Monitoring of the Fall Armyworm (*Spodoptera frugiperda* Walker) Moth for the Determination of Efficient Chemical Control in *Zea mays* L.

Castellanos-Hernández, Cesar E.[1]**; Ledesma-Miramontes, Alejandro**[2*]**; Ramírez-Díaz, José L.**[2]**; Rubio-Camacho, Ernesto A.**[2]**; Alemán-De la Torre, Ivone**[2]**; Salinas-Moreno, Yolanda**[2]**; Martínez-Ortiz, Miguel Angel**[2]

[1] Universidad de Guadalajara, Centro Universitario de Ciencias Biológicas y Agropecuarias. División de Ciencias Agronómicas, Las Agujas, Zapopan, Jalisco, México. C. P. 44600.

[2] Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Campo Experimental Centro Altos de Jalisco. Las Cruces, Tepatitlán, Jalisco, México. C. P. 47714.

* Correspondence: ledesma.alejandro@inifap.gob.mx

ABSTRACT

Objective: To determine the population dynamics of the fall armyworm (FAW), identify the critical period of highest infestation and to determine the number of agrochemicals applications for its control.

Design/methodology/approach: A monitoring and capture of male FAW moths was conducted using plastic traps with sexual attraction pheromones. A daily count of captured moths was performed during the crop season, the data were plotted to determine the period of highest infestation and the optimal timing for chemical control. Additionally, the number of insecticide applications for FAW control was evaluated, with treatments including none (T0), one (T1), two (T2), three (T3), and four (T4) applications. A randomized complete block design with nine repetitions was used. Before each application, the number of plants with visible damage and its intensity were counted using the Davis visual scale. Statistical analysis of the measured variables was conducted.

Results: The results showed that moths were evenly distributed across the planted surface, and two periods of higher infestation were identified: between 32 to 35 and 70 to 76 days after planting, respectively. The biological cycle of the FAW was between 38 to 41 days. The analysis of variance showed statistical differences ($p \leq 0.001$) among the treatments.

Findings/conclusions: Using plastic traps with sexual attraction pheromones is an efficient method for capturing, monitoring, reducing the population, estimate the length of the biological cycle, and identifying the highest infestation period of the FAW. Moreover, two insecticide applications during the periods of highest infestation resulted in optimal control of FAW.

Keywords: Sex pheromones, insecticides, trapping, *Zea mays* L.

Citation: Castellanos-Hernández, C. E., Ledesma-Miramontes, A., Ramírez-Díaz, J. L., Rubio-Camacho, E. A., Alemán-De la Torre, I., Salinas-Moreno, Y. & Martínez-Ortiz, M. A., (2024). Monitoring of the Fall Armyworm (*Spodoptera frugiperda* Walker) Moth for the Determination of Efficient Chemical Control in *Zea mays* L. *Agro Productividad*. https://doi.org/10.32854/agrop.v17i9.3029

Academic Editor: Jorge Cadena Iñiguez
Guest Editor: Juan Francisco Aguirre Medina

Received: May 14, 2024.
Accepted: August 26, 2024.
Published on-line: September 20, 2024.

Agro Productividad, 17(9) supplement. September. 2024. pp: 69-79.

INTRODUCTION

In Mexico, maize is the most important crop due to its production value and its social and cultural significance. Currently, approximately 28 million tons are produced, which is insufficient to meet the internal demand of nearly 46 million tons. Consequently, 17 million tons were imported, making Mexico the second-largest maize importer in the world (SIAP, 2022). Therefore, it is urgent to develop research strategies to increase production and grain yield. One of the main causes of loss in grain yield and quality are pests and diseases; thus, rational management and control of these factors is essential to enhance production and profitability of the crop. The fall armyworm (*Spodoptera frugiperda*) is one of the most significant pests affecting maize in Mexico. This pest is constantly adapting and is distributed throughout the Americas. In recent years, it has spread to most parts of the world, causing substantial economic losses in Africa and Asia (FAO, 2020). Although this insect has a preference for grasses, it can infest over 186 crops (Casmuz *et al.*, 2010). Previously, in Mexico, it caused significant damage in tropical and subtropical regions of the country. Currently, significant infestations are found in transitional regions and high valleys, at altitudes ranging from 1900 to 2600 meters, demonstrating the insect's adaptive changes to tolerate these climatic conditions (Casmuz *et al.*, 2010). In addition to being considered a highly aggressive pest, with significant infestations at all phenological stages of the crop, it has adapted its feeding habits. Initially, its damage was concentrated only on the whorl of the plant; however, it can now act as a defoliator, borer, cutter, and during the reproductive stage, it causes damage to the ear and tassels. Furthermore, during the grain-filling stage, it feeds on the cob, causing damage to the maize, which results in economic losses for the producer. It is reported that during critical periods, production losses can range between 10% and 30% (Bahena, 2020). One alternative for its control is the use of insecticides; however, excessive and improper use leads to control inefficiency, insecticide resistance, increased environmental contamination, and higher production costs, which ultimately results in decreased crop profitability (Bahena & Velázquez, 2012). To mitigate these issues, new control methods have been developed, such as Integrated Pest Management (IPM) and Agroecological Pest Management (APM). These approaches integrate and combine monitoring techniques with agroecological control methods, including the use of biological or chemical insecticides with low environmental impact. One of these alternative tools for monitoring and controlling fall armyworm is the use of traps with sex pheromones, which exploit the attraction and confusion of male moths during their reproductive stage. The use of pheromones is considered an effective, low-impact environmental control technique, as it allows for the reduction of populations through the capture of moths and constant monitoring of larval periods in the field. This helps to identify critical infestation periods, determine the duration of the biological cycle, and make informed applications of chemical products for optimal control. The objective of this research was to monitor male fall armyworms to determine the population dynamics and identify the critical period of highest infestation and damage to the crop. Additionally, it aimed to determine the number of insecticide applications and the optimal timing for chemical control during the maize cycle.

MATERIALS AND METHODS

This research was conducted at the Centro Altos de Jalisco Experimental Field of the National Institute of Forestry, Agricultural, and Livestock Research (INIFAP), located in Tepatitlán, Jalisco, Mexico, at an altitude of 1930 meters within the Agroecological Transition Zone. The geographic coordinates are 20° 52' 23" North latitude and 102° 42' 45" West longitude. The experiment was established on June 3 and 4 during the spring-summer (SS) agricultural cycle of 2021 and consisted of two stages.

Stage I. Moth Capture and Monitoring

The maize experiment was established in a 11,760 m^2 plot with a population density of 78,000 plants ha^{-1}. The agronomic management applied followed the recommendations provided by INIFAP for the study region (Chuela *et al.*, 2011). The traps for capturing male moths were placed immediately after planting. These traps were made from square containers, with openings on three of the four side faces and a 15 cm deep bottom, acting as a basin, which was filled with water + biodegradable soap. The traps were secured to a wooden stake and positioned at a height of 1.20 meters above the ground. A wire was threaded through the top face of the container, where a capsule containing the sex attraction pheromone was placed (Figure 1). Each pheromone trap covered a circular area of 2,500 m^2, therefore, four traps were sufficient to cover the experimental plot. The soapy solution was changed every seven days, and the capsules were replaced every 28 days, as recommended by the manufacturer.

To understand the population dynamics of the adult fall armyworm, a daily count and record of the moths captured in each trap was conducted. The daily capture data were grouped by week and plotted to observe the frequency distribution and identify the infestation peaks, which were used to schedule insecticide application dates. Additionally, a mean comparison was conducted between the number of moths captured per trap to observe the dispersion of the moths within the planted area.

Stage II. Determination of the Number of Chemical Insecticide Applications for Fall Armyworm Control

To determine the number of applications required for the chemical control of the fall armyworm, an additional experiment was established in the same location during the same SS 2021 production cycle. Five treatments were evaluated as follows: T0=Control (no applications), T1=one application at 30 days after sowing (30 DAS), T2=two applications (30 and 37 DAS), T3=three applications (30, 37, and 51 DAS), T4=four applications (30, 37, 51, and 58 DAS). A randomized complete block design with nine replications was used (Table 1). The total size of the experimental unit was eight rows, each 16.5 meters long with 0.80 meters of spacing between rows. The two central rows were used as the useful plot to avoid edge effects. A white-grain maize hybrid was used for the treatment evaluations, which was sown mechanically at a density of 70,000 plants ha^{-1}. Agronomic management

Figure 1. Appearance of the traps and their placement in the plot, supported on a wooden base. Left: Placement of the capsule with the pheromone. Center: Placement of the trap in the field. Right: Surface of the solution with captured male moths.

Table 1. Number of moths captured per trap during the crop production cycle.

Month	Trap 1	Trap 2	Trap 3	Trap 4	Total
June	309	298	458	199	1264
July	511	400	477	183	1571
August	174	290	95	532	1091
September	60	54	25	78	217
October	0	0	0	0	0
November	0	0	0	0	0
December	0	0	0	0	0
Total	1054	1042	1055	992	4143
Daily average	8.7	8.6	8.7	8.2	8.6

was carried out according to INIFAP's recommendations for maize cultivation in the study region (Chuela *et al.*, 2011), except for the number of insecticide applications for the chemical control of the fall armyworm.

In each treatment, the total number of plants was counted, and 10 plants were randomly selected. The active ingredients of the insecticide were Emamectin Benzoate+Lambda-cyhalothrin, applied at doses of 150 mL + 375 mL ha^{-1}. Applications were made using a 15 L manual backpack sprayer equipped with Lurmark 30 FCX04® full cone nozzles. The product dosage for each treatment was calibrated by measuring the output per backpack, based on a rate of 220 liters of water per hectare, which corresponded to 10.5 mL + 21 mL of Emamectin Benzoate + Lambda-cyhalothrin, respectively.

Study Variables

For the 10 plants selected within each treatment and replication, the following data were collected: Number of Plants with Visible Damage: The number of plants with visible damage: This was counted for each treatment, using a scale of 0 and 1, where 0 indicates no damage and 1 indicates damage present. Damage Intensity: For plants with visible damage, the damage was assessed using the visual scale from 1 to 9 (Davis *et al.*, 1992). In this scale, values from 1 to 3 represent minimal damage caused by larvae less than 1.0 cm in length. Values from 4 to 6 represent significant damage caused by larvae from 1.1 to 2.0 cm in length, which are already established in the plant's whorl. Finally, values from 7 to 9 represent severe damage to the plant caused by larvae greater than 2.1 cm in length (Figure 2).

Statistical Analysis

The data on the presence, absence, and intensity of damage caused by the fall armyworm were analyzed using an average filtering process of the number of plants with damage at any period of the crop for each treatment. This generated a new database with the number of damaged plants for each treatment. This new database was subjected to an analysis of variance (ANOVA) to determine the optimal number of applications for the control of the fall armyworm. Additionally, a post-hoc HSD-Tukey test was performed to determine

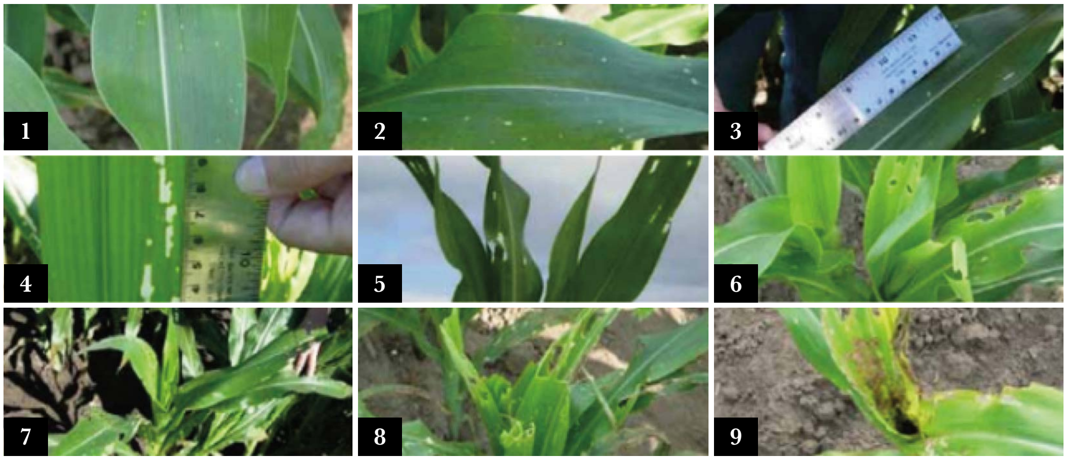

Figure 2. Davis *et al.* (1992) scale for the visual assessment of damage caused by the fall armyworm.

the differences between treatment means. Statistical analyses and graphs were conducted using R and RStudio software (R Core Team, 2022).

RESULTS AND DISCUSSION

Capture and Monitoring of Moths

A total of 4,143 moths were captured during the maize production cycle (June to December). July was the month with the highest capture of moths (1,571), while no moths were captured from October to December. Considering only the months from June to September (when moths were captured), the average daily capture per trap was very similar and showed no significant differences (Table 2). Similarly, considering only the months of moth capture, the weekly average was 259 moths captured. This capture result was lower compared to the average of 519 moths per week reported by Salazar *et*

Table 2. Comparison (Tukey≤0.05) of the treatment means for the number of insecticide applications based on the number of plants with damage.

Number of applications	Difference	Minimum	Maximum	Adjusted P-value	
T0 *vs.* T1	−9.1	−15.5	−2.7	0.002	*
T0 *vs.* T2	−14.2	−20.6	−7.8	1.5×10^{-6}	**
T0 *vs.* T3	−19.1	−25.5	−12.7	0.001	**
T0 *vs.* T4	−19.5	−26.0	−13.2	0.001	**
T1 *vs.* T2	−5.1	−11.5	1.3	0.172	ns
T1 *vs.* T3	−10.0	−16.4	−3.6	5.8×10^{-4}	**
T1 *vs.* T4	−10.4	−16.8	−4.0	3.2×10^{-4}	**
T2 *vs.* T3	−4.8	−11.3	1.5	0.208	ns
T2 *vs.* T4	−5.3	−11.7	1.1	0.142	ns
T3 *vs.* T4	−0.4	−6.8	6.0	0.999	ns

*=Significant at the 5% probability level; **=Significant at the 1% probability level; ns=Not significant.

al. (2020). These observed differences are primarily due to the study region. In the case of Salazar *et al.* (2020), the study was conducted in a tropical region (70 m altitude), where high populations of the fall armyworm are recorded compared to regions at altitudes close to 2000 m. During the vegetative and early reproductive stages of the plants (June to September), the highest number of moths was captured per month (Table 2). Similar results were observed by De la Cruz *et al.* (2018) and Salazar *et al.* (2020), who recorded higher moth populations and greater damage to the crop during the vegetative stage. On the other hand, in September (flowering stage), there was a drastic decrease in the number of moths captured, with a total of 217 moths from the four traps. However, this capture was significant because it initiates new populations of fall armyworm larvae that affect the reproductive structures of the plants (ears and silk). Nevertheless, these populations do not become very high because the larvae have a lower probability of survival due to a lack of food, the presence of other entomophagous insects, and the unfavorable environmental conditions that create non-optimal environments for the insect to reproduce, forcing it into a state of dormancy (Hardke *et al.*, 2015). In this sense, September was considered the final capture stage for moths; however, traps continued to be monitored for the remaining three months. Analyzing the total number of moths captured during the growing season (4,143), it is important to highlight two things: 1) the efficiency of the traps in reducing larval populations and 2) the identification of the period of highest adult incidence.

In the first case, if all 4,143 captured male moths had mated, they would have resulted in 4,143 ovipositions (100 eggs). If at least one larva from each oviposition reached adulthood, this would have prevented approximately 4,143 individuals from causing damage daily across the field, potentially resulting in an infestation exceeding 50% of the crop.

Based on the daily record of the number of moths captured, it was estimated that in the study area, the biological cycle of the insect lasts from 38 to 41 days (Figure 3). These results align with Bahena (2020), who reported that the biological cycle of the fall armyworm ranges from 28 to 60 days; however, it is noted that this duration depends on the agricultural zone and the crop production cycle. On the other hand, Salazar *et al.* (2020) report that in tropical areas, the biological cycle of the fall armyworm is 30 days per generation. In this context, two generations were identified during the months of June to September, which is consistent with the findings of Rojas *et al.* (2004) and Salas-Araiza *et al.* (2018), who reported that the fall armyworm exhibited two generations during the maize production cycle. They also mention that the highest infestation frequencies found serve as a reference for chemical control. However, it is essential to know the larval instars of the fall armyworm, the duration of its biological cycle, and the recommended doses and application guidelines for insecticides to achieve optimal control. The first peak of infestation occurred at 35 DAS, with 1,400 moths captured over the course of one week (Figure 3). The second peak of infestation occurred at 75 DAS, representing the second generation of moths, during which 896 moths were captured over the course of one week (Figure 3). At this peak, the moth capture was 36% lower than in the first peak. This reduction could be attributed to the timely chemical control implemented during the first generation of moths. Based on the dynamic data, the phenological stages of the crop with the highest frequency of moths and the greatest damage were identified. It was observed

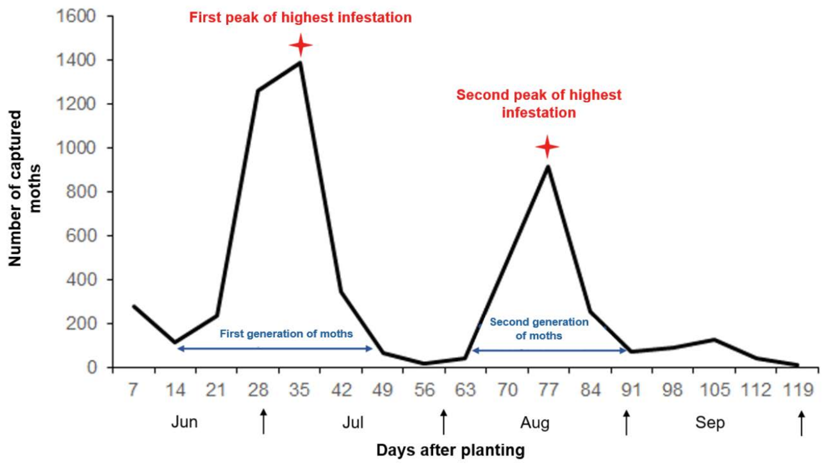

Figure 3. Weekly distribution of fall armyworm moths captured in pheromone traps during the months of peak insect presence (June-September).

that the highest frequency of infestation occurred during the vegetative stage, between the V3 and V4 stages of the crop. Therefore, the first larvae would be expected around 26 DAS. However, considering that the most effective chemical control is achieved during the first three larval instars, these would appear around 35 DAS. Thus, it is recommended to apply the insecticide between 30 and 35 DAS to control both adults and the early larval instars emerging from the hatched eggs. Furthermore, it is expected that the insecticide applied would cover a period of 21 days, which would help reduce the larval population. The second peak of infestation occurred between the V14 and VT phenological stages of the crop. During this infestation, the larvae cause damage to the foliage, flag leaf, ear, and cob. In this regard, Salas-Araiza *et al.* (2018) found a second peak of infestation of fall armyworm larvae during the same phenological stages. The duration of the second peak of infestation was 21 days; therefore, the second application is recommended between 70 and 75 DAS to control the early larval instars and prevent damage to the reproductive structures of the crop. However, due to the phenological stage of the crop, plant height, and the toxicity of the insecticides, manual application of chemical products is limited. Consequently, consideration should be given to using drones or machinery adapted for this purpose. On the other hand, the adaptability of the fall armyworm and its diverse feeding habits were confirmed, as it was observed cutting and boring into plants during the seedling stage, defoliating during the vegetative stage, and feeding on the ear, husks, and cob during the reproductive stage. Salazar *et al.* (2020) confirm this broad adaptability of the fall armyworm and emphasize the importance of implementing effective control measures to minimize crop damage.

This research confirmed that capturing and constantly monitoring fall armyworm moths using pheromone traps is a useful tool for determining population dynamics, estimating the duration of the biological cycle, defining critical stages of highest crop damage, and pinpointing the optimal time for chemical control of the fall armyworm. Similarly, Malo and Rojas (2020) highlighted the efficiency of using pheromone traps as an effective method for controlling fall armyworm in maize.

Determination of the Number of Chemical Applications for Fall Armyworm Control

The analysis of variance only showed statistical differences ($p \leq 0.001$) between treatments, indicating uniformity among repetitions. The number of plants with visible fall armyworm damage varied according to the number of applications made. The control (T0) had the highest percentage of damage, 84.2%, compared to one (T1), two (T2), three (T3), and four (T4) applications, which had percentages of 66%, 55.8%, 46%, and 45.1%, respectively (Figure 4). This indicates that the number of chemical insecticide applications reduced the number of plants with visible fall armyworm damage, but the differences in damaged plants between T2, T3, and T4 do not justify performing a third or fourth application.

There were significant differences ($p \leq 0.05$) in the comparison of means between T0 and the insecticide treatments. Therefore, applying chemical products has a significant effect on the control of the fall armyworm. Treatment T1 did not show differences compared to T2; however, T1 did have significant differences ($p \leq 0.05$) compared to T3 and T4, indicating better control when more than one application is made. On the other hand, T2 showed differences ($p < 0.001$) compared to T0, but did not show differences ($p \leq 0.05$) compared to T1, T3, and T4 (Table 4). This means that performing two applications statistically provides the same control of the fall armyworm as performing three or four applications. Therefore, based on these results, it is most advisable to perform two applications, thus avoiding excessive use of chemical products and labor. These results agree with those found by Vélez *et al.* (2021), who used the economic threshold (points of highest infestation) as their treatment guide, which provided the best control. The same authors indicate that using the economic threshold helps determine the timing for starting control strategies to prevent significant damage and reduce the number of chemical applications.

According to Mora and Paulo (2019), a higher number of chemical applications at 12-day intervals resulted in better control. However, there were no significant differences when the interval between applications was increased to every 30 days, nor did they find significant differences in yield. On the other hand, the benefit/cost ratio is higher when the

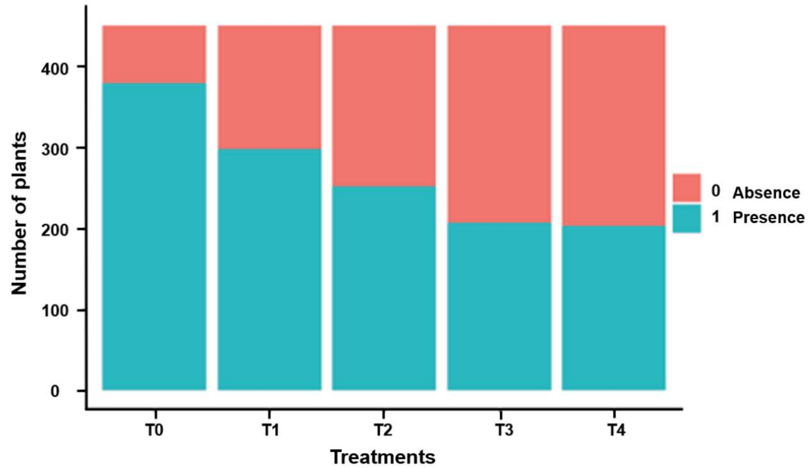

Figure 4. Presence and absence of visible damage with respect to the number of chemical applications.

number of applications is reduced, and it also represents less pollution and environmental impact (Mora and Paulo 2019). In (Figure 5), the decrease in the number of damaged plants with the increase in the number of chemical applications is observed. The number of plants with visible damage within each repetition varied according to the number of applications performed. In T0, it was observed that, on average, the number of damaged plants ranged from 40 to 45 per repetition, while T4 showed only 5 to 35 damaged plants, with the lowest average of 22 plants per repetition. These results are similar to those found by Mora and Paulo (2019), where the percentage of damage statistically decreased as the number of applications increased.

Damage Intensity

Regarding the intensity of the damage assessed using the Davis *et al.* (1992) scale, a decrease in damage intensity was observed as the number of applications increased. The control (T0) exhibited the highest percentage of damaged plants (84.2%) and an average damage intensity of 2.9. This was followed by treatment T1, which had 66% of damaged plants and an average damage intensity of 2.4. Treatment T2, with 55.8% of damaged plants, showed an average damage intensity of 2.1. Finally, treatments T3 and T4, with 46% and 45.1% of damaged plants respectively, had the lowest damage intensity values at 2.0 and 1.9 on the Davis scale (Table 3).

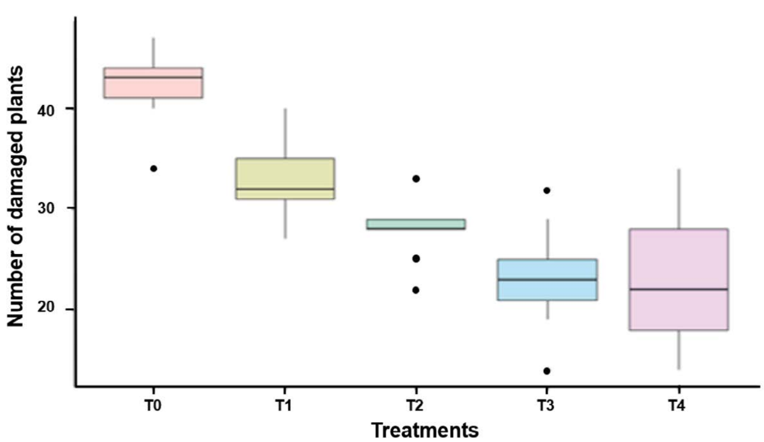

Figure 5. Average number of damaged plants per repetition depending on the number of applications performed.

Table 3. Number of Plants with Visible Damage and Damage Intensity (Davis Scale) with Respect to the Number of Insecticide Applications.

Treatment	Plants evaluated	Plants with visible damage (%)	Damage intensity (Average)*
T0	450	84.2	2.9
T1	450	66.0	2.4
T2	450	55.8	2.1
T3	450	46.0	2.0
T4	450	45.1	1.9

* The average damage intensity evaluated with the visual scale of Davis *et al.* (1992).

Additionally, it was observed that in T0 and T1, there were damage intensities ranging from 7 to 9 with 3.4% and 1.7% of plants showing visible damage, respectively, while T2, T3, and T4 did not exhibit plants with this level of damage intensity. Similarly, for damage intensities of 4 to 6, T0 and T1 had the highest damage percentages with 22.7% and 14.5%, respectively, while T2, T3, and T4 had damage percentages of 5.2%, 7.7%, and 4.4%, respectively (Table 4). This indicates that the severity of damage increases with fewer insecticide applications. Finally, for damage intensities of 1 to 3 on Davis's scale, T0 and T1 showed percentages of 7.9% and 83.8%, respectively, while T2, T3, and T4 had percentages of 94.8%, 92.3%, and 95.6%. Despite the high percentages of damage in the range of 1 to 3, this indicates that with a higher number of insecticide applications, the severity of damage decreases (Table 4).

Table 4. Damage intensity on the Davis scale depending on the number of chemical control applications.

Treatment	Damage intensity (Davis scale (%))			
	1 a 3	**4 a 6**	**7 a 9**	**Total**
T0	73.9	22.7	3.4	100
T1	83.8	14.5	1.7	100
T2	94.8	5.2	0	100
T3	92.3	7.7	0	100
T4	95.6	4.4	0	100

Considering that the maximum value on Davis *et al.* (1992) scale is 9, the control treatment (T0) had the highest damage intensity (8), confirming that not implementing chemical control for the corn borer can result in greater losses in yield and grain and/or forage quality. In this regard, Mora and Paulo (2019) found that when no insecticide applications were made, the average damage on the Davis scale was 6.5, and similarly, increasing the number of insecticide applications reduced the damage.

CONCLUSIONS

The use of pheromone traps is an effective tool for capturing, monitoring, reducing the population, estimating the biological cycle duration, and identifying peak infestations of the adult male fall armyworm. The population dynamics help determine the optimal time for chemical control. Increasing the number of chemical applications reduced the number of damaged plants and the severity of damage caused by the fall armyworm. Applying insecticide twice during the peak infestation periods is sufficient to achieve optimal control of the fall armyworm.

ACKNOWLEDGEMENTS

The Research Station 'Altos de Jalisco', now known as 'Campo Experimental Centro-Altos de Jalisco', was established in 1974. We acknowledge the institution and its dedicated personnel for their unwavering support and valuable contributions that have benefitted the people of Mexico, marking a significant milestone over decades. This manuscript stands as our tribute, commemorating 50 years of their remarkable achievements.

REFERENCES

Bahena, J. F. (2020). Manejo agroecológico del gusano cogollero del maíz en México. Serie Fitosanidad, Núm. 122. Artículos Técnicos de INTAGRI. México.

Bahena, J. F., y Velázquez, J. J. G. (2012). Manejo agroecológico de plagas en maíz para una agricultura de conservación en el Valle Morelia-Querétaro, Michoacán (Folleto técnico Núm. 27). Centro de Investigación Regional del Pacífico Centro, INIFAP. Uruapan, Michoacán.

Casmuz, A., Juárez, M. L., Socías, G., Murúa, M. G., Prieto, S., Medina, S., Willink, E., y Gastaminza, G. (2010). Revisión de los hospederos del gusano cogollero del maíz, *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *Revista de la Sociedad Entomológica Argentina*, 69, 209-231.

Chuela B., M., Alemán M., V., Ramírez D., J. L., Ramírez Z., R., Soltero D., L., y Ledesma M., A. (2011). Guía para producir maíz de temporal en el Estado de Jalisco (Folleto técnico Núm. 11). Centro de Investigación Regional del Pacífico Centro, INIFAP. Tepatitlán, Jalisco, México.

Davis, F. M., Ng, S. S., & Williams, W. P. (1992). Visual rating scales for screening whorl-stage corn for resistance to fall armyworm (MAFES Technical Bulletin 186). Mississippi: MAFES/MSU.

De la Cruz M., V., Meza P., A., y Arellano J., Del R. (2018). Uso de feromona en el control del gusano cogollero Spodoptera frugiperda. *Investigaciones Científicas y Agrotecnológicas Para la Seguridad Agroalimentaria*, 138-143.

Hardke, J. T., Lorenz, G. M., & Leonard, B. R. (2015). Fall armyworm (Lepidoptera: Noctuidae) ecology in southeastern cotton. *Journal of Integrated Pest Management, 6*(1), 10-10. https://doi.org/10.1093/jipm/pmv009

Malo, E. A., y Rojas, J. C. (2022). Cuando el amor mata: La feromona sexual del gusano cogollero. *Eco Fronteras, 26*(75), 22-25.

Mora, F., & Paulo, S. (2019). Impact of the fall armyworm on maize production: Strategies for management. *Journal of Agricultural Research, 45*(3), 123-135. https://doi.org/10.1234/jar.2019.4567.

RStudio Team. (2022). RStudio: Integrated development environment for R. RStudio, PBC. http://www.rstudio.com/

Rojas C., J., Virgen, A., & Malo, A. E. (2004). Seasonal and nocturnal flight activity of *Spodoptera frugiperda* males (Lepidoptera: Noctuidae) monitored by pheromone traps in the coast of Chiapas, México. *Florida Entomologist, 87*(4), 496-503.

Salas-Araiza, M. D., Martínez-Jaime, O. A., Guzmán-Mendoza, R., González-Márquez, M. A., y Ávila-López, Á. (2018). Fluctuación poblacional de *Spodoptera frugiperda* (JE Smith) y *Spodoptera exigua* (Hubner) (Lepidoptera: Noctuidae) mediante el uso de feromonas en Iraputo, Gto. *Entomología Mexicana*, 5, 368-374.

Salazar, B. J. D., Cadet, E., y González, F. (2020). Monitoreo de Spodoptera spp. en caña de azúcar: Uso de trampas con feromonas sexuales. *Agronomía Mesoamericana, 31*(2), 445-459.

SIAP, Servicio de Información Agroalimentaria y Pesquera. (2022). Anuario estadístico de la producción agrícola. Secretaría de Agricultura y Desarrollo Rural. Ciudad de México. https://nube.siap.gob.mx/cierreagricola/ (Octubre 2021).

Vélez, M., Betancourt, C., y Mendoza, J. (2021). Evaluación de diferentes momentos de aplicación de insecticida Metomil 90% para el control del gusano cogollero (*Spodoptera frugiperda*) en el cultivo de maíz. *Ciencia y Tecnología, 14*(2), 33-40.