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Managing Stink Bugs on Soybean Fields: Insights on Chemical Management

Rafael P. Marques[1], Alberto Cargnelutti Filho[2], Adriano A. Melo[1], Jerson V. C. Guedes[1], Cristiano De Carli[1], Alberto Rohrig[1], Henrique Pozebon[1], Clérison R. Perini[1], Dener R. Ferreira[1], Júlia G. Bevilaqua[1], Leonardo S. Patias[1], Sarah E. Forgiarini[1], Guilherme Padilha[1], João V. Leitão[1], Daniela Moro[1], Lucas Hahn[1] & Jonas A. Arnemann[1]

[1] Departament of Crop Protection, Federal University of Santa Maria, Santa Maria, Brazil

[2] Departament of Crop Science, Federal University of Santa Maria, Santa Maria, Brazil

Correspondence: Jonas A. Arnemann, Departament of Crop Protection, Federal University of Santa Maria, Avenida Roraima 1000, Santa Maria, Rio Grande do Sul 97105-900, Brazil. E-mail: jonasarnemann@gmail.com

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Abstract

Stink bugs are a major concern for pest management in soybean crops. With agricultural frontiers expanding in Brazil and cultivation techniques being heavily intensified, stink bug populations have become increasingly dispersed and hard to control, causing severe economic losses to soybean growers across the country. Chemical insecticides known as neonicotinoids, organophosphates and pyrethroids currently represent the main control strategy for this pest, being often mixed together in order to enhance control efficacy and prevent resistance development. Each of these chemical groups is characterized by a different mode of action inside the insect's body, which determines if the insecticide will provide a fast *knockdown* effect or a long residual control effect. The aim of this work was to evaluate the *knockdown* and residual control effects delivered by these groups of insecticides under field conditions and during two cropping seasons, both in isolated and combined use, determining the most efficient strategy for chemical management of stink bugs on soybean crops. The pyrethroid lambda-cyhalothrin (250 g L^{-1}) had the best *knockdown* effect, while the neonicotinoid imidacloprid (700 g kg^{-1}) provided the longest residual control. The highest control efficacy was obtained with the combination of lambda-cyhalothrin + thiamethoxam (106 + 141 g L^{-1}), which resulted in 84.8% of stink bug control.

Keywords: *Glycine max,* neonicotinoids, organophosphates, Pentatomidae, pyrethroids

1. Introduction

The phytophagous stink bugs (Hemiptera: Pentatomidae) found in the soybean crop are considered pests of great economic importance in many countries (Panizzi & Slansky, 1985; Corrêa-Ferreira, Krzyzanowski, & Minami, 2009). The relevance of these insects has increased in recent years due to several reasons, such as the expansion of area grown with soybean (currently reaching 35 million hectares in Brazil; CONAB, 2018), variation in the sowing dates and other crops serving as hosts for the pest (Panizzi & Grazia, 2001), increase of the reproductive period in modern soybean cultivars resulting in higher food offer to the insect, and reduction in the use of insecticides in *Bt* soybean cultivars (Guedes et al., 2016).

Stink bugs damage soybean by sucking the pods, leading to smaller and wrinkled grains and reducing their yield and quality (Corrêa-Ferreira et al., 2009). The intensity of the damage caused depends on the stink bug species, population density, growth stage of the soybean plants and coexistence period between pest and crop (Corrêa-Ferreira et al., 2009). The neotropical brown stink bug (*Euchistus heros*) and the green-belly stink bug (*Dichelops furcatus*) currently represent the main species found in Brazilian soybean fields (Guedes et al., 2016).

Chemical control is the most usual strategy for stink bug management in soybean crops, and the chemical insecticide groups used are restricted to the neonicotinoids, organophosphates and pyrethroids, in a total of 20 active ingredients registered in the Brazilian Ministry for Agriculture (AGROFIT, 2018). Several pyrethroids and neonicotinoids are often used together in commercial mixtures due to the complementarity of effects between them, the first causing immediate *knockdown* and the second offering a long residual control, characteristics that are determined by their modes of action (Sosa-Gómez & Omoto, 2012).

Neonicotinoids act on the synaptic transmission of nervous impulses, belonging to the IRAC Group 4A of modes of action (Nicotinic Acetylcholine Receptor Agonists; IRAC, 2018). These substances mimic the action of the neurotransmitter acetylcholine and are not hydrolyzed by the acetylcholinesterase enzyme action, maintaining the nicotinic receptors of the postsynaptic nerve cells under continuous excitation and causing the death of the insect by overstimulation and respiratory failure (Salgado, 2013).

Organophosphates also act on the synaptic transmission of nervous impulses and belong to IRAC Group 1B of modes of action (Acetylcholinesterase Inhibitors; IRAC, 2018). These substances inhibit the acetylcholinesterase enzyme action, resulting in an accumulation of the neurotransmitter acetylcholine and leading the insect to death due to hyperexcitation of the nervous cells (Salgado, 2013; Araujo, Santos, & Gonsalves, 2016).

Pyrethroids act on the axonal transmission of nervous impulses and belong to the IRAC Group 3A of modes of action (Sodium Channel Modulators; IRAC, 2018). These substances slow the closing process of sodium channels after an action potential, causing the nervous cells to become continuously re-excited and killing the insect by overstimulation (Braga & Valle, 2007; Salgado, 2013).

Considering the broad use of neonicotinoids, organophosphates and pyrethroids in the management of soybean stink bugs, either isolated or combined, the aim of this work was to evaluate the *knockdown* and residual control effects delivered by these groups of insecticides, in order to determine the most efficient strategy for stink bug control on soybean crops.

2. Material and Methods

2.1 Experimental Sites

The experiments were conducted in Santa Maria-RS/Brazil (29º42′48″ S, 53º43′59″ W, 119 meters a.s.l.) over two summer cropping seasons (2016/17 and 2017/18), using the soybean cultivar NIDERA 5909 (indeterminate growth type, maturity group 6.2, approximately 130 days for maturation). The sowing dates were 20/01/2017 and 12/01/2018, with a row spacing of 0.5 meters.

2.2 Experiment Conduction

In both experiments, weeds were controlled in post-emergence at the growth stage V3 of the soybean plants, with the spraying of glyphosate (1040 g of acid equivalent hectare^{-1}). For the control of defoliating caterpillars, lunefuron (7.5 g a.i. ha^{-1}) was sprayed at the growth stages V4 and V7. There was no use of neonicotinoid or pyrethroid insecticides aside the evaluated treatments. In addition, during the reproductive stages R1, R4 and R5.4 of the crop, three sprays of azoxystrobin (60 g a.i. ha^{-1}) + cyproconazole (24 g a.i. ha^{-1}) were made for disease control.

2.3 Treatments

The experimental design was randomized blocks with four replicates, being evaluated seven insecticide treatments (Table 1) and one untreated control. Two insecticide sprayings were made with an interval of seven days between them, using a spraying volume of 150 L ha^{-1}. The sprayings were carried out using a CO$_2$-pressurized backpack sprayer, nozzles model XR 11002®, with a spray boom 2 meters long and 0.5 meters of spacing between nozzles.

Table 1. Treatments evaluated, active ingredient (a.i.) concentration and spray doses for the control of stink bugs on soybean crop

Treatments	**Concentration of a.i.**^{1}	**Dose ha**$^{-1}$	
		c.p.^{2}	**a.i.**^{1}
1. Untreated control	-	-	-
2. Lambda-cyhalothrin + thiamethoxam	106 + 141 g L^{-1}	250	26.5 + 35.2
3. Lambda-cyhalothrin	250 g L^{-1}	106	26.5
4. Thiamethoxam	250 g kg^{-1}	141	35.2
5. Beta-cyfluthrin + imidacloprid	12.5 + 100 g L^{-1}	1000	12.5 + 100
6. Imidacloprid	700 g kg^{-1}	142	100
7. Beta-cyfluthrin	125 g L^{-1}	100	12.5
8. Acephate	750 g kg^{-1}	1000	750

Note. ^{1}a.i. = Active ingredient (g hectare^{-1}). ^{2}c.p. = Commercial product (g or mL hectare^{-1}).

2.4 Evaluations

Samplings were carried out using the vertical beat sheet method (Guedes, Farias, Guareschi, Roggia, & Lorentz, 2006), with a sampling area of 1 m² per experimental unit. Evaluations were made at 3 and 7 days after the first spraying (DA1S) and 3, 7, 10 and 14 days after the second spraying (DA2S).

2.5 Statistical Analysis

Control efficiency for each insecticide treatment was assessed through the equation of Abbott (1925), with the obtained values being submitted to variance analysis (ANOVA) and to the mean separation test of Tukey ($P \leq 0.05$). All statistical analyses were carried out using the Software SAS® (2002).

3. Results and Discussion

3.1 Experiment I

The population of stink bugs infesting the soybean plants in the first experiment (2016/17 cropping season) was composed of *Euschistus heros* (92.5%), *Dichelops furcatus* (5.1%), *Piezodorus guildinii* (2.3%) and other species (1%). The insecticide treatments were sprayed at a population density of 4.4 stink bugs m^{-2}.

All treatments presented high control efficacy at 3 days after the first spraying (3 DA1S) when compared to the untreated control, with the treatments T2 (lambda-cyhalothrin + thiamethoxam 106 + 141 g L^{-1}), T4 (thiamethoxam 250 g kg^{-1}) and T8 (acephate 750 g kg^{-1}) reducing the population to 0.0 stink bugs m^{-2}, attesting the *knockdown* effect of these insecticides. Treatment T8 (acephate 750 g kg^{-1}) kept the population density at 0.0 stink bugs m^{-2} until 7 DA1S, and showed similar results after the second spraying, maintaining its control efficiency until 7 DA2S (Table 2).

Table 2. Mean numbers of stink bugs m^{-2} (N) and percentage of control efficiency (M) on each evaluation in response to the insecticide treatments sprayed in both experiments. Santa Maria, Rio Grande do Sul, Brazil

Experiment I

Treatments	**3 DA1S**		**7 DA1S**		**3 DA2S**	
	N	**M**	**N**	**M**	**N**	**M**
1. Untreated control	1.0 a[1]	-	2.5 a	-	7.2 a	-
2. Lambda-cyhalothrin + thiamethoxam	0.0 a	100.0	1.7 ab	30.0	0.7 b	89.7
3. Lambda-cyhalothrin	0.5 a	50.0	0.7 ab	70.0	1.2 b	82.8
4. Thiamethoxam	0.0 a	100.0	1.7 ab	30.0	1.5 b	79.3
5. Beta-cyfluthrin + imidacloprid	0.2 a	75.0	0.7 ab	70.0	0.5 b	93.1
6. Imidacloprid	0.5 a	50.0	0.7 ab	70.0	2.0 b	72.4
7. Beta-cyfluthrin	0.2 a	75.0	1.0 ab	60.0	1.5 b	79.3
8. Acephate	0.0 a	100.0	0.0 b	100.0	0.5 b	93.1
CV (%)[2]	31.87		29.11		26.95	

Treatments	**7 DA2S**		**10 DA2S**		**14 DA2S**	
	N	**M**	**N**	**M**	**N**	**M**
1. Untreated control	6.5 a	-	3.2 a	-	3.7 a	-
2. Lambda-cyhalothrin + thiamethoxam	0.7 b	88.5	2.5 a	23.1	0.2 c	93.3
3. Lambda-cyhalothrin	0.2 b	96.2	0.0 b	100.0	1.2 bc	66.7
4. Thiamethoxam	1.5 b	79.9	1.0 b	69.2	1.2 bc	66.7
5. Beta-cyfluthrin + Imidacloprid	1.0 b	84.6	1.0 b	69.2	2.0 ab	46.7
6. Imidacloprid	0.5 b	92.3	0.7 b	76.9	1.0 bc	73.3
7. Beta-cyfluthrin	1.2 b	80.8	1.0 b	69.2	0.7 bc	80.0
8. Acephate	0.2 b	96.2	1.0 b	76.9	1.2 bc	66.7
CV (%)	25.5		23.34		22.75	

Experiment II

Treatments	**1 DA1S**		**3 DA1S**		**7 DA2S**	
	N	**M**	**N**	**M**	**N**	**M**
1. Untreated control	22.7 a	-	22.5 a	-	23.2 a	-
2. Lambda-cyhalothrin + thiamethoxam	3.0 bc	86.8	1.5 b	93.3	3.7 c	83.9
3. Lambda-cyhalothrin	2.7 c	87.9	2.5 b	88.9	7.2 bc	68.8
4. Thiamethoxam	6.2 bc	72.5	7.0 b	68.9	12.0 b	48.4
5. Beta-cyfluthrin + imidacloprid	3.2 bc	85.7	6.0 b	73.3	4.2 c	81.7
6. Imidacloprid	4.5 bc	80.2	4.2 b	81.1	6.7 bc	71.0
7. Beta-cyfluthrin	5.0 bc	78.0	5.7 b	74.4	7.2 bc	68.8
8. Acephate	8.5 b	62.6	2.5 b	88.9	12.0 b	48.4
CV (%)	19.34		26.49		14.36	

Treatments	**1 DA2S**		**3 DA2S**		**7 DA2S**	
	N	**M**	**N**	**M**	**N**	**M**
1. Untreated control	22.5 a	-	23.2 a	-	21.0 a	-
2. Lambda-cyhalothrin + thiamethoxam	0.7 bc	97.0	0.7 bc	96.8	0.3 c	98.5
3. Lambda-cyhalothrin	0.2 c	98.9	0.2 c	98.9	0.2 c	98.8
4. Thiamethoxam	1.2 bc	94.4	1.2 bc	94.6	2.0 bc	90.5
5. Beta-cyfluthrin + imidacloprid	1.5 bc	93.3	1.5 bc	93.5	0.7 c	96.4
6. Imidacloprid	3.5 b	84.4	3.5 b	84.9	4.7 b	77.4
7. Beta-cyfluthrin	1.5 bc	93.3	1.5 bc	93.5	2.2 bc	89.3
8. Acephate	1.7 bc	92.2	1.7 bc	92.5	1.2 bc	94.0
CV (%)	24.11		23.9		27.03	

Treatments	**10 DA2S**		**14 DA2S**	
	N	**M**	**N**	**M**
1. Untreated control	13.0 a	-	5.7 a	-
2. Lambda-cyhalothrin + thiamethoxam	0.0 d	100.0	0.0 b	100.0
3. Lambda-cyhalothrin	0.2 d	98.1	0.0 b	100.0
4. Thiamethoxam	7.7 ab	40.4	2.0 b	64.8
5. Beta-cyfluthrin + imidacloprid	1.0 cd	92.3	0.0 b	100.0
6. Imidacloprid	1.7 cd	86.5	1.7 b	69.2
7. Beta-cyfluthrin	1.2 cd	90.4	0.5 b	91.2
8. Acephate	4.2 bc	67.3	1.7 b	69.2
CV (%)	26.7		27.39	

Note. [1] Means followed by the same letter do not differ among themselves by the Tukey test ($P \leq 0.05$). [2] CV (%) = Coefficient of variation.

While the ANOVA analysis for the variable *number of stink bugs* pointed statistical significance for the factors *treatments* and *days after spraying* (Supplementary Table 1), the means of control efficiency did not differ significantly among the treatments (Table 3). The treatment T8 (acephate 750 g kg^{-1}) presented the highest corrected mortality of stink bugs, with 88.9% of control, followed by the treatment T3 (lambda-cyhalothrin 250 g L^{-1}), with 80.0%. All treatments kept the population density of stink bugs lower than the untreated control, resulting in a corrected mortality of 70.0%, near the control level considered ideal (80.0%) (Table 3 and Supplementary Table 2).

Supplementary Table 1. Analyses of ANOVA for the factors Treatments and Days after spraying (DAS) using Sums of Squares on SAS System, GLM Procedure, for both experiments

Experiment I: *Dependent Variable: Number of stink bugs (Nsb)*					
Source	**DF**	**Sum of Squares**	**Mean Squares**	**F Value**	**Pr > F[1]**
Model	12	264.5416667	22.0451389	17.39	<.0001
Error	179	226.9114583	1.2676618		
Corrected Total	191	491.4531250			
R-Square	**Coeff Var**	**Root MSE**	**Nsb Mean**		
0.538285	88.96038	1.125905	1.265625		
Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Treatments	7	219.2447917	31.3206845	24.71	<.00001
DAS	5	45.2968750	9.0593750	7.15	<.00001
Experiment II: *Dependent Variable: Number of stink bugs (Nsb)*					
Source	**DF**	**Sum of Squares**	**Mean Squares**	**F Value**	**Pr > F**
Model	14	9096.49805	649.74986	71.89	<.0001
Error	241	2178.20598	9.03820		
Corrected Total	255	11274.70402			
R-Square	**Coeff Var**	**Root MSE**	**Nsb Mean**		
0.806806	59.26142	3.006360	5.073047		
Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Treatments	7	7700.680586	1100.097227	121.72	<.0001
DAS	7	1395.817461	199.402494	22.06	<.0001

Note. [1]Values of Pr > F higher than 0.05 are considered non-significant.

Table 3. Assessment of mean number of stink bugs and corrected mortality in response to the insecticide treatments sprayed in both experiments. Santa Maria, Rio Grande do Sul, Brazil

Treatments	**Experiment I**	**Experiment II**	**Corrected mortality**		
			Exp I	**Exp II**	**Mean**
1. Untreated control	4.0 a[1]	19.2 a	-	-	-
2. Lambda-cyhalothrin + thiamethoxam	1.0 b	1.2 e	75.5	94.1	84.8
3. Lambda-cyhalothrin	0.8 b	2.1 de	80.0	88.4	84.2
4. Thiamethoxam	1.1 b	4.9 b	71.3	74.4	72.9
5. Beta-cyfluthrin + imidacloprid	0.9 b	2.3 cde	77.5	88.1	82.8
6. Imidacloprid	0.9 b	3.8 bcd	77.5	80.0	78.8
7. Beta-cyfluthrin	0.9 b	3.1 bcde	76.5	83.8	80.2
8. Acephate	0.4 b	4.2 bc	88.9	78.1	83.5
CV (%)[2]	88.96	59.26			

Note. [1] Means followed by the same letter do not differ among themselves by the Tukey test ($P \leq 0.05$). [2]CV (%) = Coefficient of variation.

3.2 Experiment II

The population of stink bugs infesting the soybean plants in the second experiment (2017/18 cropping season) differed from the previous year, being composed of the species *Piezodorus guildinii* (44.3%), *Nezara viridula* (44.1%) and *Euschistus heros* (11.6%). The insecticide treatments were sprayed at a population density of 1.8 stink bugs m^{-2}.

The treatments T2 (lambda-cyhalothrin + thiamethoxam 106 + 141 g L^{-1}) and T3 (lambda-cyhalothrin 250 g L^{-1}) showed high *knockdown* effect on the stink bug population, which is probably associated to the presence of the pyrethroid lambda-cyhalothrin. Pyrethroids act on the axonal conduction of the nervous cells leading to hyperexcitation, and since nerve axons occur throughout the whole insect’s body, these substances cause symptoms as soon as they enter the organism and are considered extremely fast-acting (*knockdown* effect; Salgado, 2013).

These treatments presented also long residual activity (until 14 DA2S), agreeing with the results obtained by Farias et al. (2006), who observed long effect of residual and control of *Piezodorus guildinii* by lambda-cyhalothrin + thiamethoxam until 14 days after the spraying. Cui et al. (2010) points out that thiametoxan has high water solubility and significant rates of translocation through the xylem tissues, displaying a basipetal movement to the upper parts of the plant and an acropetal transport to leaf margins and interveinal spaces (Basso, Kuss, Pias, Muraro, & Cutti, 2016; Stamm et al., 2016). The robust plant systemicity resulted therein is probably one of the causes of the long residual activity presented by this neonicotinoid.

Alongside treatments T2 and T3, treatments T5 (beta-cyfluthrin + imidacloprid 12.5 + 100 g L^{-1}) and T7 (beta-cyfluthrin 125 g L^{-1}) also provided high residual control until 14 DA2A. In the environment, pyrethroids are rapidly degraded by UV light, water and oxygen, besides being strongly adsorbed to soil particles, which results in low soil mobility (Salgado, 2013). Therefore, the residual control observed in the treatments that contained insecticides of this chemical group is probably a result of the decrease in the resurgence of stink bugs (Gazzoni, Corso, & Miguel, 1999), allied to the high efficacy of lambda-cyhalothrin and beta-cyfluthrin in the control of stink bug nymphs (Kuhar et al., 2012).

The ANOVA analysis for the variable *number of stink bugs* pointed statistical significance for the factors *treatments* and *days after spraying* (Supplementary Table 1). Regarding the means of control efficiency, treatment T2 (lambda-cyhalothrin + thiamethoxam 106 + 141 g L^{-1}) presented the highest average mean, reaching up to 94.1% of control and keeping the infesting population under 3.7 stink bugs m^{-2}. Conversely, treatment T4 (thiamethoxam 250 g kg^{-1}) provided the lowest mortality (74.4% of control in average; see Table 3), presenting population densities as high as 12 stink bugs m^{-2} (see Table 2). All treatments except for T4 (thiamethoxam 250 g kg^{-1}) and T8 (acephate 750 g kg^{-1}) provided average means of control efficiency equal or higher than 80.0%, which is considered a satisfactory mortality (Table 3 and Supplementary Table 2).

Supplementary Table 2. Matrix of probabilities comparing between treatments from SAS's PROC GLM procedure, in both experiments

Experiment I

Least Squares Means for effect treatments P>|t| for H0: LSMean(i) = LSMean(j) Dependent Variable: Number of stink bugs.

i/j	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1		<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
2	<.0001[1]		0.3065	0.6087	0.7979	0.7979	0.8981	0.0974
3	<.0001	0.3065		0.1257	0.4428	0.4428	0.3707	0.5224
4	<.0001	0.6787	0.1257		0.4428	0.4428	0.5224	0.0306
5	<.0001	0.7979	0.4428	0.4428		1.0000	0.8981	0.1602
6	<.0001	0.7979	0.4428	0.4428	1.0000		0.8981	0.1602
7	<.0001	0.8981	0.3707	0.5224	0.8981	0.8981		0.1257
8	<.0001	0.0974	0.5224	0.0306	0.1602	0.1602	0.1257	

Experiment II

Least Squares Means for effect treatments P> |t| for H0: LSMean(i) = LSMean(j) Dependent Variable: Number of stink bugs.

i/j	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1		<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
2	<.0001		0.5610	<.0001	0.1713	0.0007	0.0133	0.0001
3	<.0001	0.5610		<.0001	0.4303	0.0045	0.0570	0.0009
4	<.0001	<.0001	<.0001		0.0005	0.1469	0.0166	0.3399
5	<.0001	0.1713	0.4303	0.0005		0.0387	0.2627	0.0105
6	<.0001	0.0007	0.0045	0.1469	0.0387		0.3399	0.6183
7	<.0001	0.0133	0.0570	0.0166	0.2627	0.3399		0.1469
8	<.0001	0.0001	0.0009	0.3399	0.0105	0.6183	0.1469	

Note. [1] Values of $P \leq 0.05$ are considered significant according to Tukey's test.

3.3 Two-season Analysis

In the comparison of means from the two cropping seasons, the treatments T2 (lambda-cyhalothrin + thiamethoxam 106 + 141 g L^{-1}) and T3 (lambda-cyhalothrin 250 g L^{-1}) provided the highest control efficiencies, reaching up to 84.8% and 84.2% of stink bug mortality, respectively (Table 3). These two treatments also presented the highest grain yields (Supplementary Table 3). Treatment T4 (thiamethoxam 250 g kg^{-1}) provided the lowest mean, with 72.9% of control, followed by treatment T6 (imidacloprid 700 g kg^{-1}), with 78.8%. Treatments T5 (beta-cyfluthrin + imidacloprid 12.5 + 100 g L^{-1}), T7 (beta-cyfluthrin 125 g L^{-1}) and T8 (acephate 750 g kg^{-1}) stayed all above the level considered satisfactory (80.0%), presenting 82.8%, 80.2% and 83.5% of stink bug control, respectively (Table 3).

Supplementry Table 3. Soybean grain yield (kg ha^{-1}) in response to the insecticide treatments sprayed in both experiments. Santa Maria, Rio Grande do Sul, Brazil

Treatments	**Experiment I**	**Experiment II**	**Mean**
1. Untreated control	3029.8	3044.9	3087.3
2. Lambda-cyhalothrin + thiamethoxam	4165.5	3411.1	3788.3
3. Lambda-cyhalothrin	4301.3	3539.1	3920.2
4. Thiamethoxam	3240.3	3880.1	3560.4
5. Beta-cyfluthrin + imidacloprid	3295.5	3477.5	3386.5
6. Imidacloprid	3697.3	3823.5	3760.4
7. Beta-cyfluthrin	3559.3	3461.3	3510.3
8. Acephate	-[1]	-	-

Note. [1]Data not available.

The means of control efficiency differed considerably between the two experiments, being overall higher and with less variation in the second year (2017/18 cropping season), as shown in Figure 1. These divergences of control efficiency observed for the same insecticide treatments between the two experiments can be attributed to the composition of the stink bug population, which was composed mainly of *Euschistus heros* in the first year (92.5%) and *Piezodorus guildinii* in the second (44.3%). Only treatment T8 (acephate 750 g kg^{-1}) presented lower control means in experiment II compared to experiment I; accordingly, acephate has been proved less effective in the control of *P. guildinii* when compared to other insecticides (Farias et al., 2006), which explains the higher performance of this active ingredient in the first year (where this species comprised only 2.3% of the stink bug population).

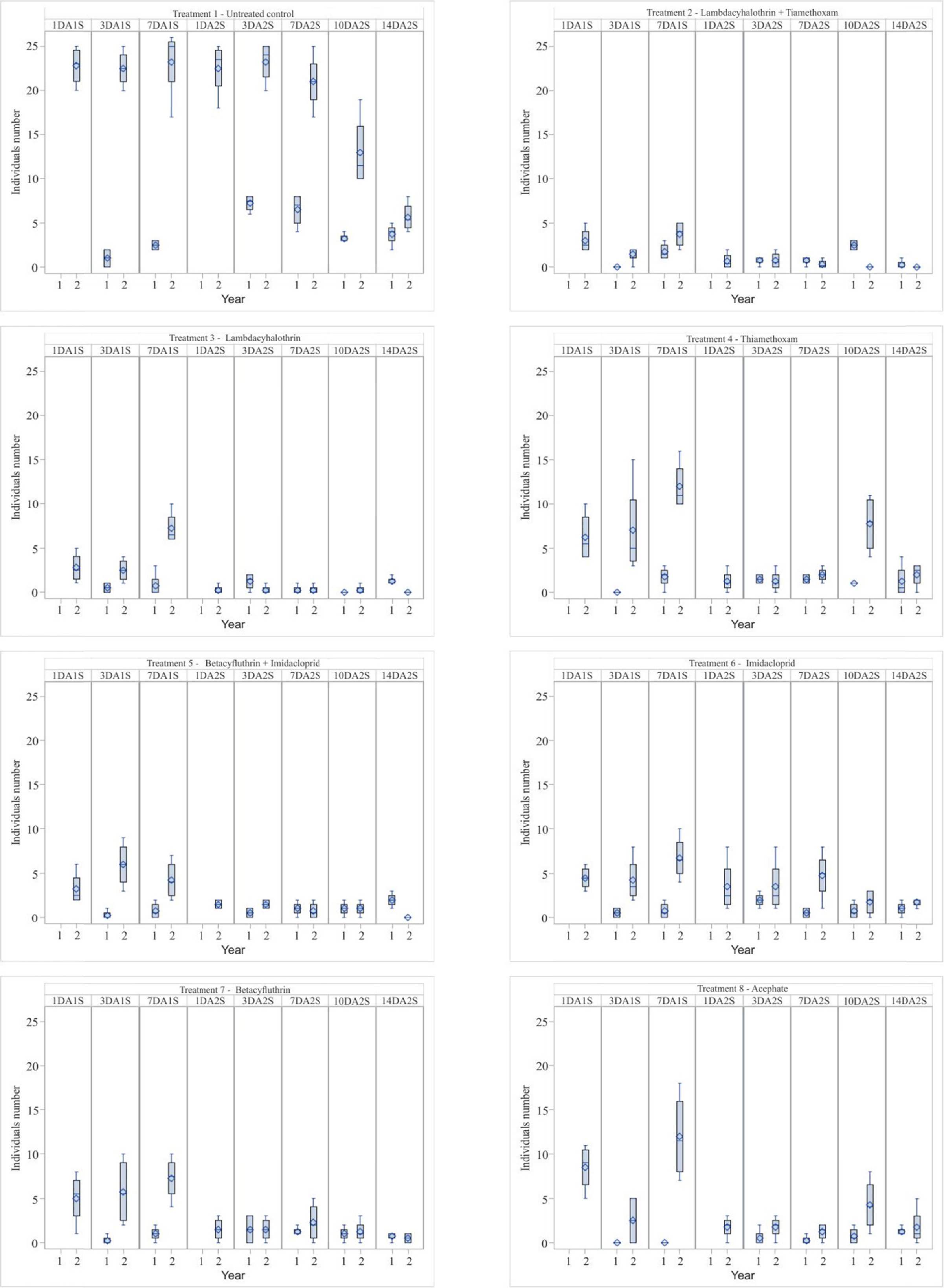

Figure 1. Number of stink bugs in response to the insecticide treatments sprayed, in the 2016/17 and 2017/18 cropping seasons and in each evaluation. Santa Maria, Rio Grande do Sul, Brazil

Regarding the lower means obtained in experiment I for most treatments, control failures of *E. heros* have already been reported for beta-cyfluthrin + imidacloprid, in the Brazilian state of Goiás, and for lambda-cyhalothrin + thiamethoxam in the Brazilian state of Paraná, as well as cases of resistance to methamidophos (Sosa-Gómez & Silva, 2010; Tuelher et al., 2017). According to Soares, Cordeiro, Santos, Omoto, and Correa (2018), *E. heros* populations have evolved through millennia into two genetic diverse lineages across the different Brazilian biomes, with the northern lineage (present in the Amazon and Caatinga biomes) being older and more diverse, and the southern lineage (prevalent in the Chaco and Atlantic Forest biomes) being younger and less diverse. Further contact between the two lineages is probably occurring due to the expansion of agricultural frontiers, and this combination might be one of the reasons for the increasing lack of control in this pest population.

While the combined use of pyrethroids and neonicotinoids remains efficient in the control of all major species of stink bugs, the growing occurrence of adapted populations of *E. heros* sets an alert to the long-term sustainability of this strategy, raising the need for alternative control methods inside the *integrated pest management* (IPM) approach. Accordingly, further studies should focus on this pest species in particular, aiming the construction of a control program both efficient and sustainable for the management of the neotropical brown stink bug on soybean crops.

4. Conclusions

(1) Lambda-cyhalothrin + thiamethoxam (106 + 141 g L^{-1}) is the most efficient treatment for the control of stink bugs in soybean, reaching 84.8% of control efficiency;

(2) The pyrethroid with highest control efficiency is lambda-cyhalothrin (250 g L^{-1}), presenting a high *knockdown* effect and preventing the resurgence of stink bugs in an order of 84.2%;

(3) The neonicotinoid with highest control efficiency is imidacloprid (700 g kg^{-1}), providing 14 days of residual control effect and reaching up to 78.8% of stink bug control**.**

References

AGROFIT (Sistema de Agrotóxicos Fitossanitários). (2018). *Consulta de Praga/Doença—Percevejo*. Brasília: Ministério da Agricultura, Pecuária e Abastecimento. Retrieved from http://agrofit.agricultura.gov.br/agrofit_cons/principal_agrofit_cons

Araújo, C. R. M., Santos, V. L. dos A., & Gonsalves, A. A. (2016). Acetylcholinesterase-AChE: A pharmacological interesting enzyme. *Revista Virtual de Química, 8*(6), 1818-1834. https://doi.org/10.21577/1984- 6835.20160122

Basso, C. J., Kuss, C. C., Pias, O. H. C. de, Muraro, D. S., & Cutti, L. (2016). Neonicotinoid insecticide systemicity in soybean plants and its effect on brown stink bugs. *Pesquisa Agropecuária Tropical, 46*(1), 96-101. https://doi.org/10.1590/1983-40632016v4638908

Braga, I. A., & Valle, D. (2007). *Aedes aegypti*: Inseticidas, mecanismos de ação e resistência. *Epidemiologia e Serviços de Saúde, 16*(4), 279-293. Retrieved from https://www.arca.fiocruz.br/handle/icict/18453

CONAB (Companhia Nacional de Abastecimento). (2018). *Observatório Agrícola: 2017/2018-Décimo primeiro levantamento*. Brasília: Ministério da Agricultura, Pecuária e Abastecimento.

Corrêa-Ferreira, B. S., Krzyzanowski, F. C., & Minami, C. A. (2009). *Percevejos e a qualidade da semente de soja—Série sementes.* Retrieved from https://www.embrapa.br/soja/busca-de-publicacoes/-/publicacao/471343/percevejos-e-a-qualidade-da-semente-de-soja---serie-sementes

Cui, L., Sun, L., Shao, X., Cao, Y., Yang, D., Li, Z., & Yuan, H. (2010). Systemic action of novel neonicotinoid insecticide IPP-10 and its effect on the feeding behaviour of *Rhopalosiphum padi* on wheat. *Pest Management Science, 66*(7), 779-785. https://doi.org/10.1002/ps.1942

Farias, J. R., França, J. A. S., Sulzbach, F., Bigolin, M., Fiorin, R. A., Maziero, H., & Guedes, J. V. C. (2006). Eficiência de tiametoxam + lambda-cialotrina no controle do percevejo-verde-pequeno, *Piezodorus guildinii* (Westwood, 1837) (Hemiptera: Pentatomidae) e seletividade para predadores na cultura da soja. *Revista da FZVA, 13*(2), 10-19.

Gazzoni, D. C., Corso, I. C., & Miguel, M. (1999). Effect of insecticides on predators and parasitoids of soybean pests. *Pesquisa Agropecuária Gaúcha, 5*(2), 255-264.

Guedes, J. V. C., Perini, C. R., Burtet, L. M., Stacke, R. F., Melo, A. A., & Arnemann, J. A. (2016). Lucro ameaçado. *Cultivar Grandes Culturas, 205*, 17-19.

Guedes, J. V. C., Farias, J. R., Guareschi, A., Roggia, S., & Lorentz, L. H. (2006). Capacidade de coleta de dois métodos de amostragem de insetos-praga da soja em diferentes espaçamentos entre linhas. *Ciência Rural, 36*, 1299-1302. https://doi.org/10.1590/ S0103-84782006000400040

IRAC (Insecticide Resistance Action Committee). (2018). *IRAC Mode of Action Classification Scheme*. Retrieved from https://www.irac-online.org/documents/moa-structures-poster-english/?ext=pdf

Kuhar, T., Doughty, H., Kamminga, K., Philips, C., Aigner, J., Wallingford, A., … Jenrette, J. (2012). *Performance of insecticides on brown marmorated stink bug on vegetables*. Virginia Cooperative Extension, Blacksburg. Retrieved from http://pubs.ext.vt.edu/content/dam/pubs_ext_vt_edu/ENTO/ENTO-28/ENTO-28_ PDF.pdf

Panizzi, A. R., & Slansky, Jr. F. (1985). Review of phytophagous pentatomids (Hemiptera: Pentatomidae) associated with soybean in the Americas. *Florida Entomologist, 68*(1), 184-214. https://doi.org/10.2307/3494344

Panizzi, A. R., & Grazia, J. (2001). Stink bugs (Heteroptera, Pentatomidae) and an unique host plant in the Brazilian subtropics. *Iheringia Série Zoologia, 90,* 21-35. https://doi.org/10.1590/S0073-47212001000100003

Salgado, V. L. (2013). *BASF Insecticide Mode of Action Technical Training Manual*. Retrieved from https://www.researchgate.net/publication/275959530_BASF_Insecticide_Mode_of_Action_Technical_Training_Manual

Soares, P. L., Cordeiro, E. M. G., Santos, F. N. S., Omoto, C., & Correa, A. S. (2018). The reunion of two lineages of the Neotropical brown stink bug on soybean lands in the heart of Brazil. *Scientific Reports, 8*(1), 2496. https://doi.org/10.1038/s41598-018-20187-6

Sosa-Gómez, D. R., & Silva, J. J. (2010). Neotropical Brown stink bug (*Euschistus heros*) resistance to methamidophos in Paraná, Brazil. *Pesquisa Agropecuária Brasileira, 45*(7), 767-769. https://doi.org/10.1590/S0100-204X2010000700019

Sosa-Gómez, D. R., & Omoto, C. (2012). Resistência a inseticidas e outros agentes de controle em artrópodes associados à cultura da soja. In C. B. Hoffmann-Campo, B. S. Corrêa-Ferreira, & F. Moscardi (Eds.), *Soja: Manejo integrado de insetos e outros artrópodes-praga* (pp. 673-723). Londrina, Embrapa Soja.

Stamm, M. D., Heng-Moss, T. M., Baxendale, F. P., Siegfried, B. D., Blankenship, E. E., & Nauen, R. (2016). Uptake and translocation of imidacloprid, clothianidin and flupyradifurone in seed-treated soybeans. *Pest Management Science, 72*, 1099-1109. https://doi.org/10.1002/ps.4152

Tuelher, E. S., Silva, E. H. da, Rodrigues, H. S., Hirose, E., Guedes, R. N. C., & Oliveir, E. E. (2017). Area-wide spatial survey of the likelihood of insecticide control failure in the neotropical brown stink bug *Euschistus heros*. *Journal of Pest Science, 91*(2), 849-859. https://doi.org/10.1007/s10340-017-0949-6

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