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Toxic Bait as an Alternative Tool in the Management of *Spodoptera frugiperda* in Second Corn Crops

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Abstract

Managing the fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith, 1797), has been increasingly difficult owing to the increase in individual resistance to insecticides and genetically modified *Bacillus thuringiensis* (Bt) plants. This study used the attracting and killing method to control FAW adults in the field by spraying Noctovi® with methomyl insecticide. The experiments were conducted in commercial cornfields, non-Bt and Bt crops, over two agricultural years (2018 and 2019) at eight sites distributed in three cities located in the south of Mato Grosso do Sul State, Brazil. The following six insecticide treatments were used: spraying in continuous bands spaced every 100, 50, and 25 m; intermittent spraying every 25 m; control (without insecticide application); and spraying the entire area with insecticide (positive control). Food bait associated with the insecticide molecule was applied to the crop at vegetative stages V1 and V3, and the adult population size and level of leaf damage caused by the caterpillars (assessed via the Davis scale) were evaluated. The application of toxic bait in bands with spacing less than or equal to 50 m significantly reduced the percentage of damage to the plants, with the effect stronger in Bt crops. We suggest that the control of FAW adult populations would be more efficient if the attracting and killing technique was incorporated in integrated pest management programs for second corn crops.

Keywords: fall armyworm, adult control, Davis scale, spraying in bands, semiochemical

1. Introduction

Corn *Zea mays* L. is one of the main crops worldwide, and in Brazil, it is grown throughout the country using different technological systems and levels of technology use (Campanha et al., 2012).

Among the pests that attack corn, the fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith, 1797) (Lepidoptera: Noctuidae), is the most important, causing irreversible damage. In Brazil, productivity losses due to this pest can reach 60% depending on the genotype, plant developmental stage, and growing season (Carnevalli & Florcovski, 1995; Cruz & Turpin, 1982; Cruz et al., 1999).

Eggs deposited by the adult insects are seen immediately after the emergence of the first leaves on the plants (Toscano et al., 2012). After emergence, even though the caterpillar feeds on corn during all its growth stages, it prefers the young plants (Gallo et al., 2002).

In Brazil, chemical control and the use of genetically modified *Bacillus thuringiensis* (Bt) plants are the main strategies for the management of several pest species (Costa & Queiroz, 2014). However, *S. frugiperda* has not been easy to control, and some insecticides and Bt plants currently available on the market have failed in this task (Bernardi & Omoto, 2018).

The intensive use of insecticides has led to the development of generalized and multiple resistance, and severe negative impacts on non-target species, including natural enemies, parasitoids, and pollinators (Liu et al., 2017).

Bt plants have provided a new control strategy for FAW. However, the bioecological characteristics of the pest in some regions, such as high reproductive potential, relatively short biological cycle, and polyphagia, associated with the scenario of overlap and succession of host plant crops ("green bridge"), have made FAW populations vulnerable to the high selection pressure of insecticides and Bt proteins. This provides a favorable scenario for increased resistance and subsequent compromise of control strategies (Bernardi & Omoto, 2018).

Some pests have evolved resistance to both insecticides and Bt plants, with FAW being the leading example, showing resistance to the Cry1F protein expressed in corn in several countries (Farias et al., 2014; Lu et al., 2010; Santos-Amaya et al., 2015; Storer et al., 2010; Tabashnik et al., 2013) and in Bt plants that express the proteins Cry1A.105 + Cry2Ab2 (Souza et al., 2019).

Thus, the effective implementation of resistance management strategies is essential for ensuring the durability of any control strategy for *S. frugiperda*. One alternative is to target adults of pest species using semiochemicals, such as pheromones or volatiles from pest host plants (Witzgall et al., 2010). However, one of the limitations to the use of sex pheromones is that they only attract adult males of the target species, whereas food baits composed of vegetable volatiles attract both sexes of various lepidopteran species, which can significantly decrease the adult populations, oviposition, and subsequent larval populations (Del Socorro et al., 2010a; Del Socorro et al., 2010b; Su et al., 2001).

Semiochemicals can be an efficient alternative control method and tool for managing resistance development. Recently, studies conducted under controlled laboratory conditions have demonstrated the possibility of using commercial semiochemicals associated with chemical insecticide molecules for the management of FAW adults (Justiniano & Fernandes, 2020).

Noctovi® is composed of oleoresins and sugars. The oleoresins release volatiles that attract moths at great distances and the sugars stimulate the moths to feed, also ingesting the lethal insecticide that is associated. Thus, we aimed to evaluate the viability of a new tool for the integrated pest management of second corn crops via the application of the Noctovi® commercial product with methomyl active insecticide to control FAW adults and reduce caterpillar infestation under real field conditions.

2. Materials and Methods

2.1 Study Location and Experimental Plots

The experiments were conducted in commercial areas producing second corn crops in three municipalities in the of Mato Grosso do Sul State, Brazil, in eight locations (plots/blocks) in 2018 and 2019 (Table 1).

Table 1. General characteristics of sampling sites for the field experiment on the effect of toxic bait on the management of *S. frugiperda* adults in second corn crops with or without Bt plants. Mato Grosso do Sul, Brazil

Site	Crop	County	Farm	Latitude	Longitude	Seeding
1	2018	Dourados	Esperança	-22°01′10″S	-54°55′33″W	2/23/2018
2	2018	Dourados	Esperança	-22°04′43″S	-54°55′27″W	3/4/2018
3	2018	Dourados	Esperança	-22°01′47″S	-54°55′50″W	3/19/2018
4	2018	Dourados	Esperança	-22°02′23″S	-54°56′00″W	3/20/2018
5	2019	Douradina	Boa Vista	-22°01′04″S	-54°32′27″W	1/27/2019
6	2019	Douradina	Boa Vista	-22°02′00″S	-54°34′50″W	2/8/2019
7	2019	Rio Brilhante	Flor do Cerrado	-21°40′50″S	-54°38′09″W	2/25/2019
8	2019	Rio Brilhante	Flor do Cerrado	-21°40′30″S	-54°38′37″W	2/26/2019

The commercial areas were planted with Bt hybrid VT PRO3®, which expresses the proteins Cry1A.105 and Cry2Ab2 for protection against caterpillars, Cry3Bb1 against corn rootworm larva, and CP4-EPSPS that provides tolerance to the glyphosate herbicide, and non-Bt hybrid RR2®, which expresses CP4-EPSPS that is used for planting a structured refuge (CIB, 2012).

The corn was sown with 50 cm spacing between the rows, with 3 to 3.2 seeds per meter, resulting in a population between 60,000 and 64,000 plants ha^{-1}. The control of weeds and non-target insect species in the study areas was undertaken by farmers without distinguishing between treatments and crop technologies.

The experiments were performed in commercial plots of second corn crops, with each replicate using both VT PRO3® and RR2® technologies. Each experimental plot, located within the producer's commercial area, consisted of 1 ha spaced laterally every 10 m (border). The experimental block was composed of 12 plots, with six Bt and six non-Bt plots (Figure 1).

The experiment was repeated for the 2018 and 2019 crops, with four locations each year. One of the following treatments was applied to each plot: treatment 1, continuous spraying spaced every 100 meters; treatment 2, continuous spraying spaced every 50 m; treatment 3, continuous spraying spaced every 25 m; treatment 4, intermittent spraying spaced every 25 m; treatment 5, no spray (negative control); and treatment 6, insecticide application in the entire area (positive control).

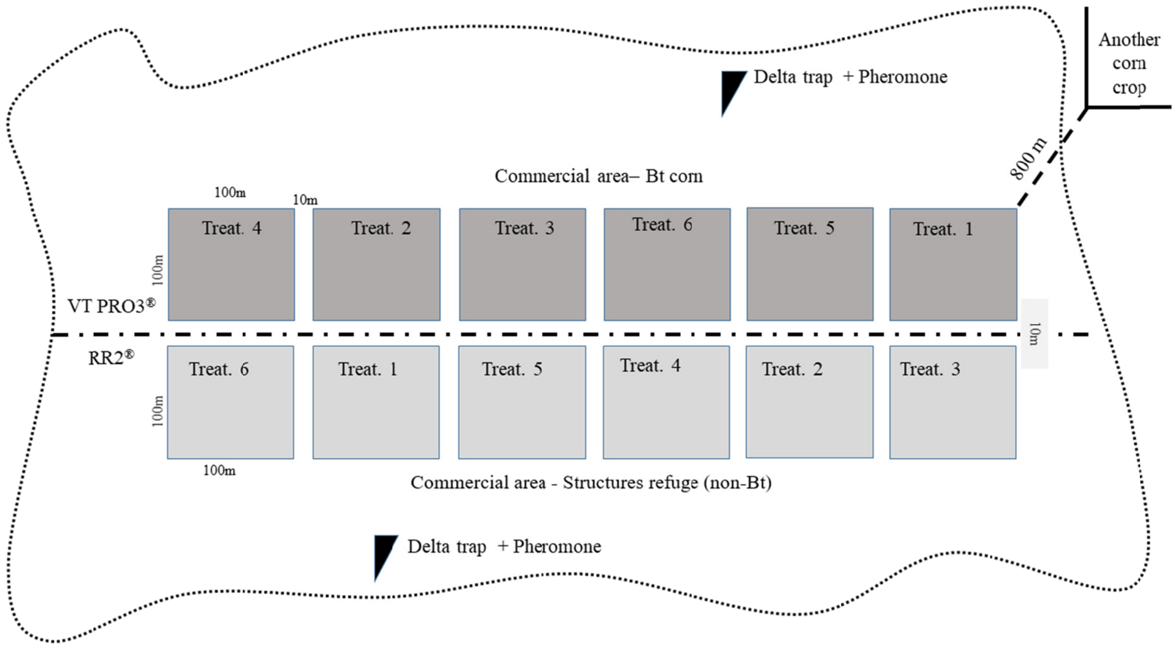

Figure 1. Illustrative schema of the experimental design of one of the sites (block) containing the different treatments of Bt and non-Bt corn. Mato Grosso do Sul, Brazil

2.2 Toxic Bait Application

Toxic bait was applied at 1 L ha^{-1} in the treatments and contained the Noctovi® 43sb commercial food (ISCA, Brazil) bait with 20 mL ha^{-1} of the methomyl active ingredient insecticide (Lannate® BR commercial product) at a 2% volume per spray rate volume. We used this combination because it was previously proven effective in combating FAW adults, causing up to 100% mortality in laboratory conditions (Justiniano & Fernandes, 2020).

At the time of sowing, two "Delta" traps were installed 1.5 m above the ground, one in the area next to the Bt corn plots and the other in the non-Bt corn plots. The bottom of the traps contained a sticky coating and the synthetic Bio Spodoptera sex pheromone for FAW (ChemTica International S.A.), consisting of a mixture of (Z)-7-dodecenyl acetate, (Z)-9-tetradecenyl acetate, and (Z)-11-hexadecenyl acetate. The pheromone was hung from the top of the trap and remained active for 30 days.

Food bait containing the insecticide was applied twice. The first application was between 8 and 12 days after crop emergence (DAE) (vegetative stage V1) and the second was between 17 and 21 DAE (vegetative stage V3).

A spraying device mounted on a Suzuki® 160 cc quadricycle with controlled speed was used for treatment applications. Continuous application in bands was performed with a Branco® sprayer powered by gasoline, which was equipped with a hydraulic circuit, pressure gauge for pressure calibration, and four hydraulic nozzles spaced every 0.5 m positioned on the corn lines and at a height of 0.3-0.5 m above the plants. The intermittent application was performed with a PRECISA® brand sprayer, mounted under the same motorized quadricycle, and the sprayer was calibrated to a 1 second application after 3 seconds without application, with a closed pressure-regulating valve and the same hydraulic circuit, pressure gauge, and four hydraulic nozzles as that of the continuous sprayer (Monteiro, 2017).

The toxic bait application rate was approximately 1 L ha^{-1} and XR80.03 tips without sieves (Spraying Systems, Cia) were used. The number of open tips during applications varied with the width of the application bands: treatment 1 was performed with four open tips, treatment 2 used two open tips, treatment 3 had only one open tip, and treatment 4 had four tips that applied the mixture only 25% of the time.

The equipment speed was 10 km h^{-1} and the hydraulic circuit pressure was constant between 1.5 and 1.8 bar, resulting in a flow rate between 0.42 and 0.45 L min^{-1}, which was lower than that indicated in the manufacturer's manual where the tests were performed with water.

The commercial food attractive used, Noctovi® 43sb, has different characteristics depending on the application modality (applied pure or together with the insecticide without adding water), such as the density and viscosity of the liquid. The mists generated from the applications deposited 1 to 3 drops per 100 cm^2 at spots ranging between 1 and 1.5 cm in diameter.

Treatment 5 (negative control) did not receive any application of insecticide or toxic bait for the management of FAW, whereas in treatment 6, insecticide containing methomyl at a commercial dose of 1.2 L ha^{-1} diluted in water was applied to the entire area at a rate of 150 L ha^{-1}. For this, we used model XR110.02 tips with sieves spaced every 0.5 m at a height of 0.5 m above the plants and with a pressure of approximately 3 bar, together with toxic bait application twice at the V1 and V3 stages.

Meteorological conditions, especially rainfall, were monitored throughout the experiment and toxic bait applications because rainfall can drastically reduce the residual persistence of the bait if it occurs soon after application. At least 48 h without rain after application was required to isolate this variable. If this did not occur, all treatments were reapplied.

2.3 Data Collection

The *S. frugiperda* population was monitored weekly by collecting and identifying the adults captured in the sticky bottom of the Delta traps containing sex pheromones. The sticky bottom was replaced during collection to avoid catch failure in the following week.

The damage caused by the attack of caterpillars on corn leaves was quantified according to the damage scale described by Davis, Ng, and Williams (1992), which provides plant damage scores depending on the type, size, and shape of the damage caused to the leaves by FAWs (Table 2). Evaluations occurred at the following five stages (Hanway, 1971; Ransom & Endres, 2014): V1 corresponded to the first leaf; V2 was characterized by two completely expanded leaves, where the insertion ring of the sheath is clearly defined; and V3, V4, and V6 corresponded to three, four, and six completely expanded leaves, respectively.

Table 2. Visual classification scale to estimate the damage to corn leaves caused by the feeding of fall armyworm caterpillars *(Spodoptera frugiperda)* (adapted from Davis et al., 1992)

Score	Description	
	7 days	14 days
0	No visible damage.	No visible damage.
1	Only pinhole lesions present on whorl leaves.	Only pinhole lesions present on whorl leaves.
2	Pinholes and small circular lesions present on whorl leaves.	Pinholes and small circular lesions present on whorl leaves.
3	Pinholes, small circular lesions, and a few small, elongated (rectangular-shaped) lesions up to 1.3 cm (1/2″) in length present on whorl and furl leaves.	Small, circular lesions and a few small, elongated (rectangular-shaped) lesions up to 1.3 (1/2″) in length present on whorl and/or furl leaves.
4	Small, elongated lesions present on whorl leaves and a few mid-sized elongated lesions of 1.3-2.5 cm (1/2-1″) in length present on whorl and/or furl leaves.	Several small- to mid-sized elongated lesions of 1.3-2.5 cm (1/2-1″) in length present on a few whorl and furl leaves.
5	Small, elongated lesions and several mid-sized elongated lesions present on whorl and furl leaves.	* Several large elongated lesions greater than 2.5 cm (1″) in length present on a few whorl and furl leaves and/or a few small- to mid-sized uniform to irregularly shaped holes (basement membrane consumed) eaten from the whorl and/or furl leaves.
6	Small- and mid-sized elongated lesions plus a few large elongated lesions of greater than 2.5 cm (1″) in length present on whorl and/or furl leaves.	* Several large elongated lesions present on several whorl and furl leaves and/or several large uniform to irregularly shaped holes eaten from furl and whorl leaves.
7	Many small- and mid-sized elongated lesions present on whorl leaves plus several large elongated lesions present on furl leaves.	Many elongated lesions of all sizes present on several whorl and furl leaves plus several large uniform to irregularly shaped holes eaten from the whorl and furl leaves.
8	Many small- and mid-sized elongated lesions present on whorl leaves plus many large elongated lesions on the furl leaves.	Many elongated lesions of all sizes present on most whorl and furl leaves plus many mid- to large-sized uniform to irregularly shaped holes eaten from the whorl and furl leaves.
9	Many elongated lesions of all sizes on whorl and furl leaves plus a few uniform to irregularly shaped holes (basement membrane consumed) eaten from the base of the whorl and/or furl leaves.	Whorl and furl leaves almost completely destroyed.

Note. * Scores 5 and 6 adjust for feeding damage caused by migratory mid-instar larvae.

The evaluations started before the first application and continued during the initial vegetative period, which was critical for the culture owing to the attack of the FAW. A total of 10 points were sampled per replicate (each point was composed of 10 plants in sequence, 100 plants per replicate), during vegetative stages V1, V2, V4, and V6 (7-12, 12-15, 20-24, and 28-32 DAE, respectively). The total number of plants evaluated was 38,400, being 100 plants per replicate × 4 evaluations per site × 6 treatments per site × 2 technologies per site × 4 evaluations × 2 years.

2.4 Data Analysis

The experiments were conducted in blocks with six treatments, two technologies (Bt and non-Bt corn), eight replicates (local), and two years, and were tested at four sites each year. Data normality was tested to assess compliance with analysis of variance (ANOVA) assumptions. The treatment means were compared at a significance level of 5% ($p < 0.05$) using Tukey's test. All analyses were performed in the R language (R Core Team, 2019), and the partial residues of the multifactorial ANOVA were obtained using the car package (Fox & Weisber, 2019).

3. Results

During the study, 2460 FAW adults were captured in areas cultivated with second corn crops, with 1218 and 1242 on Bt and non-Bt corn, respectively. Moths were present during all the initial growth stages of the crops and had similar population dynamics, regardless of the applied treatment. However, there was a slight population increase in stages V4 and V6, although this was not statistically different. The total number of individuals, mean (dispersion), on Bt and non-Bt corn was as follows: V1, 288 (36) and 314 (39.25); V2, 300 (37.5) and 298 (37.25); V4, 326 (40.75) and 309 (38.62); and V6, 304 (38) and 321 (40.12), respectively (Figure 2).

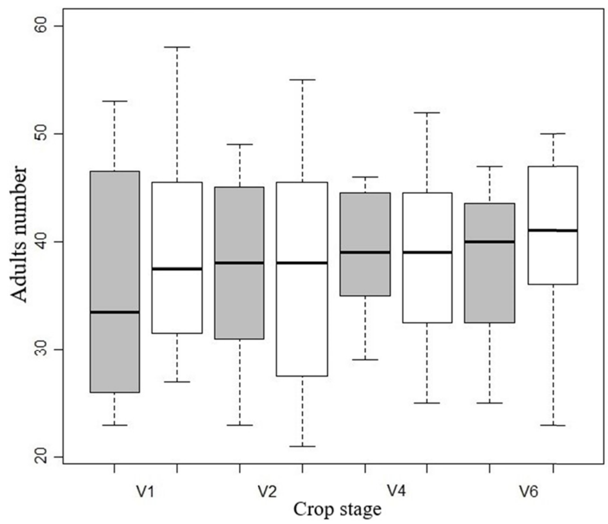

Figure 2. Population fluctuation of *S. frugiperda* adults in second corn crops, median and data dispersion in Bt (gray column) and non-Bt (white column) crops during the initial vegetative stages during management using food bait at eight sites. Mato Grosso do Sul State, Brazil in the agricultural year 2018-2019

The distribution of the Davis scale scores, with mean and amplitude transformed and equalized using partial residuals, representing that part of the variation indicating the effect of a variable in a multiple or multifactorial model excluding the effects of other variables, showed significant differences ($p < 0.001$) among years ($F_{1, 3823}$ = 165.93), technologies ($F_{1, 3823}$ = 1,322.44), and plant stages ($F_{3, 3823}$ = 1932.37) (Figure 3), and the damage caused by FAW larvae attacks during the second harvest in 2018 was more marked than that in 2019 (Figure 3A).

When comparing technologies, Bt plants showed much less damage than non-Bt plants, demonstrating that the proteins Cry1A.105 and 2Ab2 present in Bt plants provided partial protection to the corn plants from FAW attacks (Figure 3B). Regarding the plant developmental stages, the caterpillars developed as the plants grew, consuming more leaf area and increasing the damage. Infestations increased owing to overlapping generations within the same site (Figure 3C).

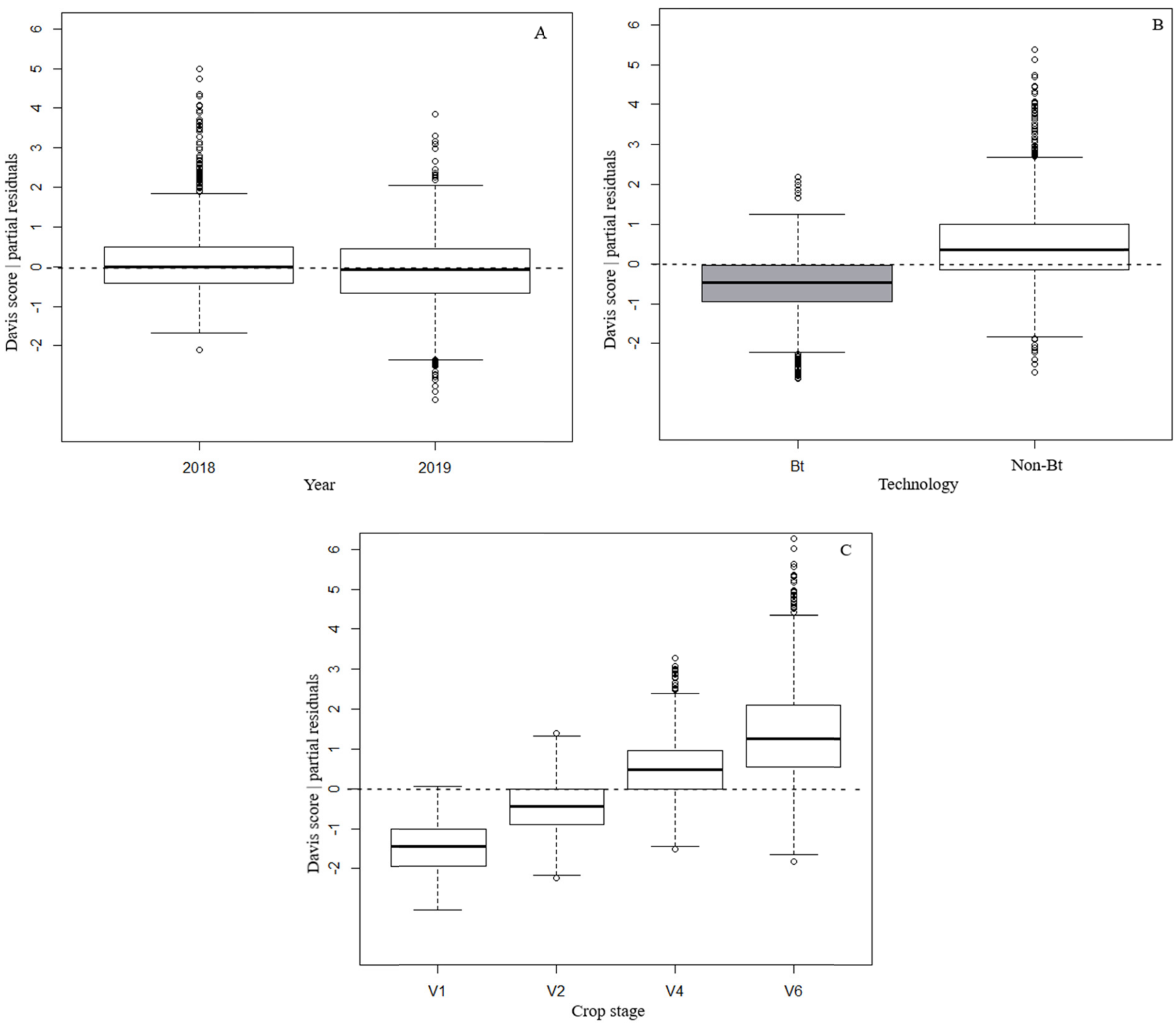

Figure 3. Partial residuals in a multifactorial analysis of variance for the effects of year (A), technology (B), and crop stage (C) variables on leaf damage (Davis scale) in corn crops. Mato Grosso do Sul State, Brazil in the agricultural year 2018-2019

Considering the toxic bait treatments, grouping the different stages of the culture, with and without Bt plants, those sprayed in continuous bands spaced every 50 and 25 m (treatments 2 and 3) did not differ from those spaced every 25 m with intermittent application (treatment 4). However, there were differences among treatments 1 (spraying on a continuous band spaced every 100 m), 5 (no spraying, control), and 6 (insecticide application over the entire area). Mean differences greater than 0.5 were observed in the partial residuals of treatments when comparing treatments 5 and 6 and treatments 1 and 6 (Figure 4).

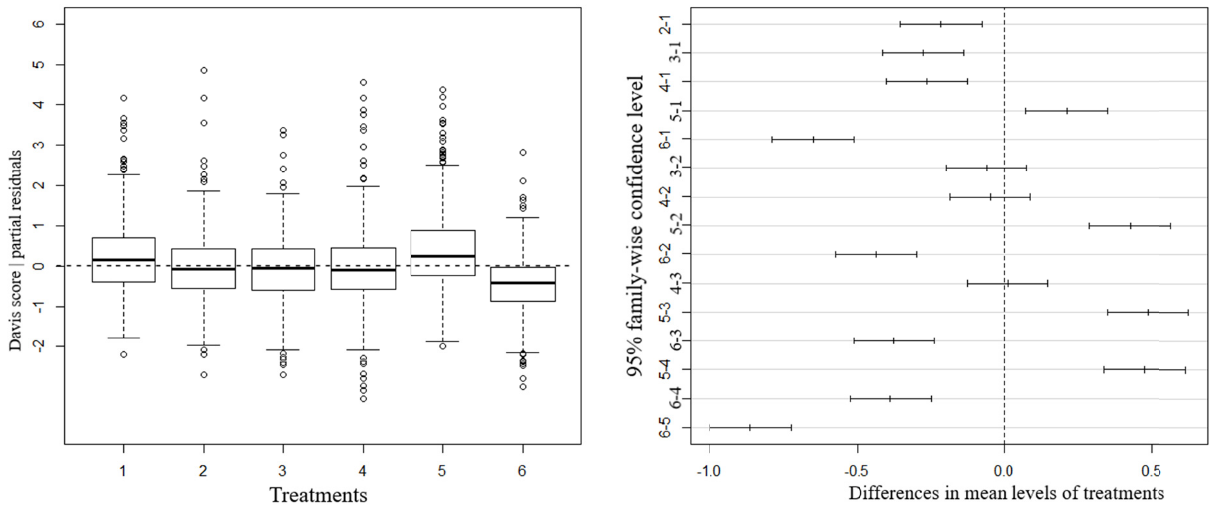

Figure 4. Partial residuals for Davis scale scores in treatments and differences in average treatment levels. Mato Grosso do Sul State, Brazil in the agricultural year 2018-2019

Treatments 2, 3, and 4 did not differ from each other, showing intermediate leaf damage. The control plants (treatment 5) had the highest damage levels, similar to treatment 1. Moreover, the positive control (treatment 6) had the lowest damage levels (Figure 5).

The Davis scale scores were classified by damage: mild (≥ 3), moderate (≥ 5), and severe (≥ 7); vegetative stage of corn; Bt and non-Bt corn; and the respective treatments (Figure 5 and Table 3). For non-Bt corn, treatments 2, 3 and 4 did not differ significantly from each other regardless of the culture stage. In the control treatment (treatment 5), the moderate damage caused by FAW was significantly higher than that in treatments 2, 3, 4, and 6 in the non-Bt cultivation for V4 and V6 stages using the same treatments.

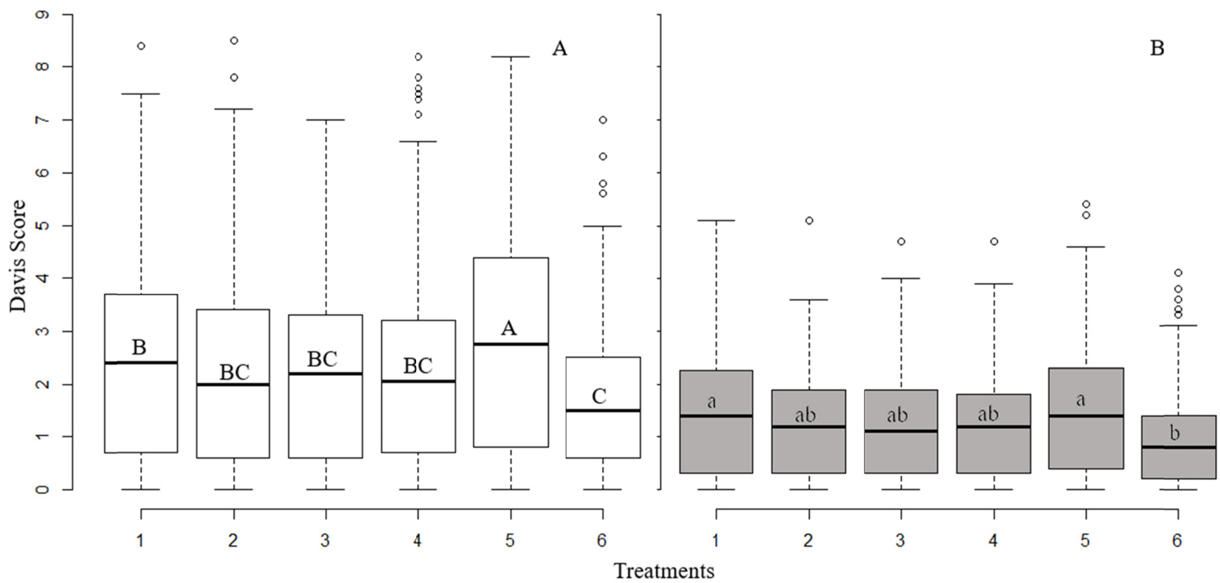

Figure 5. Dispersion and median for the Davis scale scores of treatments non-Bt (A) and Bt (B) owing to the attack and feeding of *S. frugiperda* caterpillars on genetically modified corn planted in the second harvest in the state of Mato Grosso do Sul State, Brazil in the agricultural year 2018-2019

In Bt corn, even with minor damage in the control treatment compared to that in the control treatment of non-Bt corn, the use of toxic bait significantly contributed to damage reduction, especially in treatments with 25 m bands (continuous or intermittent) considering mild and moderate damage.

Treatments 2, 3, 4, and 6 yielded similar results regarding the percentage of mild damage in the V2 stage and moderate damage in the V4 and V6 stages. Toxic bait applied every 50 and 25 m, continuously and intermittently for V4 and every 25 m for V6, showed similar damage to those in the positive control (treatment 6). Meanwhile, treatment 1 showed similar results to those in the control treatment for Bt corn plots and differed in plots without Bt plants only during the V4 stage, having a higher percentage of mild and moderate damage (Table 3).

Table 3. Percentage of Davis scale scores (mean±standard error) with technology, treatment, vegetative stage, and intensity of damage from the attack and feeding of *S. frugiperda* caterpillars on genetically modified corn grown during the second crop in Mato Grosso do Sul State, Brazil in the agricultural year 2018-2019

Technology/Treatments		Vegetative stages/Davis scale (scores)[(1)]								
		V1	V2		V4			V6		
		≥ 3	≥ 3	≥ 5	≥ 3	≥ 5	≥ 7	≥ 3	≥ 5	≥ 7
Non-Bt	100 m continuously	3.25±0.45A	38.63±10.56AB	5.13±2.16AB	65.63±9.50B	25.13±4.99B	1.75±1.01B	76.25±6.04AB	53.25±7.87AB	27.00±6.28AB
	50 m continuously	3.50±1.02A	31.50±8.20AB	1.00±0.68AB	63.50±7.43B	18.38±4.39BC	0.75±0.41B	73.50±5.98AB	46.75±7.73B	18.75±6.30ABC
	25 m continuously	3.00±0.73A	38.25±10.33AB	2.00±0.91AB	61.13±6.07B	18.25±4.64BC	1.25±0.86B	68.75±6.49B	39.00±8.43B	14.50±5.10BC
	25 m intermittently	3.50±0.92A	36.63±10.79AB	1.88±0.99AB	60.88±7.00B	19.75±3.96BC	0.63±0.50B	66.63±8.55BC	45.25±9.31B	21.63±8.53ABC
	Without application	3.63±1.02A	46.00±9.80A	6.25±2.16A	78.75±6.65A	37.50±6.23A	8.25±1.97A	84.13±4.82A	63.50±9.00A	33.25±6.39A
	Insecticide application in the whole area	2.75±0.82A	23.25±5.57B	0.25±0.16B	46.88±7.85C	10.50±3.46C	0.88±0.74B	55.88±6.98C	24.13±6.80C	8.00±3.58C
C.V. % [(2)]		23.69	16.18	55.18	6.64	17.03	49.32	6.47	10.86	21.57
Bt	100 m continuously	1.63±0.96a	22.75±7.45a	0.13±0.13a	40.00±6.69a	1.88±0.88ab	0.00±0.00a	52.00±4.64ab	17.63±4.33a	1.75±0.62a
	50 m continuously	1.75±0.86a	15.00±4.90ab	0.00±0.00a	27.25±5.52ab	0.50±0.27b	0.00±0.00a	49.00±3.84ab	12.50±3.04ab	0.88±0.40a
	25 m continuously	1.75±0.72a	16.25±5.69ab	0.00±0.00a	32.75±4.69a	1.00±0.63b	0.00±0.00a	44.63±5.32bc	11.75±4.80ab	0.50±0.38a
	25 m intermittently	1.88±0.79a	16.63±5.25ab	0.00±0.00a	27.38±4.02ab	1.38±0.73b	0.00±0.00a	42.13±4.51bc	10.50±2.95b	0.50±0.27a
	Without application	1.63±0.46a	31.50±7.43a	0.00±0.00a	37.50±5.15a	3.25±0.80a	0.00±0.00a	58.13±5.26a	19.00±5.08a	1.63±0.87a
	Insecticide application in the whole area	1.75±0.59a	10.75±4.11b	0.00±0.00a	16.88±5.09b	0.50±0.38b	0.00±0.00a	32.38±6.50c	7.13±4.44b	0.50±0.38a
C.V. % [(2)]		26.59	19.41	10.41	17.21	31.56	0.00	10.02	23.50	33.17

Note. [(1)] Means followed by the same letters in the columns do not differ by Tukey's test at a significance level of 5%.

[(2)] C.V. % is the percentage of coefficient variation in the data transformed into $\sqrt{(x + 0.5)}$.

4. Discussion

Attracting and killing insects by combining bait food and a contact insecticide in a sticky formulation is one method for controlling pests (Poullot et al., 2001). The toxic bait adds a mortality factor, with a synthetic insecticide normally used (Arruda-Gatti & Ventura, 2003). Lepidopterans have been controlled previously in cotton and soybean crops with the application of a mixture of molasses (1 L), water (10 L), and 21.5% methomyl insecticide (30 mL) in 5 L for 5 m of plant line bands at a distance of 50 m (Gallo et al., 2002). Baits with cartap insecticide at doses of 500 and 750 g ha^{-1} (active ingredient) added to 0.5% sugar were found to effectively control the adult pink bollworm *Pectinophora gossypiella* population (Papa et al., 2003).

In our study, the infestation of FAW adults was affected by the year, site, and time of sowing, and, consequently, influenced the infestation of caterpillars and damage to crops. However, damage reduction after applying food bait with insecticide sprayed continuously or intermittently in bands spaced 50 and 25 m were similar to each other and to that after application of the methomyl-based insecticide over the entire area.

The application of the Noctovi® 43sb commercial food bait in combination with the Lannate® BR (methomyl) insecticide controlled a considerable part of the adult population of *S. frugiperda* in the treated areas, directly influencing oviposition and, consequently, caterpillar infestation, and reducing damage, as indicated by the mean scores on the Davis scale during the initial stages (V1 to V6) of the second corn crops.

Research under laboratory conditions corroborated the adult FAW mortality caused by toxic bait using the active insecticides methomyl, lambda-cyhalothrin, and spinosad together with the Noctovi® 43sb commercial food bait, with these mixtures causing 100% mortality in adults up to 5.29 h (Justiniano & Fernandes, 2020).

The attracting and killing technique can be used in integrated pest management programs. However, one of the weaknesses of this method is that its efficiency decreases for high-density pests because there is greater competition for the resource (El-Sayed et al., 2009). Conversely, this technology is highly effective for controlling isolated and low-density populations and can add value to long-term pest management programs (Guerrero et al., 2014).

The combination of toxic baits with crops expressing the proteins Cry1A.105 + Cry2Ab was efficient in managing *S. frugiperda* caterpillars. In the present study, both technologies showed a significant reduction in damage when using the toxic bait in bands less than 50 m apart. However, the percentage of attacked plants in most stages remained above the recommended level for pest control.

Pest control is recommended in corn plants where 20% and 10% of plants are affected aged up to 30 days and 40-60 days, respectively (Gallo et al., 2002; Rosa & Barcelos, 2012). Regarding the leaf damage index, pest control is recommended where 20% and 10% of plants have Davis scale scores ≥ 3 for non-Bt and Bt, respectively (Bernardi & Omoto, 2018).

The presence of visible damage in areas containing Bt crops and constant reports of insect resistance to Cry1F in Brazil (Farias et al., 2014) indicate that the populations of FAW in Brazil are resistant, even to those plantations containing pyramid resistance genes (Santos-Amaya et al., 2015; Barcelos & Angelini, 2018). On the other hand, insecticides have often shown control failures due to problems in application technology, the habit of these pests that make control difficult and, in some cases, the increase in the frequency of resistant individuals as a result of frequent spraying of insecticides with the same mode of action (Bernardi & Omoto, 2018; Fernandes et al., 2019).

In this way, the management using toxic bait provided a reduction in the percentage of damage caused by the feeding of FAW caterpillars, resembling the standard management of the producer with the application of the insecticide in a total area that also did not keep the damage below the level of pest control threshold. For the high levels of infestation evidenced in these fields, it is necessary to use more management tools to control and maintain the levels of infestation below the control threshold.

5. Conclusion

The technique of attracting and killing insect pests meets and complies with the general principles of managing resistance to insecticides and Bt plants.

For *S. frugiperda* moths, the application of this control method using 1 L ha^{-1} of the toxic bait Noctovi® 43sb commercial food bait together with the active ingredient methomyl in a dose 60 times lower (20 mL ha^{-1}) than the amount sprayed over the entire area, reduced the adult population, and thus significantly decreased the percentage of damage to the crop. Moreover, this effect was stronger in Bt than non-Bt corn crops.

This scenario of medium and high infestation of adults requires the use of other management tools in addition to attracting and killing techniques.

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