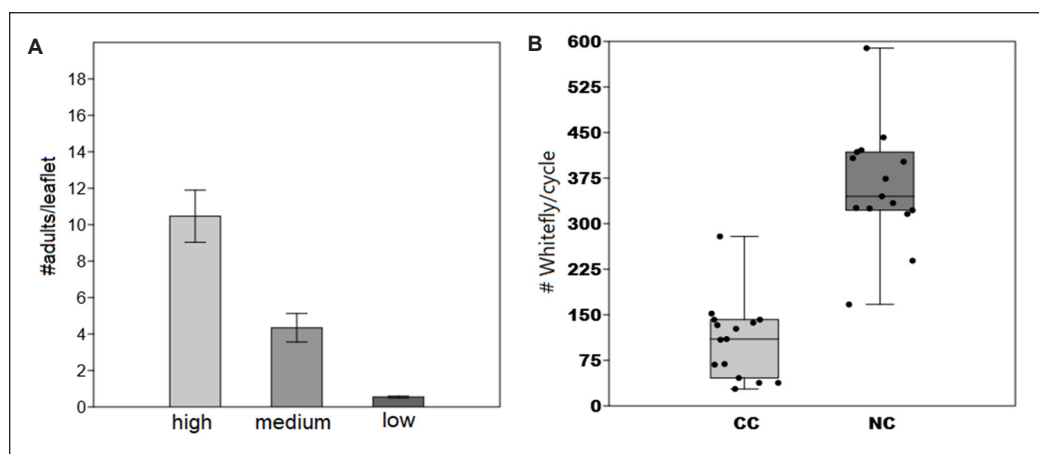


Figure 1. Whitefly adult population dynamics throughout the crop cycle: (A) Number of individuals per leaflet in the upper, middle, and lower thirds of the plant; and (B) Total number of adult individuals per plant in the NC and CC treatments

population of plants, was 203 g for CC, 154 g for BZ, and 136 g for NC. The number of pods per plant was 40 for CC, 35 for BZ, and 32 for NC. A summary of the whitefly population data and productive parameters by treatment is provided in Table 1.

There were no significant differences in the number of pods per plant ($F = 2.576$, $p = 0.08804$). However, significant differences were observed in both unshelled weight ($F = 7.276$, $p = 0.001935$) and dry weight ($F = 9.038$, $p = 0.0005332$). In the case of unshelled weight, the differences were found between the Chemical Control (CC) and No Control (NC) treatments ($p = 0.001874$) and between CC and the Buffer Zone (BZ) ($p = 0.02554$). For dry weight, significant differences were observed between CC and NC ($p = 0.0005332$) and between CC and BZ ($p = 0.01158$) (Figure 2).

A total of 18 linear regressions were conducted to relate production to pest population (Table 2) to estimate the Damage Index (DI). Of these, the regressions with the best fit and statistical significance were selected (Figure 3). The final regression suggested a DI of 3.52 g of dry beans per plant for each additional whitefly adult per leaflet (Figure 4). In our linear regressions, 30 data points were analyzed, resulting in 28 total degrees of freedom. Specifically, the degrees of freedom for treatment were 1, and the degrees of freedom for error were 28.

The average production of shelled dry beans in the CC treatment was 109.76 g/plant, compared to 64.8 g/plant in the NC treatment, showing a difference of 44.96 g/plant. This corresponds to the yield loss per plant due to the absence of whitefly control.

When extrapolated to a planting density of 13,333 plants/ha, this difference results in an estimated loss of approximately 600 kg/ha. Based on a local sale price of COP 6,000/kg, the economic loss per hectare without whitefly control would be around COP 3,600,000.

The Economic Injury Level (EIL) was calculated using a market price of COP 6,000/kg and a control cost of COP 3,130,285/ha, which included labor, insecticide costs, and equipment depreciation. The DI (3.52 g/plant) was adjusted to the estimated yield losses per hectare, with a planting density of 13,333 plants/ha. This resulted in an approximate loss of 46.90 kg/ha for every one whitefly adult per leaflet. The average control efficacy over the crop cycle was 80%. Substituting these values into the EIL equation:

Table 1
Summary of whitefly adult population indicators and bean crop production parameters

	Parameters	n	Min	Max	Median	Std. desv
Whitefly	Total/cycle	40	24	568	172.60	134.87
	WF/week6	30	6	247	64.73	55.88
	WF/week10	40	1	167	36.15	44.86
	Max/leaflet	40	5	134	54.23	32.02
	Avg-upper/cycle	40	0.25	39.88	9.544	9.30
	Avg/leaflet	40	1.39	31.56	10.92	7.10
Bean production	CC	15	67	203	132.33	33.89
	BZ	15	31	176	95.8	35.04
	NC	15	47	139	82.8	30.12

Note. WF: Whitefly; Avg: average; CC: Chemical Control; NC: No Control; BZ: Buffer Zone

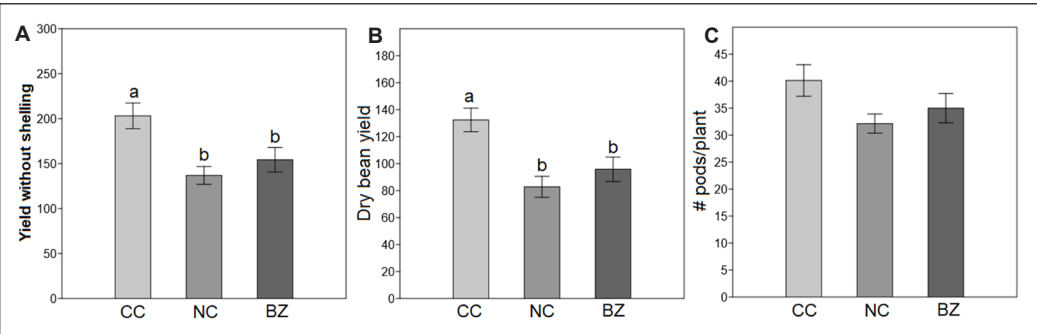


Figure 2. Production parameters of white cargamanto beans in eastern Antioquia under three whitefly management systems: Chemical Control (CC), No Control (NC), and Buffer Zone (BZ). (A) Unshelled bean production in grams per plant; (B) Dry-shelled bean production; and (C) Number of pods per plant

Table 2
Statistical analysis of linear regressions for whitefly populations and most significant production parameters

Parameters	Slope (DI)	Intercept	r ²	P value
Total/Cycle	-0.109(-0.18454; -0.011358)	126.46 (106.72; 143.44)	-0.38	0.0136
Whitefly/week10	-0.41(-0.61; -0.20)	122.5 (108.11; 136.49)	-0.48	0.0014
Unshelled weight	-0.56(-0.82; -0.30)	191.17 (168.92; 212.46)	-0.46	0.0027
Avg-upper/cycle	-2.44(-4.6747; 0.40765)	197.33 (162.1; 227.02)	-0.31	0.048

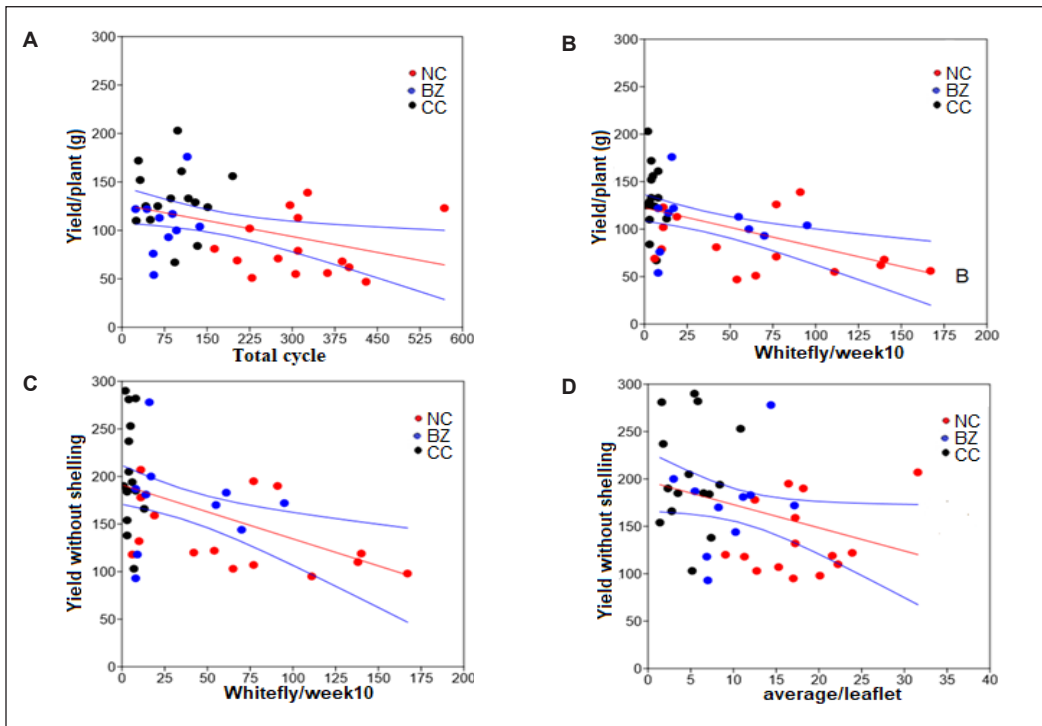


Figure 3. Relationship between whitefly population and production parameters of white cargamanto beans: (A) Total whitefly population throughout the crop cycle and production per plant (g); (B) Whitefly population at week ten and production per plant; (C) Whitefly population at week ten and unshelled bean weight; and (D) Average number of whiteflies per leaflet and unshelled bean weight

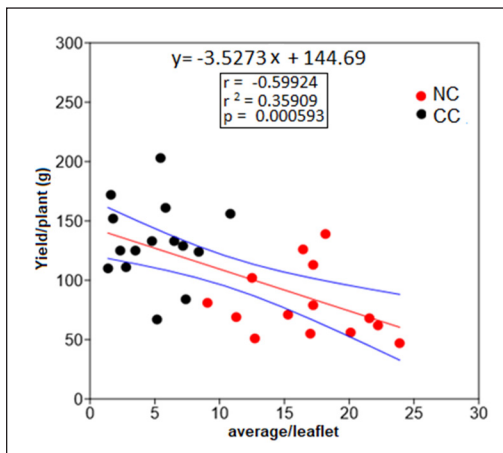


Figure 4. Damage index of white cargamanto bean plants estimated from linear regression of average whiteflies per leaflet and production per plant (in grams) for crops with Chemical Control (CC) and No Control (NC)

$$\text{EIL} = \frac{\$3130285}{\$6000 * 46.90\text{kg} * 0.8}$$

$$= 13.90 \text{ whitefly/leaflet}$$

Thus, the EIL was estimated to be approximately 14 adult whiteflies per leaflet.

DISCUSSION

Although whiteflies are a common pest in various crops, particularly beans, there is a lack of comprehensive monitoring methods and data to measure their populations and the associated crop damage. Despite the importance of the Damage Index (DI) in pest management, it is not well-established

for widely cultivated crops like beans. In this study, we estimated that each whitefly adult found per leaflet results in a loss of 3.52 grams of dry beans per plant. Extrapolating these data to the region's planting density of 13,333 plants per hectare, we calculate a potential decrease of 47 kilograms per hectare when an average of one adult whitefly per leaflet is present throughout the crop's production cycle.

Gonzalez et al. (2015) calculated the sap consumption rates of whiteflies on bean plants throughout their life cycle. They found that the first and second instars consumed 0.052 mg and 0.14 mg per day, respectively; the third instar consumed 0.19 mg/day, and adults consumed 0.27 mg/day. Over a lifespan of approximately 45 days (excluding egg incubation), the total sap consumption amounts to 6.35 mg per whitefly. Given that the sap's solute concentration is around 20% (Jensen et al., 2013), this translates to 1.27 mg of solutes consumed per whitefly. Thus, 114 whiteflies would be required to consume the equivalent of the bean production in the CC treatment, which averages 145 grams per plant.

Bueno et al. (2005) investigated whitefly sampling methods and spatial distribution in beans and snap beans. They estimated the DI for snap beans at 4.97 grams per whitefly nymph found in 2.25 cm², with an Economic Injury Level (EIL) of 12 nymphs per 2.25 cm² leaflet. Although these findings contribute to understanding pest dynamics, estimating nymphs in the field remains challenging for producers. The DI calculated in this study, based on adult whiteflies, can enhance decision-making processes. Previous research has provided valuable data on various aspects of whitefly biology and management, but there has been limited focus on calculating DI and EIL specifically for bean crops.

Campuzano-Martínez et al. (2010) proposed an intrinsic growth rate (r) for whiteflies of 0.04/day, which can be used to estimate the Economic Threshold (ET) of whiteflies in bean crops using the exponential growth equation (Stern et al., 1959). Assuming the final population as the EIL and the initial population as the ET, with a 14-day action time between indicators (Pérez-Marulanda & Giraldo-Sánchez, 2020), the calculation yields:

$EIL = ET \text{ (Economic Threshold)} e^{r \cdot t}$, so,

$$ET = \frac{13.90}{e^{(0.04 \cdot 14)}} = 8.00 \text{ whitefly/leaflet/plant}$$

This suggests that control measures should be initiated when the average population reaches around eight whiteflies per leaflet, before it exceeds the EIL of approximately 14 adults per leaflet, to prevent economic losses. This value can be adjusted based on local conditions, including variations in sale prices and production costs, providing a practical decision rule for commercial bean production. Future research should focus on evaluating whitefly population parameters under diverse field conditions and climatic regimes to refine ET estimates for different regions, enhancing integrated pest management strategies.

While extensive research has been conducted on whitefly oviposition (de Jesus et al., 2011), preferred cultivars (Morales & Cermeli, 2007), population sampling (Bueno et al., 2005), resistance to insecticides (Campuzano-Martínez et al., 2010), and symbiosis with fungi and viruses (Otzoy-Rosales & Rodas-Rodríguez, 2003; Perea et al., 2003), few studies have focused on damage indices, Economic Injury Levels, or Economic Thresholds (Nava-Camberos & Cano-Ríos, 2000). This study provides valuable insights for managing whitefly populations in bean crops, offering useful information for decision-making in both current and future pest management practices in regions with moderate cold climates.

The observed variability in whitefly populations and crop yield can be explained by the inherent heterogeneity of field conditions and plant physiological responses. The influence of environmental factors such as microclimate variations, natural enemy activity, and plant resilience mechanisms can contribute to fluctuations in pest populations and yield outcomes. Despite this variability, our statistical analyses allowed us to establish a clear Damage Index, reinforcing the economic relevance of whitefly control in bean crops. Moreover, the use of extensive sampling and statistical modeling provided reliable estimates of the Economic Injury Level and Economic Threshold, ensuring their applicability in real-world production systems. These results highlight the importance of integrating population monitoring with decision-making tools to optimize pest management strategies while minimizing unnecessary pesticide applications.

The results of this study highlight the significant economic impact of whitefly infestations on bean crops and emphasize the importance of accurate monitoring and timely intervention. By establishing a clear relationship between whitefly populations and yield loss, this research provides a practical tool for growers to estimate potential damage and implement control measures before economic thresholds are exceeded. The calculated economic threshold (ET) of eight whiteflies per leaflet provides a practical benchmark for the initiation of pest management strategies which can be adapted to local conditions and market dynamics. Furthermore, incorporating these findings into integrated pest management (IPM) programs could improve the sustainability of bean production by reducing unnecessary pesticide use and minimizing crop losses. Future research should focus on validating these thresholds under different climatic conditions and bean varieties to ensure their applicability in different agricultural contexts, thereby supporting more resilient and efficient pest management practices of whitefly populations, not only in this region, but also in other temperate cold climate producing regions.

CONCLUSION

Under the evaluated field conditions, the Damage Index (DI) for whiteflies is 3.52 grams of dry beans per plant for each whitefly found per leaflet. Consequently, the Economic Injury Level (EIL) and the Economic Threshold (ET) for the study period and conditions

were determined to be 14 and 8 adult whiteflies per leaflet, respectively. This indicates that whitefly populations in bean crops can significantly reduce yields and lead to economic losses for local farmers if not properly managed.

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