Efficacy of Selected Insecticides in Combination with Economic Thresholds in Managing Fall Armyworm (Lepidoptera: Noctuidae) Larvae in Maize Grown in Mexico[1]

Manuel Alejandro Tejeda-Reyes[2], J. Concepción Rodríguez-Maciel[3], José Francisco Díaz-Nájera[4], Mateo Vargas-Hernández[5], Néstor Bautista-Martínez[3], Sergio Hernández-Hernández, Irvin Mauricio Mendoza-Espinoza, Tania Monserrat Ramírez-Fernández, Alejandro Guillermo Rojas-Rosales, Paola Vera-Barreto, and Guillermo Sainos-Guzmán

Departamento de Parasitología Agrícola, Universidad Autónoma Chapingo, Texcoco, Estado de México, México

J. Entomol. Sci. 58(2): 166–186 (April 2023)
DOI: 10.18474/JES22-31

Abstract In Mexico, conventional insecticides are the main tools used to manage the fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), in maize, *Zea mays* L. This scenario results in the need to continually assess the biological efficacy of insecticides used to combat this pest. In this study, we evaluated the efficacy of insecticides with different modes of action in diverse locations under different levels of *S. frugiperda* larval infestation. The insecticides evaluated decreased larval density per plant to levels below the recommended economic threshold (ET) of 2.0 larvae per 10 plants (0.2/plant), resulting in decreased levels of damage to the plant whorl. When applied at infestation levels below the ET, larval numbers remained below the ET for at least 7–14 d after application. In contrast, when applied with infestation levels above the recommended ET, the performance of some insecticides in terms of effectively reducing larval density decreased. We, however, found that Coragen® (chlorantraniliprole; FMC Agroquímica de México), Clavis® (thiodicarb + triflumuron; Bayer de México), and Pleo® 50 EC (pyridalyl; Valent de México) can be used under these conditions to provide adequate protection up to 21 d after application. The information obtained in our experiments confirms the need to adjust the current ET depending on the type of compound to be used, since the insecticides used performed more efficiently and for a long time at densities lower than 2.0 larvae per 10 plants.

Key Words invasive pest, pest management, chemical control, fall armyworm, economic threshold

Maize, *Zea mays* L., is the most extensively cultivated crop in Mexico. Yearly, more than 7 million ha are in maize production, representing about 30% of the total

[1]Received 05 July 2022; accepted for publication 05 September 2022.
[3]Posgrado en Fitosanidad-Entomología y Acarología, Colegio de Postgraduados Campus Montecillo, Montecillo, Texcoco, Estado de México, México.
[4]Departamento de Fitotecnia, Colegio Superior Agropecuario del Estado de Guerrero, Iguala, Guerrero, México.
[5]Departamento de Suelos, Universidad Autónoma Chapingo, Texcoco, Estado de México, México.
[2]Corresponding author (email: mtejedar@chapingo.mx, manuel.tejeda.r@gmail.com).

cultivated area in Mexico (SIAP 2022). The most important pest of this crop is the fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), which can cause yield losses $>$20% (Andrews 1980, Day et al. 2017, Sisay et al. 2019a). The fall armyworm is polyphagous, reportedly feeding on approximately 300 plant species; however, its greatest impact is on maize and sorghum (*Sorghum bicolor* (L.) Moench) (Andrews 1980, Montezano et al. 2018).

Management of the pest is a challenge for maize production in different regions of the world (Blanco et al. 2016, Day et al. 2017, Li et al. 2021). Combating this pest involves timely implementation of diverse and effective management strategies. The use of these strategies should be supported by objective evaluations of their ability to protect the crop to avoid unnecessary expenditures and prevent major economic losses resulting from pest infestations. The development of an effective strategy involves knowledge of the biological effectiveness of the available tools to enable use of only those that maintain pest density at a tolerable level. In Mexico, crop preemergence recommendations include impregnating the seed with insecticides before planting and the use of traps baited with sex pheromones to monitor population density days before crop emergence (CIMMYT 2016, PROVIVI FAW 2022, Syngenta México 2022). After crop emergence, sampling for larvae every 5–7 d is recommended to estimate *S. frugiperda* larval density. Insecticide application is recommended when the percentage of infestation is $\geq$20% of at least 100 randomly selected plants per hectare (Cortez-Mondaca and Rodríguez-Cota 2012, McGrath et al. 2021). Worldwide, the use of conventional insecticides is the main tactic used against this pest (Blanco et al. 2010, Gutiérrez-Moreno et al. 2019, Martinelli et al. 2006); however, development of resistance in fall armyworm populations is a major limitation (Gutiérrez-Moreno et al. 2019, León-García et al. 2012) and, thus, should be deployed judiciously.

It is necessary to monitor the biological effectiveness of insecticides used to combat this pest under different levels of infestation. This information can be used to promote the most efficacious products and practices to benefit maize growers. Therefore, the objective of this study was to evaluate in the field the biological efficacy of selected commercially available insecticides authorized for use in Mexico in the integrated pest management (IPM) of the fall armyworm under infestation levels above and below the recommended economic threshold (ET).

Materials and Methods

Insecticides. Eight commercially available insecticide formulations were evaluated (Table 1). These products were selected for their frequency of application by growers to control fall armyworm and also represented active ingredients with different modes of action recently approved for use in Mexico. Only two of those products were not authorized for use in maize: Apta® (tolfenpyrad; FMC Agroquímica de México, Jalisco, Mexico) and Xentari® (*Bacillus thuringiensis* Berliner subsp. *aizawai*; Valent de México, Jalisco, Mexico). The biological activity of the former on lepidopteran insects is unknown, whereas the latter is authorized for the control of lepidopterans in a number of vegetable crops in Mexico (Valent 2022).

Tests. Six experiments were conducted in 2021 and 2022 at different locations and with different conditions. Locations, GPS coordinates, plant growth stage, pest

Table 1. Insecticides evaluated against fall armyworm in 2021 and 2022 testing in Mexico.

Commercial Name	Active Ingredient	Concentration (g a.i.*)	Manufacturer	Concentration/ha
Coragen®	Chlorantraniliprole	200	FMC Agroquímica de México	100 ml
Denim® 19 CE	Emamectin benzoate	19.2	Syngenta Agro	150 ml
Exalt™	Spinetoram	60	CORTEVA	100 ml
Pleo® 50 EC	Pyridalyl	500	Valent de México	125 ml
Clavis®	Thiodiocarb + triflumuron	360 + 120	Bayer de México	350 ml
XenTari®	*Bacillus thuringiensis* subsp. *aizawai***	103	Valent de México	1.0 kg
Belt® 480 SC	Flubendiamide	480	Bayer de México	100 ml
Karate® Zeon 5 CS	Lambda cyhalothrin	50	Syngenta Agro	300 ml
Apta®	Tolfenpyrad**	159	FMC Agroquímica de México	1.5 L
Caronte®	Diflubenzuron	240	Helm de México	350 ml

* g a.i.: grams of active ingredient per liter or kilogram of formulated product.
** Not authorized for the control of fall armyworm in Mexico.

density, test initiation date, number of insecticide applications, and water volume applied for each test are listed in Table 2. Each test was established as a randomized complete block design with four replications per treatment (including a control with no insecticide applied). Plots were five rows wide planted on 0.8-m centers and 5 m long. Each row had a mean of 150 plants. The three center rows of each plot were used for sampling larval density and damage.

Insecticides were applied using a motorized Arimitsu® (SD-260D; Anoka, MN) sprayer equipped with a full-cone nozzle TG-2 at a pressure of 827 kg/cm^2 (120 psi). Spray was directed over the plant whorls at a distance of 25 cm. The nonionic adjuvant Inex®-A (Cosmocel S.A., División Agrícola, Nuevo Leon, México) was applied at 0.1% (v/v) with each treatment.

The number of fall armyworm larvae within each plot was determined before each insecticide application and at 7, 14, and 21 d after the last application (DAA). For each sample, 10 randomly selected plants were inspected for larvae. The number of live larvae per plant per plot was recorded. The last sample for each test (21 DAA) included determining the foliar damage severity rating for each plant sampled. This rating was based a modified scale originally proposed by Davis and Williams (1992) (Table 3). Protection of the three youngest leaves also was considered because of the fall armyworm habit of feeding on the heart of the plant, affecting the integrity of these young leaves. This served as indicator of the residual effect that treatments might have on larval populations.

Statistical analysis. Statistical analyses were conducted for each separate test because of the variation in the test conditions. For each test, the data were subjected to analysis of variance (PROC GLM; SAS Institute 2016). Where statistically significant ($P = 0.05$), treatment means were separated by Tukey's honestly significant differences (hsd) method. Prior to the analysis, the data were transformed to the function Log10($x + 1$), and the results were expressed in the original units. The data on foliar damage severity in the young leaves (categorical variable) were subjected to an analysis of variance and analyzed with the nonparametric Friedman test ($P = 0.05$). The average damage rating per treatment was used to classify the level of damage as high ($>$1.0), moderate (0.5–1.0), or low ($<$0.5).

Results

Test 1. Prior to application of insecticides, fall armyworm larval density was uniform and not statistically different among the treatment plots, and all met or exceeded the recommended ET of 2.0 larvae per 10 plants (Table 4). At 7 DAA, treatments with Coragen® (chlorantraniliprole; FMC Agroquímica de México), Exalt™ (spinetoram; CORTEVA, Jalisco, Mexico), Pleo® 50 EC (pyridalyl; Valent de México), and Clavis® (thiodiocarb + triflumuron; Bayer de México, Ciudad de Mexico, Mexico) had significantly lowered larval density by 79–90% below that of the untreated control (4.2 $\pm$ 0.9 per 10 plants). Larval density at 14 DAA remained significantly lower than the untreated control in treatments with Coragen, Exalt, Pleo, and Clavis. Treatment with Belt® 480 SC (flubendiamide; Bayer de México) and Karate® Zeon 5 CS (lambda cyhalothrin; Syngenta Agro, Ciudad de Mexico, Mexico) also significantly reduced larval density below that of the untreated control,

Table 2. Information on applications and sites of testing in 2021 and 2022 evaluations in maize.

Characteristic	Test Number					
	1	**2**	**3**	**4**	**5**	**6**
Nearest city	Yautepec, Morelos	Cocula, Guerrero	Yautepec, Morelos	Apipilulco, Guerrero	Yautepec, Morelos	Metztitlán, Hidalgo
GPS	N18°51′54.75″, W99°02′11.61″	N18°15′47.67″, W99°39′3.81″	N18°51′48.17″, W99°02′21.47″	N18°10′32.99″, W99°38′59.98″	N18°51′53.54″, W99°02′08.56″	N20°36′09.20″, W98°46′52.57″
Elevation asl* (m)	1,205	634	1,206	623	1,207	1,276
Plant stage**	V4–V5	V4–V5	V4–V5	V3–V4	V5–V6	V3–V4
Maize hybrid	A-7573	DK-357	A-7573	DK-357	A-7573	'Antilope'
Pest density† (per 10 plants)	2.9	1.4	2.4	1.9	3.3	0.7
Date initiated	20 Feb. 2021	14 May 2021	3 Mar. 2021	25 July 2021	4 Mar. 2022	12 Mar. 2022
Number of applications‡	1	1	2	2	2	2
Water volume (L/ha)	300	350	300	300	350	300

* asl = above sea level.
** Plant growth stage: V = vegetative growth; number = number of leaves.
† Recommended economic threshold = 2.0 larvae per 10 plants.
‡ Applications were spaced 7 d apart if more than one application was made.

Table 3. Visual rating scale of foliar damage caused by fall armyworm, as modified from Davis and Williams (1992).

Rating	Younger Leaf	Two Adjacent Leaves
0	No leaf damage	No leaf damage
1	No leaf damage	Pinholes, circular and elongated lesions of up 2.0 cm in length
2	No leaf damage	Circular and elongated lesions greater than 2.0 cm in length
3	With damage (pinholes, circular or elongated lesions, or totally destroyed)	Pinholes, circular and elongated lesions

but those larval densities exceeded the recommended ET. At 21 DAA, numbers of larvae were significantly lower than the untreated control (6.7 ± 1.4 per 10 plants) in treatments with Coragen, Denim® 19 CE (emamectin benzoate; Syngenta Agro), Exalt, Pleo, Clavis, and Belt. Numbers were below the ET only in treatments with Coragen and Clavis; however, those larval densities did not differ statistically from the other insecticide treatments. XenTari failed to significantly lower larval infestations over the 21-d sampling period (Table 4).

Table 4. Mean (± SEM) number of fall armyworm larvae per 10 whorl-stage maize plants at 0, 7, 14, and 21 d after a single application (DAA) of insecticide, Yautepec, Morelos, Mexico, in February–March 2021.*

Treatment	0 DAA	7 DAA	14 DAA	21 DAA
Control	2.9 ± 0.3 a	4.2 ± 0.9 a	5.7 ± 1.2 a	6.7 ± 1.4 a
Coragen®	3.0 ± 0.3 a	0.4 ± 0.4 b	1.4 ± 0.6 c	1.4 ± 0.6 b
Denim® 19 CE	2.0 ± 0.3 a	1.2 ± 0.6 ab	2.2 ± 0.6 c	2.5 ± 0.6 b
Exalt™	3.2 ± 0.8 a	0.9 ± 0.3 b	1.9 ± 0.5 c	2.7 ± 0.8 b
Pleo® 50 EC	3.2 ± 0.3 a	0.6 ± 0.7 b	1.6 ± 0.3 c	2.3 ± 0.5 b
Clavis®	3.5 ± 0.3 a	0.7 ± 0.3 b	1.4 ± 0.3 c	1.6 ± 0.5 b
XenTari®	2.4 ± 0.7 a	2.2 ± 0.3 ab	4.2 ± 0.5 ab	3.5 ± 0.3 ab
Belt® 480 SC	2.9 ± 0.5 a	1.2 ± 0.9 ab	2.5 ± 0.9 bc	2.1 ± 1.1 b
Karate® Zeon 5 CS	2.7 ± 0.4 a	1.8 ± 1.0 ab	2.5 ± 1.1 bc	3.7 ± 0.9 ab
Probability (*P*)	0.2706	0.0009	<0.0001	0.0002

* Treatment means within a column followed by the same lowercase letter are not significantly different ($P = 0.05$, Tukey's hsd test).

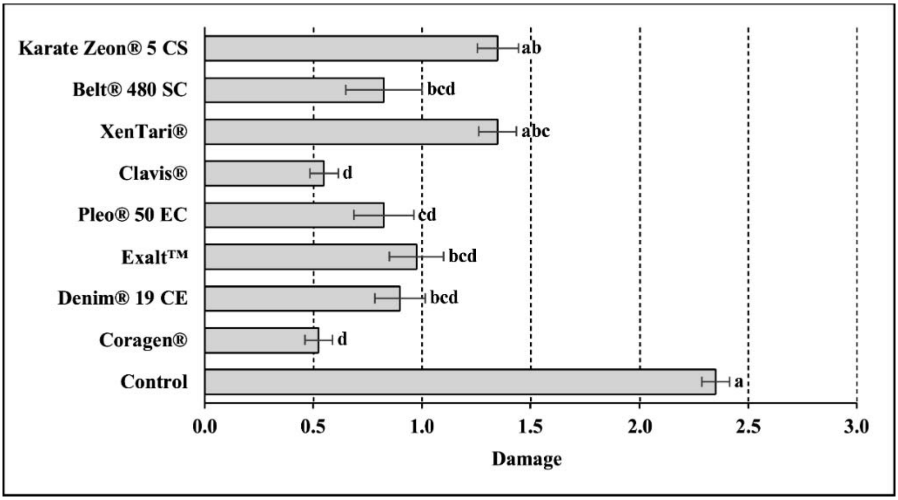

Fig. 1. Mean foliar damage, as indicated by a visual rating scale, in whorl-stage maize caused by fall armyworm 21 d after one application of insecticide (Yautepec, Morelos, Mexico, in February–March 2021). Bars with the same lowercase letter are not significantly different ($P =$ 0.05; Friedman's test).

Foliar damage, as indicated by the visual rating scale at 21 DAA, was greatest in the untreated control (Fig. 1). Damage caused by fall armyworms differed significantly ($F = 11.84$; df = 8, 35; $P = <0.0001$) among the treatments. Coragen and Clavis exhibited the lowest level of damage, but those two treatments did not differ statistically from Belt, Pleo, Exalt, and Denim in side-by-side comparisons.

Test 2. Prior to application of the treatments, mean larval density did not differ statistically among the plots with the control having 1.4 ± 0.3 larvae per 10 plants. At 7 DAA, larval density in the control (3.4 ± 0.5 larvae per 10 plants) was significantly higher than the larval densities in each of the eight insecticide treatments, which maintained larval density below the ET. At 14 DAA, XenTari was the only treatment with a level of infestation above the ET. By 21 DAA, the ET was exceeded in treatments with XenTari and Karate, which did not differ statistically from levels in the untreated control (Table 5). Foliar damage also was significantly higher ($F = 9.00$; df = 8, 35; $P = <0.0001$) in the untreated control and in treatments with XenTari and Karate Zeon 5 CS. The least damage was recorded with Coragen (Fig. 2).

Test 3. As in the previous two tests, larval infestation did not differ among the plots prior to application of the treatments. All the insecticide treatments maintained larval infestations below 1.7 larvae per 10 plants at 7 d after the first application (DA1A), while the untreated control had 4.7 ± 0.5 larvae per 10 plants. At 7 d after the second application (DA2A), larval infestations in all the insecticide treatments were at or below 1.4 larvae per 10 plants, whereas the untreated control had 6.2 ± 0.6 larvae per 10 plants. By 14 DA2A and 21 DA2A, the XenTari and Karate treatments had ≥2.5 larvae per 10 plants and ≥3.6 larvae per 10 plants (Table 6).

Table 5. Mean (± SEM) number of fall armyworm larvae per 10 whorl-stage maize plants at 0, 7, 14, and 21 d after a single application (DAA) of insecticide, Cocula, Guerrero, Mexico, in May–June 2021.*

Treatment	0 DAA	7 DAA	14 DAA	21 DAA
Control	1.4 ± 0.3 a	3.4 ± 0.5 a	5.2 ± 0.5 a	5.7 ± 0.5 a
Coragen®	1.7 ± 0.3 a	0.2 ± 0.2 b	0.4 ± 0.3 b	0.7 ± 0.3 d
Denim® 19 CE	1.0 ± 0.0 a	0.0 ± 0.0 b	0.9 ± 0.4 b	1.4 ± 0.3 bcd
Exalt™	1.7 ± 0.3 a	0.2 ± 0.2 b	1.2 ± 0.3 b	1.7 ± 0.3 bcd
Pleo® 50 EC	1.2 ± 0.3 a	0.2 ± 0.2 b	1.2 ± 0.3 b	1.6 ± 0.5 bcd
Clavis®	2.0 ± 0.0 a	0.0 ± 0.0 b	0.7 ± 0.3 b	1.0 ± 0.6 cd
XenTari®	1.2 ± 0.3 a	0.7 ± 0.3 b	2.1 ± 0.5 ab	3.4 ± 0.6 ab
Belt® 480 SC	1.2 ± 0.3 a	0.4 ± 0.3 b	0.6 ± 0.5 b	1.4 ± 0.3 bcd
Karate® Zeon 5 CS	1.0 ± 0.0 a	0.4 ± 0.3 b	1.9 ± 0.4 ab	2.9 ± 0.4 abc
Probability (*P*)	0.2840	<0.0001	0.0001	<0.0001

* Treatment means within a column followed by the same lowercase letter are not significantly different ($P = 0.05$, Tukey's hsd test).

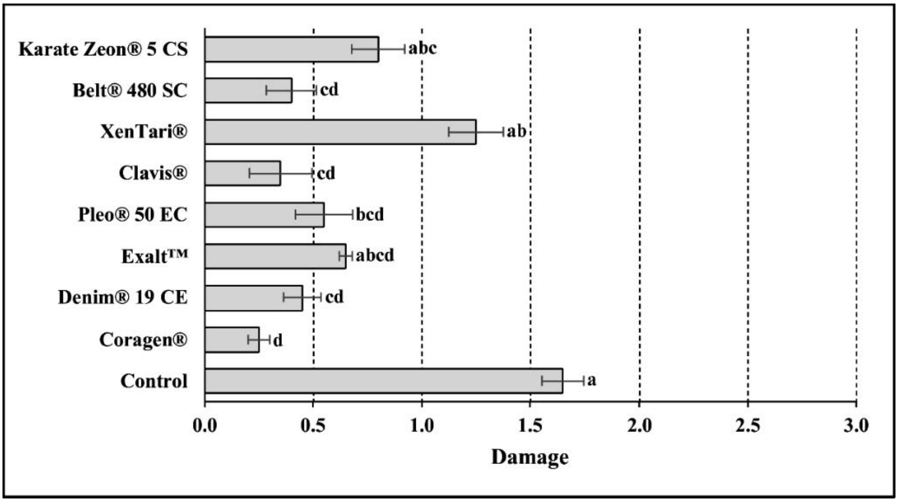

Fig. 2. Mean foliar damage, as indicated by a visual rating scale, in whorl-stage maize caused by fall armyworm 21 d after one application of insecticide (Cocula, Guerrero, Mexico, in May–June 2021). Bars with the same lowercase letter are not significantly different ($P = 0.05$; Friedman's test).

Table 6. Mean (± SEM) number of fall armyworm larvae per 10 whorl-stage maize plants at 7, 14, and 21 d after one (DA1A) and two (DA2A) applications of insecticide, Yautepec, Morelos, Mexico, in March 2021.*

Treatment	0 DAA**	7 DA1A	7 DA2A	14 DA2A	21 DA2A
Control	1.9 ± 0.4 a	4.7 ± 0.5 a	6.2 ± 0.6 a	7.7 ± 0.5 a	8.7 ± 0.4 a
Coragen®	2.7 ± 0.3 a	0.2 ± 0.2 b	0.2 ± 0.2 cd	0.2 ± 0.2 d	0.7 ± 0.3 d
Denim® 19 CE	2.1 ± 0.5 a	0.7 ± 0.3 b	0.4 ± 0.3 bcd	1.0 ± 0.0 cd	1.7 ± 0.5 cd
Exalt™	2.2 ± 0.3 a	0.9 ± 0.4 b	0.4 ± 0.3 bcd	0.7 ± 0.3 cd	1.9 ± 0.3 cd
Pleo® 50 EC	2.5 ± 0.3 a	0.6 ± 0.5 b	0.2 ± 0.2 cd	0.4 ± 0.3 d	1.0 ± 0.3 d
Clavis®	3.4 ± 0.5 a	0.2 ± 0.2 b	0.0 ± 0.0 d	0.4 ± 0.3 d	1.2 ± 0.5 d
XenTari®	2.4 ± 0.5 a	1.7 ± 0.3 ab	1.4 ± 0.3 b	3.2 ± 0.3 ab	5.2 ± 0.5 ab
Belt® 480 SC	2.5 ± 0.3 a	0.9 ± 0.4 b	0.4 ± 0.3 bcd	0.4 ± 0.3 d	1.1 ± 0.3 d
Karate® Zeon 5 CS	1.7 ± 0.3 a	1.4 ± 0.3 ab	1.2 ± 0.3 bc	2.5 ± 0.3 bc	3.6 ± 0.3 bc
Probability (P)	0.2481	0.0001	<0.0001	<0.0001	<0.0001

* Treatment means within a column followed by the same lowercase letter are not significantly different ($P = 0.05$, Tukey's hsd test).

** DAA = days after application of insecticide.

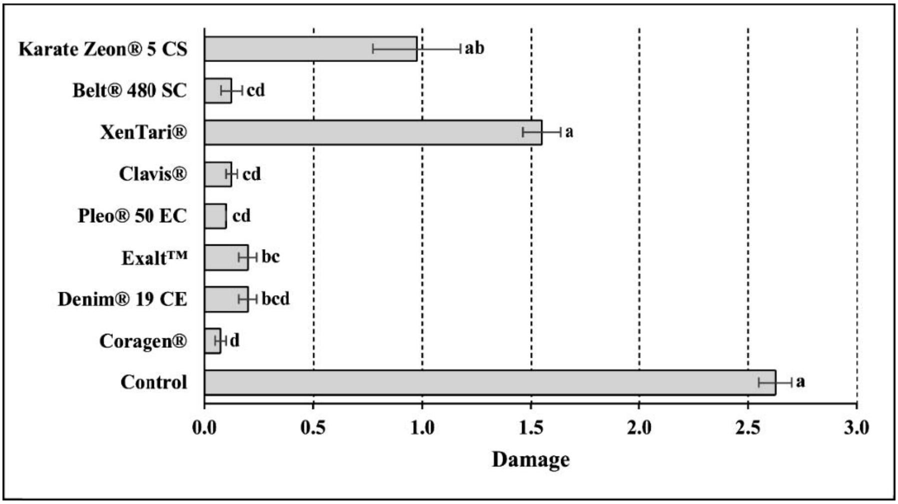

Fig. 3. Mean foliar damage, as indicated by a visual rating scale, in whorl-stage maize caused by fall armyworm 21 d after two applications of insecticide (Yautepec, Morelos, Mexico, in March 2021). Bars with the same lowercase letter are not significantly different (P = 0.05; Friedman's test).

Correspondingly, the XenTari and Karate treatments, along with the untreated control, had significantly greater ($F = 18.56$; df = 8, 35; $P = <0.0001$) foliar damage than the other six insecticide treatments (Fig. 3).

Test 4. An overall average of 1.9 larvae per 10 plants infested the plots of this test prior to the first application of the treatments. By 7 DA1A, the numbers of larvae in the untreated control reached 6.0 ± 0.4 larvae per 10 plants, while each of the insecticide treatments had ≤1.0 larvae per 10 plants. At 7 DA2A, all the insecticide treatments maintained the infestation level ≤0.9 larvae per 10 plants, while the untreated control reached 7.0 ± 0.4 larvae per 10 plants. At 14 and 21 DA2A, the XenTari and Karate treatments had infestation levels above ET but significantly lower than the untreated control (Table 7). Foliar damage was significantly greater ($F = 13.27$; df = 8, 35; $P = <0.0001$) in the untreated control and the XenTari and Karate treatments than the remaining six treatments (Fig. 4).

Test 5. The average level of infestation per plot before the first application of the treatments was 3.3 larvae per 10 plants. In all the evaluations, statistically significant differences ($P < 0.05$) were observed. At 7 DA1A and 7 DA2A, XenTari, Apta, and Karate were unable to reduce infestation levels below the recommended ET of 2.0 larvae per 10 plants. At 14 DA2A, larval numbers in the XenTari, Apta, Belt, and Karate treatments exceeded the recommended ET. By 21 DA2A, only Coragen, Denim, Pleo, and Clavis maintained infestations of <2.0 larvae per 10 plants (Table 8). The greatest level of foliar damage was observed in the Apta, XenTari, and the control treatments (Fig. 5).

Test 6. Before the first application, the overall average infestation was 0.70 larvae per 10 plants. After the first application, statistically significant differences were found

Table 7. Mean (± SEM) number of fall armyworm larvae per 10 whorl-stage maize plants at 7, 14, and 21 d after one (DA1A) and two (DA2A) applications of insecticide, Cocula, Guerrero, Mexico, in July–August 2021.*

Treatment	0 DAA**	7 DA1A	7 DA2A	14 DA2A	21 DA2A
Control	1.7 ± 0.3 a	6.0 ± 0.4 a	7.0 ± 0.4 a	8.2 ± 0.3 a	9.2 ± 0.3 a
Coragen®	1.9 ± 0.4 a	0.4 ± 0.3 b	0.2 ± 0.2 b	0.0 ± 0.0 d	0.2 ± 0.2 d
Denim® 19 CE	1.6 ± 0.5 a	1.0 ± 0.0 b	0.4 ± 0.3 b	0.4 ± 0.3 d	1.2 ± 0.3 bcd
Exalt™	1.8 ± 0.6 a	0.9 ± 0.4 b	0.4 ± 0.3 b	0.7 ± 0.3 cd	0.9 ± 0.4 cd
Pleo® 50 EC	2.1 ± 0.5 a	0.4 ± 0.3 b	0.2 ± 0.2 b	0.2 ± 0.2 d	0.7 ± 0.3 d
Clavis®	1.4 ± 0.6 a	0.4 ± 0.3 b	0.0 ± 0.0 b	0.0 ± 0.0 d	0.4 ± 0.3 d
XenTari®	2.1 ± 0.5 a	0.9 ± 0.4 b	0.9 ± 0.4 b	2.5 ± 0.3 b	3.5 ± 0.3 b
Belt® 480 SC	1.9 ± 0.4 a	0.6 ± 0.5 b	0.4 ± 0.3 b	0.4 ± 0.3 d	0.7 ± 0.3 d
Karate® Zeon 5 CS	1.4 ± 0.3 a	0.9 ± 0.4 b	0.7 ± 0.3 b	2.2 ± 0.3 bc	2.9 ± 0.4 bc
Probability (*P*)	0.9606	<0.0001	<0.0001	<0.0001	<0.0001

* Treatment means within a column followed by the same lowercase letter are not significantly different ($P = 0.05$, Tukey's hsd test).
** DAA = days after application of insecticide.

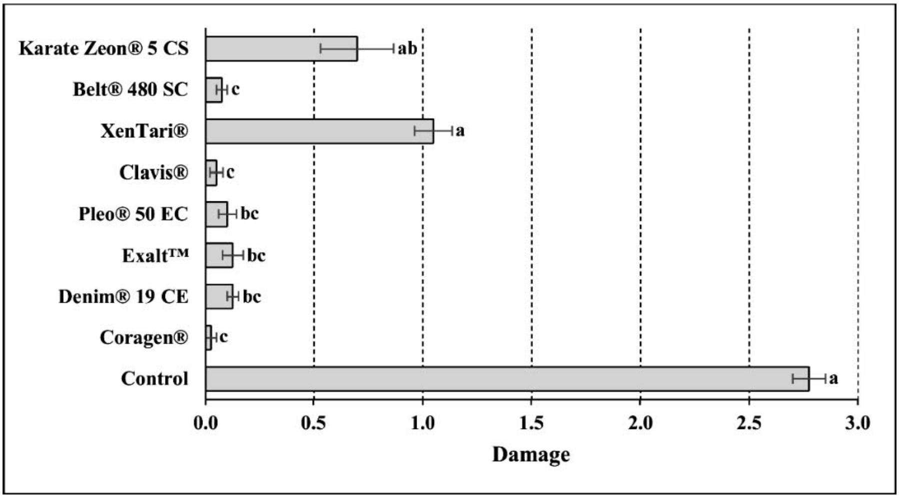

Fig. 4. Mean foliar damage, as indicated by a visual rating scale, in whorl-stage maize caused by fall armyworm 21 d after two applications of insecticide (Cocula, Guerrero, Mexico, in July–August 2021). Bars with the same lowercase letter are not significantly different ($P = 0.05$; Friedman's test).

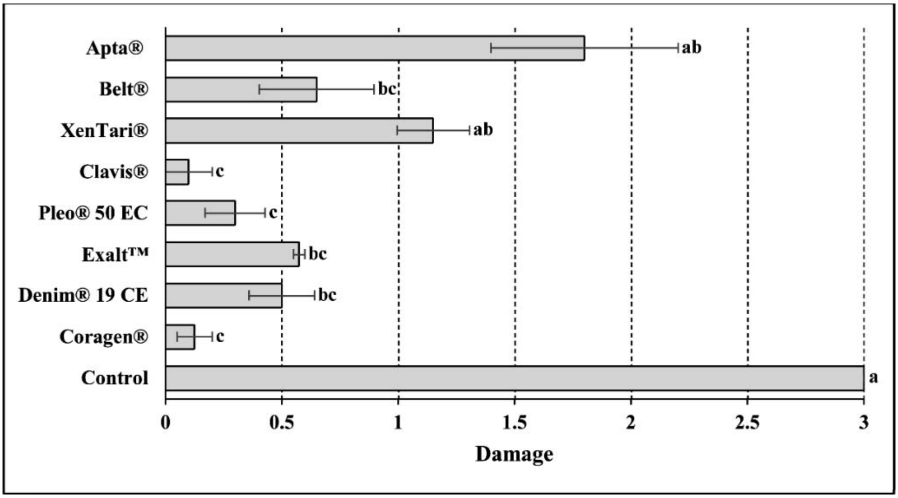

Fig. 5. Mean foliar damage, as indicated by a visual rating scale, in whorl-stage maize caused by fall armyworm 21 d after two applications of insecticide (Yautepec, Morelos, Mexico, in March–April 2022). Bars with the same lowercase letter are not significantly different ($P = 0.05$; Friedman's test).

Table 8. Mean (± SEM) number of fall armyworm larvae per 10 whorl-stage maize plants at 7, 14, and 21 d after one (DA1A) and two applications (DA2A) of insecticide, Yautepec, Morelos, Mexico, in March–April 2022.*

Treatment	0 DAA**	7 DA1A	7 DA2A	14 DA2A	21 DA2A
Control	3.5 ± 0.3 a	5.4 ± 0.6 a	8.2 ± 0.5 a	8.2 ± 0.3 a	9.5 ± 0.3 a
Coragen®	2.9 ± 0.4 a	1.2 ± 0.3 bc	0.5 ± 0.5 b	0.6 ± 0.5 c	0.4 ± 0.3 c
Denim® 19 CE	3.2 ± 0.3 a	0.2 ± 0.2 c	0.4 ± 0.4 b	0.8 ± 0.8 c	2.9 ± 1.0 abc
Exalt™	2.7 ± 0.3 a	0.6 ± 0.5 bc	0.3 ± 0.3 b	1.4 ± 0.3 bc	3.4 ± 0.5 ab
Pleo® 50 EC	2.7 ± 0.5 a	0.7 ± 0.3 bc	0.6 ± 0.5 b	0.3 ± 0.3 c	1.5 ± 0.9 c
Clavis®	3.2 ± 0.5 a	0.0 ± 0.0 c	0.8 ± 0.8 b	1.0 ± 0.0 c	0.3 ± 0.3 c
XenTari®	3.7 ± 0.5 a	2.4 ± 0.5 ab	2.5 ± 1.4 ab	5.6 ± 1.4 ab	6.9 ± 0.8 a
Belt® 480 SC	3.2 ± 0.3 a	0.9 ± 0.4 bc	0.6 ± 0.5 b	2.6 ± 0.6 abc	3.4 ± 0.9 ab
Karate® Zeon 5 CS	3.7 ± 0.3 a	2.1 ± 0.5 ab	6.6 ± 0.9 a	6.8 ± 0.9 a	6.7 ± 1.5 a
Probability (*P*)	0.4440	<0.0001	0.0001	<0.0001	<0.0001

* Treatment means within a column followed by the same lowercase letter are not significantly different ($P = 0.05$, Tukey's hsd test).
** DAA = days after application of insecticide.

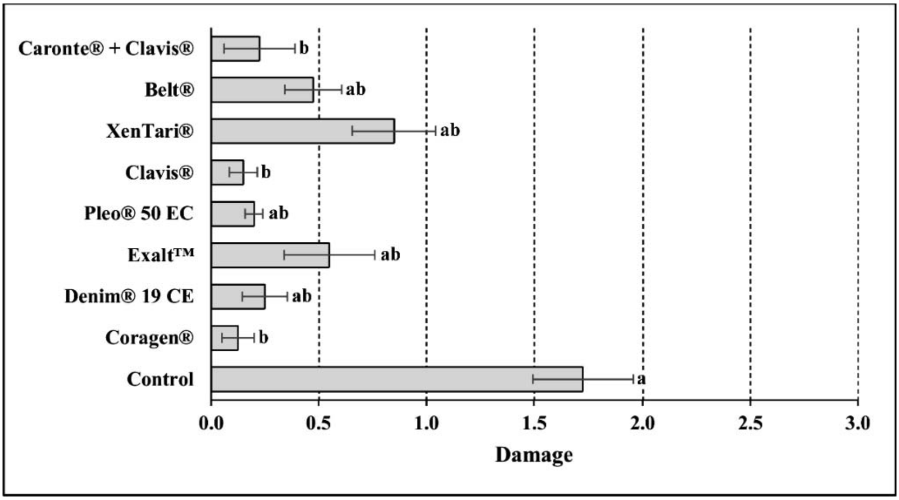

Fig. 6. Mean foliar damage, as indicated by a visual rating scale, in whorl-stage maize caused by fall armyworm 21 d after two applications of insecticide (Metztitlán, Hidalgo, Mexico, in March–April 2022). Bars with the same lowercase letter are not significantly different (*P* = 0.05; Friedman's test).

among the treatments ($P = 0.05$). Up to 14 DA2A, the insecticide treatments exhibited an infestation level of ≤1.20 larvae per 10 plants. At 21 DA2A, the treatments with Exalt, Belt, and XenTari resulted in infestation levels of >2.0 larvae per 10 plants (Table 9). Treatments with Coragen, Clavis, and Caronte® (Helm de Mexico S. A., Estado de Mexico, Mexico) + Clavis exhibited significantly less ($F = 3.98$; df = 8, 35; $P = 0.0004$) foliar damage than the untreated control (Fig. 6).

Discussion

IPM in agriculture, within an economic and social scenario, involves the use of different tactics that are aimed at reducing losses caused by pests (Ahissou et al. 2021). Of these tactics, insecticides have an important role in reaching this goal (Oerke 2006). However, the constant use of the same type of insecticides can lead to significant decreases in target pest susceptibility (Georghiou 1994). To prevent or mitigate this problem, information should be continually generated on the response of insect pests to insecticides, with the objective of providing growers with effective management options.

Except for the insecticide Apta used in one test, all the active ingredients applied in the different tests maintained fall armyworm infestations below the recommended ET of 2.0 larvae per 10 plants for at least 7 d after application. This efficacy was reflected in the decrease in foliar damage caused by the pest. The diverse scenarios in which the experiments were conducted confirm that the moment of insecticide application is an important factor in managing fall armyworm. Our results indicate that at low levels of infestation, the performance of the insecticides

Table 9. Mean (± SEM) number of fall armyworm larvae per 10 whorl-stage maize plants at 7, 14, and 21 d after one (DA1A) and two (DA2A) applications of insecticide, Metztitlán, Hidalgo, Mexico, in March–April 2022.

Treatment	0 DAA**	7 DA1A	7 DA2A	14 DA2A	21 DA2A
Control	1.2 ± 0.6 a	2.1 ± 0.5 a	2.3 ± 1.1 a	3.9 ± 0.6 a	6.9 ± 0.7 a
Coragen®	1.0 ± 1.0 a	0.4 ± 0.3 b	0.2 ± 0.2 b	0.2 ± 0.3 b	0.4 ± 0.3 a
Denim® 19 CE	0.4 ± 0.3 a	0.2 ± 0.2 b	0.0 ± 0.0 b	0.2 ± 0.3 b	0.9 ± 0.4 a
Exalt™	0.3 ± 0.3 a	0.2 ± 0.2 b	0.2 ± 0.2 b	1.2 ± 0.6 ab	2.3 ± 1.0 a
Pleo® 50 EC	0.2 ± 0.2 a	0.0 ± 0.0 b	0.3 ± 0.3 ab	1.1 ± 0.5 ab	1.7 ± 0.3 a
Clavis®	0.4 ± 0.3 a	0.0 ± 0.0 b	0.0 ± 0.0 b	0.0 ± 0.0 b	0.7 ± 0.3 a
XenTari®	0.7 ± 0.7 a	0.6 ± 0.5 ab	0.3 ± 0.3 ab	1.0 ± 1.0 ab	3.3 ± 0.9 a
Belt® 480 SC	0.3 ± 0.3 a	0.0 ± 0.0 b	0.4 ± 0.3 ab	0.5 ± 0.5 b	2.6 ± 0.6 a
Caronte® + Clavis®	0.4 ± 0.4 a	0.6 ± 0.5 ab	0.0 ± 0.0 b	0.0 ± 0.0 b	0.9 ± 0.8 a
Probability (*P*)	0.7510	0.0004	0.0154	0.0023	0.0012

* Treatment means within a column followed by the same lowercase letter are not significantly different ($P = 0.05$, Tukey's hsd test).

** DAA = days after application of insecticide.

increased (Tables 5, 7, 9) relative to applications with infestation levels of $\geq$2.0 larvae per 10 plants (Tables 4, 8).

The success in executing a management tactic depends considerably on its timely application. Therefore, it is an important factor in integrated management of diverse agricultural pests (Myers et al. 2005, Viteri and Linares-Ramírez 2022, Viteri et al. 2019). Our results indicate that it is important to apply an insecticide before fall armyworm reaches an infestation level of 2.0 larvae per 10 plants. If a measure is not executed in a timely manner, alternatives diminish in terms of the number of insecticides capable of adequately reducing fall armyworm densities to levels that will not result in significant yield reduction. The lack of attention to the relationship between fall armyworm density and the possibility of satisfactory management of the pest using authorized insecticides may lead the grower to use additional insecticides. This could have economic consequences and risks for the environment as well as for human health.

In Mexico, growers base their management of the fall armyworm on insecticides (Gutiérrez-Moreno et al. 2019). The use of emamectin benzoate, chlorantraniliprole, and spinetoram perform well and are frequently used. These products are applied at least twice in early stages of the crop, with the goal of decreasing the infestation levels, and once after spiking. However, there are other little publicized management options that can provide alternatives in efficient management of fall armyworm. Moreover, they can be important components in programs of insecticide resistance management used in the control of this lepidopteran pest.

Chlorantraniliprole (Coragen) is an active ingredient of frequent use in the main maize-growing regions of Mexico. We evaluated it in all the tests, and plots treated with it showed low levels of infestation and damage in young leaves. It is a product that activates the ryanodine receptors, permitting the unregulated release of calcium. Consequently, the muscle fibers contract, producing rigid muscular paralysis, decreased feeding, and death of the insect (Cordova et al. 2006). This compound is registered for the control of diverse species of lepidopterans worldwide. Our results show its potential for controlling *S. frugiperda*. One application of this product, regardless of the level of fall armyworm infestation, provided protection for at least 21 d after application. Similar results have been obtained in other studies (Deshmukh et al. 2020, Sisay et al. 2019b). However, this level of performance may also be its principal downfall since inadequate use by growers can lead to repeated use of this active ingredient, creating an ideal scenario for developing resistance in fall armyworm populations. Therefore, we should complement it with other management alternatives to delay the onset of this scenario.

The commercial product Denim contains emamectin benzoate, which acts on the insect nervous system, allosterically modulating the chlorine channels that depend on glutamate (IRAC 2022). In Mexico, it is frequently used to combat the fall armyworm. This insecticide exhibited efficient control when applied on infestations of 2.0 larvae per 10 plants (Tables 5, 7, 9) and provides a period of protection of up to 21 d after application. However, in experiments conducted with high initial infestation, this period decreased to 14 d after one or two applications (Tables 4, 8). Therefore, we can infer that the best time to use this product should be before the level of infestation reaches the recommended threshold for insecticide application.

Similar results have been reported in other field experiments (Deshmukh et al. 2020, Sisay et al. 2019b, Viteri and Linares-Ramírez 2022).

Spinetoram is an active ingredient that acts on the insect nervous system, allosterically modulating the nicotinic receptor of acetylcholine (IRAC 2022). In Mexico, it is sold under the commercial brands Exalt and Palgus®. This insecticide performed similar to that of emamectin benzoate. When it is applied at low infestations (Tables 5, 7, 9), it provides protection for 21 d. But, if it is applied with infestations of approximately 3.0 larvae per 10 plants, this period decreases to 14 d. Therefore, application is timely when there is an average of 2.0 larvae per 10 plants. Similar findings have been reported by Sisay et al. (2019b), Deshmukh et al. (2020), and Nonci et al. (2021).

In 2018, Valent de México launched the product Pleo 50 EC, which contains the active ingredient pyridalyl, on the Mexican market. The mode of action of this product is unknown (IRAC 2022), but it is registered for use against fall armyworm and has shown acceptable biological efficacy in the control of lepidopteran larvae, such as the diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), and the beet armyworm, *Spodoptera exigua* (Hübner) (Lepidoptera: Noctuidae) (Chakraborty and Somchoudhury 2011, Palumbo 2005), in economically important crops. This active ingredient showed protection for 21 d regardless of the initial infestation level, making it an additional option for fall armyworm management in maize.

Recently, in 2020, Bayer de México placed the commercial product Clavis on the Mexican market. This product contains a mixture of the insecticides thiodicarb (a carbamate insecticide that acts on the insect nervous system, inhibiting the enzyme acetylcholinesterase) and triflumuron (a compound that belongs to the group of benzoylureas and inhibits biosynthesis of chitin) for the control of the fall armyworm in maize and sorghum (BAYER 2022, IRAC 2022). This product performs notably well in the control of fall armyworm. Regardless of the initial level of infestation, its application resulted in levels of infestation below 1.6 larvae per 10 plants throughout all the evaluations. These results place it, like chlorantraniliprole, among the most effective treatments for fall armyworm control in maize. Moreover, plots treated with these insecticides consistently showed a lower level of damage to maize foliage (Figs. 1–6). For this reason, it is a promising tool for *S. frugiperda* management and is a good candidate for inclusion in fall armyworm resistance management programs.

The growing need to use management tactics with an environmentally friendly approach leads to integrating into pest control low-impact products such as XenTari formulated with *B. thuringiensis* subsp. *aizawai*, which has shown activity against fall armyworm in the laboratory and the field (dos Santos et al. 2009, Lara-Becerra et al. 2021). However, we found valuable results related to the timely application of this insecticide that acts on the lepidopteran digestive system (IRAC 2022). One application of XenTari at an initial level of 3.7 larvae per 10 plants did not decrease the fall armyworm infestation level 7 d after application (Table 8). This is attributed to larva excreta, which obstructs insecticide access to fall armyworm feeding sites. Consequently, the larvae of this species consume a sublethal amount of the applied product when they feed. When it was applied in conditions of low infestation (Tables 5, 7, 9), we observed improved performance, with protection lasting between 7 and 14 d. This level of protection is valuable, despite the inferior results, relative to those obtained with application of conventional insecticides. Another possible explanation of the low effectivity of this product is that the young leaves are exposed to high incidence of solar radiation, adversely affecting the viability of this product (Cohen et al. 1991, Leong et al. 1980). The active growth of the plant may also have an influence in the low efficacy since the contact nature of this product entails leaving the new plant tissue of the shoot unprotected and product residue is reduced. Therefore, its use should be restricted to when infestation levels are low.

Flubendiamide is a diamide available in the market for fall armyworm management under the commercial name Belt. This product provided protection up to 14 d after application. However, we observed that its use in infestation levels $>$2.0 larvae per 10 plants (Tables 4, 8) may lack biological efficacy.

Traditionally, management of the fall armyworm in Mexico concentrated on the use of organophosphates and pyrethroids, especially chlorpyrifos and lambda cyhalothrin, respectively. Lambda cyhalothrin is sold in Mexico under the name Karate. This product maintained acceptable control up to 14 d when it was used with low infestations (Table 5). However, when it was applied at infestations higher than the recommended threshold, its period of protection decreased to 7 d (Table 4). This also was reflected in the level of damage to the plant. It is likely that performance of this type of compound is affected by solar radiation in the field (Fernandez-Alvarez et al. 2007). Despite this, considering its limitations, its integration into fall armyworm resistance management should be considered. However, we should take precautions with this type of compound because of the demonstrated biological activity it can have against nontarget organisms, such as predators and parasitoids (Tillman and Mulrooney 2000).

The insecticide tolfenpyrad (Apta) acts as an inhibitor of electron transport in the mitochondrial complex I (IRAC 2022). At present, it is not registered for use in maize for fall armyworm control in Mexico, but it is recommended for control of sucking insects in potato (*Solanum tuberosum* L.), chili (*Capsicum annuum* L.), and tomato (*Solanum lycopersicum* L.) (FMC 2022). This active ingredient did not exhibit biological activity against fall armyworm, with infestation levels similar to those of the control. Therefore, its use is not recommended for management of fall armyworm.

At the Metztitlán site, we conducted an initial application of Caronte and, 7 d later, an application of Clavis. This sequence maintained the infestation level at $<$0.9 larvae per 10 plants 21 d after the last application. These results point to the advisability of field evaluations of rotation of commercial products that can provide effective control of fall armyworm. Unlike the traditional evaluation of insecticides, investigation of the potential of rotational use of products with different modes of action can provide valuable information for their rational use.

Knowledge of the effectiveness of insecticides with different modes of action and of the timeliness of their application will permit effective decision-making relative to fall armyworm density to enable integration of different compatible options. The rational use of insecticides is only one component of *S. frugiperda* management, and their adequate integration into a system of management is fundamental in decreasing the impact of this pest.

In summary, timely application of the evaluated insecticides in these tests is when fall armyworm density is $\leq$2.0 larvae per 10 plants. The different tests conducted showed that the insecticides Coragen, Clavis, and Pleo provide longer periods of protection, reducing the level of infestation and damage by fall armyworm larvae. Moreover, we believe that Denim, Exalt, and Belt when applied in conditions of low infestation, have high potential for management of *S. frugiperda*, broadening the spectrum of available tools for use with the aim of diminishing the development of resistance. The insecticides XenTari and Karate can also be valuable tools in fall armyworm management, although they have limitations that should be considered before integrating them into programs of management for this insect. More research is needed on the effectiveness of other available insecticides, their rotation, and mixtures, as well as their inclusion in an integral management approach with the aim of preventing or delaying the development of resistance to the tools most used in the combat of *S. frugiperda*.

Acknowledgment

Sergio Hernández-Hernández, Irvin Mauricio Mendoza-Espinoza, Tania Monserrat Ramírez-Fernández, Alejandro Guillermo Rojas-Rosales, Paola Vera-Barreto, and Guillermo Sainos-Guzmán thank the Universidad Autónoma Chapingo for financing their bachelor studies.

References Cited

Ahissou, B.R., W.M. Sawadogo, A. Bokonon-Ganta, I. Somda and F. Verheggen. 2021. Integrated pest management options for the fall armyworm *Spodoptera frugiperda* in West Africa: Challenges and opportunities. A review. Biotechnol. Agron. Soc. Environ. 25: 192–207.

Andrews, K.L. 1980. The whorlworm, *Spodoptera frugiperda*. Central America and neighboring areas. Fla. Entomol. 64: 456–467.

BAYER (Bayer de México S.A. de C.V.). 2022. Clavis. 1 May 2022. (https://www.micultivo.bayer.com.mx/#/Producto/Clavis).

Blanco, C.A., W. Chiaravalle, M. Dalla-Rizza, J.R. Farias, M.F. García-Degano, G. Gastaminza, D. Mota-Sánchez, M.G. Murúa, C. Omoto, B.K. Pieralisi, J. Rodríguez, J.C. Rodríguez-Maciel, H. Terán-Santofimio, A.P. Terán-Vargas, S.J. Valencia and E. Willink. 2016. Current situation of pest targeted by Bt crops in Latin America. Curr. Opin. Insect Sci. 15: 131–138.

Blanco, C.A., M. Portilla, J.L. Jurat-Fuentes, J.F. Sánchez, D. Viteri, P. Vega-Aquino, A.P. Terán-Vargas, A. Azuara-Domínguez, J.D. López, R. Arias, Y.C. Zhu, D. Lugo-Barrera and R. Jackson. 2010. Susceptibility of isofamilies of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) to Cry1Ac and Cry1Fa proteins of *Bacillus thuringiensis*. Southwest. Entomol. 35: 409–415.

Chakraborty, G. and A.K. Somchoudhury. 2011. Effect of pyridalyl against *Plutella xylostella* (L.) on cabbage and natural enemies. J. Crop Weed 7: 142–145.

CIMMYT (Centro Internacional de Mejoramiento de Maíz y Trigo). 2016. Manejo agroecológico de gusano cogollero: Feromonas. 1 April 2022. (https://repository.cimmyt.org/bitstream/handle/10883/18261/58527.pdf?sequence=1&isAllowed=y).

Cohen, E., H. Rozen, T. Joseph, S. Braun and L. Margulies. 1991. Photoprotection of *Bacillus thuringiensis kurstaki* from ultraviolet irradiation. J. Invertebr. Pathol. 57: 343–351.

Cordova, D., E.A. Benner, M.D. Sacher, J.J. Rauh, J.S. Sopa, G.P. Lahm, T.P. Selby, T.M. Stevenson, L. Flexner, S. Gutteridge, D.F. Rhoades, L. Wu, R.M. Smith and Y. Tao. 2006. Anthranilic diamides: A new class of insecticides with a novel mode of action, ryanodine receptor activation. Pestic. Biochem. Physiol. 84: 196–214.

Cortez-Mondaca, E. and F.G. Rodríguez-Cota. 2012. Manejo Integrado de Gusano Cogollero Basado en el Aprovechamiento de Enemigos Naturales en Maíz, en Sinaloa, México. Folleto Técnico No. 36, Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, Juan José Ríos, Sinaloa, México.

Davis, F.M. and W.P. Williams. 1992. Visual rating scales for screening whorl-stage corn for resistance to fall armyworm. Mississippi Agric. For. Res. Exp. Sta. Tech. Bull. 186, Mississippi State, MS, USA.

Day, R., P. Abrahams, M. Bateman, T. Beale, V. Clottey, M. Cock, Y. Colmenarez, N. Corniani, R. Early, J. Godwin, J. Gomez, P. Gonzalez-Moreno, S.T. Murphy, B. Oppong-Mensah, P. Noah, C. Pratt, S. Silvestri and A. Witt. 2017. Fall armyworm: Impacts and implications for Africa. Outlooks Pest Manag. 28: 196–201.

Deshmukh, S., H.B. Pavithra, C.M. Kalleshwaraswamy, B.K. Shivanna, M.S. Maruthi and D. Mota-Sanchez. 2020. Field efficacy of insecticides for management of invasive fall armyworm, *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) on maize in India. Fla. Entomol. 103: 221–227.

dos Santos, K.B., P. Neves, A.M. Meneguim, R.B. dos Santos, W.J. dos Santos, G.V. Boas, V. Dumas, E. Martins, L.B. Praca, P. Queiroz, C. Berry and R. Monnerat. 2009. Selection and characterization of the *Bacillus thuringiensis* strains toxic to *Spodoptera eridania* (Cramer), *Spodoptera cosmioides* (Walker) and *Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae). Biol. Control 50: 157–163.

Fernandez-Alvarez, M., M. Lores, M. Llompart, C. Garcia-Jares and R. Cela. 2007. The photochemical behaviour of five household pyrethroid insecticides and a synergist as studied by photo-solid-phase microextraction. Anal. Bioanal. Chem. 388: 1235–1247.

FMC (FMC Agroquímica de México, S. de R.L. de C.V.). 2022. Apta. 1 May 2022. (https://www.fmcagroquimica.com.mx/producto/apta/).

Georghiou, G.P. 1994. Principles of insecticide resistance management. Phytoprotection 75: 51–59.

Gutiérrez-Moreno, R., D. Mota-Sanchez, C.A. Blanco, M.E. Whalon, H. Terán-Santofimio, J.C. Rodríguez-Maciel and C. DiFonzo. 2019. Field-evolved resistance of the fall armyworm (Lepidoptera: Noctuidae) to synthetic insecticides in Puerto Rico and Mexico. J. Econ. Entomol. 112: 792–802.

IRAC (Insecticide Resistance Action Committee). 2022. IRAC Mode of Action Classification Scheme v.10.2. 1 June 2022. (https://irac-online.org/mode-of-action/).

Lara-Becerra, M.C., M.A. Tejeda-Reyes, Á. Lagunes-Tejeda, G. Silva-Aguayo and J.C. Rodríguez-Maciel. 2021. Concentration–mortality response of Mexican populations fall armyworm (Lepidoptera: Noctuidae) to commercial formulations of *Bacillus thuringiensis*. J. Entomol. Sci. 56: 70–83.

León-García, I., E. Rodríguez-Leyva, L.D. Ortega-Arenas and J.F. Solís-Aguilar. 2012. Susceptibilidad de *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) a insecticidas asociada a césped en Quintana Roo, México. Agrociencia 46: 279–287.

Leong, K.L.H., R.J. Cano and A.M. Kubinski. 1980. Factors affecting *Bacillus thuringiensis* total field persistence. Environ. Entomol 9: 593–599.

Li, Y., Z. Wang and J. Romeis. 2021. Managing the invasive fall armyworm through biotech crops: A Chinese perspective. Trends Biotechnol. 39: 105–107.

Martinelli, S., R.M. Barata, M.I. Zucchi, M.C. Silva-Filho and C. Omoto. 2006. Molecular variability of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) populations associated to maize and cotton crops in Brazil. J. Econ. Entomol. 99: 519–526.

McGrath, D.M., J.E. Huesing, P.C. Jepson, V.M. Peschke, B.M. Prasanna and T.J. Krupnik. 2021. Fall armyworm scouting, action thresholds, and monitoring, Pp. 21–35. *In* Prasanna, B.M., J.E. Huesing, V.M. Peschke, and R. Eddy (eds.), Fall Armyworm in Asia: A Guide for Integrated Pest Management. CIMMYT, Ciudad de México, México.

Montezano, D.G., A. Specht, D.R. Sosa-Gómez, V.F. Roque-Specht, J.C. Sousa-Silva, S.V. Paula-Moraes, J.A. Peterson and T.E. Hunt. 2018. Host plants of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in the Americas. Afr. Entomol. 26: 286–300.

Myers, S.W., D.B. Hogg and J.L. Wedberg. 2005. Determining the optimal timing of foliar insecticide applications for control of soybean aphid (Hemiptera: Aphididae) on soybean. J. Econ. Entomol. 98: 2006–2012.

Nonci, N., S. Pakki and A. Muis. 2021. Field testing of synthetic insecticides on fall armyworm (*Spodoptera frugiperda* JE Smith) in corn plant. IOP Conf. Ser.: Earth Environ. Sci. 911: 012059.

Oerke, E.C. 2006. Crop losses to pests. J. Agric. Sci. 144: 31–43.

Palumbo, J.C. 2005. Evaluation of pyridalyl for control of lepidopterous larvae on fall lettuce. Arthropod Manag. Tests 30: E40.

PROVIVI FAW. 2022. La Ciencia: Que son las fermonas? 1 April 2022. (https://www.provivi.com/mx/portafolio/gusano-cogollero).

SAS Institute. 2016. SAS User's Manual 9.4. SAS Institute Inc., Cary, NC.

SIAP (Servicio de Información Agroalimentaria y Pesquera). 2022. Anuario Estadístico de la Producción Agrícola 1 April 2022. (https://nube.siap.gob.mx/cierreagricola/).

Sisay, B., J. Simiyu, E. Mendesil, P. Likhayo, G. Ayalew, S. Mohamed, S. Subramanian and T. Tefera. 2019a. Fall armyworm, *Spodoptera frugiperda* infestations in East Africa: Assessment of damage and parasitism. Insects 10: 195.

Sisay, B., T. Tefera, M. Wakgari, G. Ayalew and E. Mendesil. 2019b. The efficacy of selected synthetic insecticides and botanicals against fall armyworm, *Spodoptera frugiperda*, in maize. Insects 10: 45.

Syngenta México. 2022. Fortenza 600 FS. 1 April 2022. (https://www.syngenta.com.mx/product/crop-protection/fortenza-600-fs).

Tillman, P.G. and J.E. Mulrooney. 2000. Effect of selected insecticides on the natural enemies *Coleomegilla maculata* and *Hippodamia convergens* (Coleoptera: Coccinellidae), *Geocoris punctipes* (Hemiptera: Lygaeidae), and *Bracon mellitor*, *Cardiochiles nigriceps*, and *Cotesia marginiventris* (Hymenoptera: Braconidae) in cotton. J. Econ. Entomol. 93: 1638–1643.

Valent (Valent de México S.A. de C.V.). 2022. Insecticidas. 1 April 2022. (https://www.valent.mx/productos_insecticidas.php).

Viteri, D.M. and A.M. Linares-Ramírez. 2022. Timely application of four insecticides to control corn earworm and fall armyworm larvae in sweet corn. Insects 13: 278.

Viteri, D.M., L. Sarmiento, A.M. Linares and I. Cabrera. 2019. Efficacy of biological control agents, synthetic insecticides, and their combinations to control tobacco budworm [*Heliothis virescens* (Lepidoptera: Noctuidae)] in pigeon pea. Crop Prot. 122: 175–179.