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Selectivity of chlorantraniliprole and lambda-cyhalothrin to the egg parasitoid *Telenomus podisi* (Hymenoptera: Platygasteridae)

Seletividade de chlorantraniliprole e lambda-cialotrina ao parasitoide de ovos *Telenomus podisi* (Hymenoptera: Platygasteridae)

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Abstract

Soybean plants host a diverse complex of pest insects, which can occur simultaneously during crop development. Thus, the use of egg parasitoids for the management of *Euschistus heros* (Fabricius) (Hemiptera: Pentatomidae) depends on the selectivity of the pesticides to the stink bug. Thus, the selectivity of the active ingredients chlorantraniliprole and chlorantraniliprole + lambda-cyhalothrin to the parasitoid *Telenomus podisi* (Ashmead) (Hymenoptera: Platygasteridae) was evaluated. The bioassays were carried out under controlled conditions (27 ± 2 °C and $50 \pm 10\%$ relative humidity) for the pupal and adult phases of the parasitoid. The design was completely randomized, with 10 treatments and five replicates composed of the insecticides chlorantraniliprole and chlorantraniliprole + lambda-cyhalothrin in different doses, as well as a negative control using water and a positive control using chlorpyrifos. We used a Potter Tower for the applications, and evaluations were carried out 24, 72, and 120 hours after the applications. Experimental methods and analyses to determine the harmfulness of the products to the insects were in accordance with International Organization for Biological Control standards. Chlorantraniliprole, at all doses tested, was less harmful to the parasitoid, especially in the adult phase; the doses were classified as class 1. The chlorantraniliprole + lambda-cyhalothrin mixture at its highest dose was classified as class 4, at 72 and 120 hours after application. For the pupal phase of the parasitoid, there were no significant differences, and the products were classified as class 1, except for the highest dose of chlorantraniliprole, which classified as class 2, at 24 hours after application. Thus, chlorantraniliprole can be considered a tool in the management of soybean pests. Its selectivity to *T. podisi* under the conditions tested presents low or no negative interference when sprayed on pupae and adults. However, the chlorantraniliprole + lambda-cyhalothrin mixture should be used with caution, respecting the time of application and the recommended doses, as it interferes negatively in the development of the parasitoid and should be replaced when possible.

Key words: Biological control. Chemical control. Integrated pest management. Soybean.

Resumo

A soja apresenta um diversificado complexo de insetos-praga, que podem ocorrer no mesmo período de desenvolvimento da cultura. Assim, a utilização de parasitoides de ovos para o manejo de *Euschistus heros* (Fabricius) (Hemiptera: Pentatomidae) depende em parte da seletividade dos agrotóxicos

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utilizados para o controle de pragas que atacam a lavoura concomitantemente aos percevejos. A partir disso, avaliou-se a seletividade dos princípios ativos chlorantraniliprole e chlorantraniliprole + lambdacialotrina no desenvolvimento do parasitoide *Telenomus podisi* (Ashmead) (Hymenoptera: Platygasteridae). Os bioensaios foram realizados em laboratório sob condições controladas (temperatura 27 ± 2 °C e UR $50 \pm 10\%$) nas fases de pupa e adulto do parasitoide. O delineamento utilizado foi inteiramente casualizado, com dez tratamentos e cinco repetições compostas pelos inseticidas chlorantraniliprole e chlorantraniliprole + lambdacialotrina em diferentes doses, bem como um controle negativo com água. As aplicações foram feitas com a Torre de Potter e as avaliações realizadas após 24, 72 e 120 horas. A condução do experimento e classificação utilizada para determinar a nocividade dos produtos aos insetos foi de acordo com as normas da IOBC (International Organization for Biological and Integrated Control). Chlorantraniliprole em todas as doses foi menos nocivo ao parasitoide, principalmente sobre a fase adulta, onde as doses se enquadraram na classe 1 (inócuo). A mistura chlorantraniliprole + lambdacialotrina em sua maior dose foi enquadrada na classe 4 (nocivo) às 72 e 120 horas após a aplicação. Para a fase de pupa do parasitoide, não houve diferenças significativas, sendo os produtos enquadrados na classe 1 (inócuo), exceto para a maior dose de clorantraniliprole, pertencente à classe 2 (levemente nocivo) 24 horas após a aplicação. Assim, chlorantraniliprole pode ser considerado uma ferramenta no manejo de pragas da soja considerando a sua seletividade a *T. podisi* nas condições testadas, pois não apresenta interferência negativa no desenvolvimento do parasitoide, quando pulverizado sobre pupas e adultos. Entretanto, a mistura chlorantraniliprole + lambda-cialotrina deve ser utilizada com cautela, respeitando-se o momento de aplicação e as doses recomendadas, pois interfere negativamente no desenvolvimento do parasitoide, devendo ser substituída quando possível.

Palavras-chave: Controle biológico. Controle químico. Manejo integrado de pragas. Soja.

Introduction

Integrated pest management (IPM) uses different control tactics in a concerted manner. The goal is to complement natural, biological forms of pest control and to maintain pest populations below the levels that cause damage, thus conserving the environment and beneficial arthropods. In this goal, parasitoids and agrochemicals can be used simultaneously, provided there is compatibility between these control methods (REISS et al., 1998; POLANCZYK et al., 2010). Thus, the selectivity of insecticides to natural enemies is of great importance and should be evaluated when choosing insecticides for IPM programs (BUENO et al., 2012).

Insecticide selectivity to natural enemies has been studied for decades (HASSAN et al., 1998; ZOTTI et al., 2008; FONSECA et al., 2012; DIAMANTINO et al., 2014). However, in addition to being specific to the biological organism under study and its phases of development, pesticide selectivity is directly related to its concentration (DESNEUX et al., 2004). Changes in dosage can directly impact its selectivity classification

(BUENO et al., 2017). Those changes can occur, for example, after occurrence of *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) in crops in Brazil (CZEPAK et al., 2013), when pesticides started to be used in higher concentrations than those normally recommended for other pest species, since target-pest populations already showed resistance to several insecticides (WYCKHUYS et al., 2013). Thus, such intensified use of insecticides can significantly impact beneficial entomofauna and lead to changes in IPM strategies (BUENO et al., 2008).

Helicoverpa armigera gained attention in soybeans, where it is detrimental throughout the vegetative and reproductive stages of plant development because it consumes leaves and pods (WANG; LI, 1984; CZEPAK et al., 2013). It occurs simultaneously with other important pests, such as the brown stink bug *Euschistus heros* (Fabricius) (Hemiptera: Pentatomidae). Considering the cultivation of soybeans as a system in which various organisms coexist, the chemical control of *H. armigera* can impact the natural biological control of other pests. Pesticides can have deleterious effects

on the natural enemies of the brown stink bug when nonselective products or abusive pesticide dosages are used (POMARI-FERNANDES et al., 2015).

Among the natural enemies of *E. heros*, the egg parasitoid *Telenomus podisi* (Ashmead) (Hymenoptera: Platygastridae) stands out as a species that shows a preference for this stink bug's eggs (CORRÊA-FERREIRA; AZEVEDO, 2002, DOETZER; FOERSTER, 2007). This further reinforces the importance of integrating different control tactics into IPM and the study of the selectivity of new products and/or new dosages.

Among the products used in the management of *H. armigera* are chlorantraniliprole and a mixture of chlorantraniliprole with lambda-cyhalothrin. However, few studies have assessed the effect of chlorantraniliprole or lambda-cyhalothrin on *T. podisi* at higher doses that might be used to control

H. armigera. Therefore, we evaluated the possible impacts of spraying chlorantraniliprole and lambda-cyhalothrin during the pupal and adult stages of *T. podisi* and determined the toxicity of different doses of those chemicals.

Materials and Methods

The insects used in the bioassays were taken from laboratory rearing that is maintained in the Embrapa Soybean. The eggs of *E. heros* that were used in the bioassays were previously stored in liquid nitrogen.

We used an application rate of 150 L ha⁻¹. The solutions for each treatment (Table 1) were sprayed through a Potter Tower previously calibrated to deposit 1.25 ± 0.25 mg per cm², accordingly standardized protocols recommended by the International Organization for Biological Control (IOBC) (HASSAN et al., 1985).

Table 1. Insecticides tested during the pupal and adult phases of the egg parasitoid *Telenomus podisi*.

Commercial product (c.p.)	Formulation	Active ingredient (a.i.)	Dose c.p. (mL ha ⁻¹)	Dose a.i. (g a.i. ha ⁻¹)
Premio®	200 SC	chlorantraniliprole ¹	50	10
Premio®	200 SC	chlorantraniliprole ¹	75	15
Premio®	200 SC	chlorantraniliprole ¹	100	20
Premio®	200 SC	chlorantraniliprole ¹	150	30
Premio®	200 SC	chlorantraniliprole ¹	250	50
Ampligo®	100/50 SC	chlorantraniliprole+ lambda-cyhalothrin ²	100	10 + 5
Ampligo®	100/50 SC	chlorantraniliprole+ lambda-cyhalothrin ²	300	30 + 15
Ampligo®	100/50 SC	chlorantraniliprole+ lambda-cyhalothrin ²	500	50 + 25
Water (negative control)	-	-	-	-
Lorsban 480BR® (positive control)	480 EC	chlorpyrifos	2000	960

¹Insecticide from the anthranilamides chemical group. ²Insecticide from the pyrethroids chemical group.

Selectivity of chlorantraniliprole and chlorantraniliprole + lambda-cyhalothrin to pupae of T. podisi

Cards containing *T. podisi* pupae inside *E. heros* eggs (13 days post-parasitism) were sprayed (parasitoids pupae approximately 24 hours before adult emergence). Subsequently, the cards remained in environmental conditions (27 ± 2 °C and $50 \pm 10\%$ RH) for 2 hours in order for the insecticide to dry. Thereafter, the cards were transferred to standard IOBC cages (DEGRANDE et al., 2002).

Contact cages proposed by Degrande et al. (2002), with glass panels composing the bottom and the top of the cage, were used. The outer surface of the glass plates was covered with black cardboard paper that had a center square (7 cm \times 7 cm) removed. The cards containing *T. podisi* pupae were inserted into the cages. Twenty-four, 72, and 120 h after the emergence of the parasitoids, new cards were inserted with approximately 70 *E. heros* eggs. The following parameter were evaluated: emergence of adults (%), parasitism (%) of F_0 generation, and emergence (%) of F_1 generation.

Parasitism capacity of T. podisi adults from pupae sprayed with chlorantraniliprole and chlorantraniliprole + lambda-cyhalothrin

We used four females, which emerged from sprayed eggs (Table 1), per replication for the bioassays. Approximately 40 *E. heros* eggs were attached to 2.5 cm \times 5 cm white paperboard cards. The cards were placed into Duran-type tubes containing droplets of pure honey for parasitoid feeding. They were then given to *T. podisi* females for parasitism. The tubes were sealed with plastic film and kept in temperature-controlled chambers regulated at 25 ± 2 °C and $70 \pm 10\%$ RH, with a photoperiod of 14/10 hours light/dark. Every 24 hours, the cards were removed and changed. This procedure was repeated daily for a period of 15 days. The cards removed from the tubes were placed into plastic bags and kept in the same environmental conditions as where

they were parasitized. We assessed the total number of parasitized eggs per female, lifetime parasitism (%), adult emergence (%), the longevity of parental females (days), and the sex ratio of the parasitoids.

Selectivity of chlorantraniliprole and chlorantraniliprole + lambda-cyhalothrin to T. podisi adults

Glass plates (13 \times 13 cm, 2 mm thick) were sprayed with various doses of the products (Table 1). Afterwards, they remained in environmental conditions (27 ± 2 °C and $50 \pm 10\%$ RH) for 2 hours, for complete evaporation of the pesticides, leaving a film of the product on the glass to allow for contact between the parasitoids and the insecticides. In the preparation of cages, the glass plates were covered externally with black cardboard paper, whose central square (7 cm \times 7 cm) was removed (DEGRANDE et al., 2002).

Telenomus podisi adults at 48 hours of age were inserted into the contact cage through emergence tubes (CARMO et al., 2009), connected through holes in the cages. The parasitoids were given cards containing 100 non-sprayed *E. heros* eggs after 24, 72, and 120 hours, to assess the parasitism of the F_0 generation, emergence of adults, and sex ratio of the F_1 generation. Cardstock cards containing honey droplets were placed inside each cage to feed the parasitoids.

Statistical analyses

The experiments were carried out using a completely randomized experimental design, with 10 treatments and five repetitions for each bioassay. The results were submitted to exploratory analyses to evaluate the normality assumptions of the residuals (SHAPIRO and WILK, 1965), the homogeneity of variance of the treatments, and the additivity of the model (BURR and FOSTER, 1972), to apply analysis of variance (ANOVA). The means were compared by the F test or the Tukey

test ($p \leq 0.05$) (SAS Institute, 2009). In addition, the effect of the treatments on *T. podisi* was determined by comparison with the negative control (water), calculated with the formula used by Hassan et al. (1985):

- Adults: $E_1(\%) = (1 - \text{Parasitism in the treatment} / \text{Parasitism in the negative control}) \times 100$;

- Pupae: $E_2(\%) = (1 - \text{Viability of sprayed pupae with the treatment} / \text{viability of the pupae in the negative control}) \times 100$.

Thus, the treatments were classified according to their toxicity: class 1 = innocuous ($E < 30\%$), class 2 = slightly harmful ($30\% \leq E < 80$), class 3 = moderately harmful ($80\% \leq E < 99$), and class 4 = noxious ($E \geq 99\%$) (HASSAN et al., 1985).

Results

Selectivity of chlorantraniliprole and chlorantraniliprole + lambda-cyhalothrin to *T. podisi* pupae

The largest percentage of *T. podisi* emergence (79.84%) occurred in the control treatment with water, followed by the lower concentrations of 10 and 15 g active ingredient (a.i.) ha^{-1} of chlorantraniliprole, with percentages of 71.34% and 73.53%, respectively. This was followed by the lowest concentration of 10 + 5 g a.i. ha^{-1} (chlorantraniliprole + lambda-cyhalothrin), with a percentage of 70.86% (Table 2). The emergence percentages were 66.00%, 67.02%, and 63.28% at the highest concentrations of 20, 30, and 50 g a.i. ha^{-1} of chlorantraniliprole, respectively. The mixture of 20 + 10 g a.i. ha^{-1} (chlorantraniliprole + lambda-cyhalothrin) had a percentage of 64.73%. The mixture with higher concentrations of chlorantraniliprole + lambda-cyhalothrin (30 + 15 g a.i. ha^{-1}) resulted in 54.05% emergence. The lowest percentage of emergence was observed in the chlorpyrifos treatment (51.09%) (Table 2).

Table 2. Emergence of *Telenomus podisi* from pupae sprayed with chlorantraniliprole and chlorantraniliprole + lambda-cyhalothrin in different doses.

Treatment (g a.i. ha^{-1})	Emergence (%) ^{1,2}
Chlorantraniliprole 10	71.34 ± 3.07ab
Chlorantraniliprole 15	73.53 ± 3.96ab
Chlorantraniliprole 20	66.00 ± 3.33abc
Chlorantraniliprole 30	67.02 ± 1.71abc
Chlorantraniliprole 50	63.28 ± 3.32abc
Chlorantraniliprole 10 + lambda-cyhalothrin 5	70.86 ± 2.93ab
Chlorantraniliprole 20 + lambda-cyhalothrin 10	64.73 ± 1.90abc
Chlorantraniliprole 30 + lambda-cyhalothrin 15	54.05 ± 1.09dc
Water	79.84 ± 4.30a
Chlorpyrifos 960	51.09 ± 3.32d
CV (%)	10.32
F	8.04
p	< 0.0001

¹Means (± SE) followed by the same letter in the column do not differ by the Tukey test ($p \leq 0.05$). ²Emergence (%) of *T. podisi* that were sprayed in the pupal phase with chlorantraniliprole and chlorantraniliprole + lambda-cyhalothrin in various concentrations.
^{ns}ANOVA not significant.

For the percentage of parasitism of adults that emerged from sprayed pupae, for all periods tested, the chlorpyrifos spray resulted in the lowest values. These values were 28.24%, 29.12%, and 16.85%, respectively, at 24, 72, and 120 hours. The percentage of parasitism 24 hours after emergence was higher for the water treatment (77.48%) and for 20 g a.i. ha⁻¹ of chlorantraniliprole (73.48%). Chlorantraniliprole at 50 g a.i. ha⁻¹ resulted in a lower percentage of parasitism at 53.12% (Table 3).

At 72 hours after emergence, the highest percentage of parasitism was observed in the treatment with 15 g a.i. ha⁻¹ of chlorantraniliprole (77.4%). For chlorantraniliprole at 50 g a.i. ha⁻¹, a lower percentage of parasitism was observed: 52.93%. The other treatments ranged from 58.28% for the mixture of chlorantraniliprole + lambda-cyhalothrin at 30 + 15 g a.i. ha⁻¹, to 69.4% for 10 + 5 g a.i. ha⁻¹. For parasitism at 120 hours, the values were more than 70%, with no difference among the treatments, except for chlorpyrifos (Table 3).

Regarding the classification of parasitoid toxicity, the results indicate that the concentrations were

within class 1 (innocuous) according to the IOBC classification, except for 50 g a.i. ha⁻¹ of chlorantraniliprole, which was classified as slightly harmful (class 2) (Table 4).

Parasitism capacity of T. podisi adults from pupae sprayed with chlorantraniliprole and chlorantraniliprole + lambda-cyhalothrin

The total number of parasitized eggs was significantly lower only in the chlorpyrifos treatment, where each non-sprayed female

parasitized 0.5 *E. heros* eggs (Table 5). Females sprayed with chlorantraniliprole, chlorantraniliprole + lambda-cyhalothrin, and water parasitized between 79.20 eggs in the treatment with 20 g a.i. ha⁻¹ chlorantraniliprole to 106.6 eggs in the treatment with water (Table 5).

Significant differences occurred in the emergence of *T. podisi* only for the treatment with chlorpyrifos, with a percentage of 8.33%. The remaining treatments varied between 47.93% and 58.20% viability for chlorantraniliprole at 15 g a.i. ha⁻¹ and chlorantraniliprole + lambda-cyhalothrin at 30 + 15 g a.i. ha⁻¹, respectively, without significant differences (Table 5).

The sex ratio was shown to vary according to the product/concentration tested. There was emergence of 100% males in the treatment with chlorpyrifos and 86% in the mixture of chlorantraniliprole + lambda-cyhalothrin at 20 + 10 g a.i. ha⁻¹. For the other treatments, the sex ratio did not differ and had values between 0.36 for the mixture of chlorantraniliprole + lambda-cyhalothrin at 30 + 15 g a.i. ha⁻¹ to 0.66 for chlorantraniliprole at 50 g a.i. ha⁻¹ (Table 5).

The longevity of the parent females was lower for chlorpyrifos (1 day) and higher for water (19.55 days). Among the tested concentrations of chlorantraniliprole and chlorantraniliprole + lambda-cyhalothrin at 10 + 5 and 20 + 10 g a.i. ha⁻¹, there was no difference, with variations between 14.85 and 17.85 days for the treatments of chlorantraniliprole at 30 g a.i. ha⁻¹ and chlorantraniliprole + lambda-cyhalothrin at 10 + 5 g a.i. ha⁻¹, respectively. Females treated with the higher concentration mixture (30 + 10 g a.i. ha⁻¹) had a longevity of approximately 14.20 days (Table 5).

Table 3. Parasitism of the F₀ generation and emergence of the F₁ generation of *Telenomus podisi* from pupae sprayed with chlorantraniliprole and chlorantraniliprole + lambda-cyhalothrin in different doses.

Treatment (g. a.i. ha ⁻¹)	Hours after emergence					
	24 h		72 h		120 h	
	¹ Parasitism	¹ Emergence	Parasitism ¹	Emergence ¹	Parasitism ¹	Emergence ¹
Chlorantraniliprole 10	71.05 ± 2.39 ^{ab}	40.15 ± 4.21 ^{ns}	66.31 ± 1.52 ^{ab}	60.04 ± 10.41 ^{ns}	81.67 ± 3.20 ^a	69.8 ± 3.79 ^{ns}
Chlorantraniliprole 15	69.27 ± 3.43 ^{ab}	39.95 ± 4.79	77.4 ± 3.06 ^a	63.73 ± 11.27	78.45 ± 2.74 ^a	66.47 ± 1.97
Chlorantraniliprole 20	73.48 ± 3.95 ^a	38.38 ± 3.40	63.81 ± 2.76 ^{ab}	68.52 ± 13.26	75.69 ± 5.56 ^a	64.36 ± 3.43
Chlorantraniliprole 30	61.372 ± 4.18 ^{ab}	51.75 ± 5.01	66.72 ± 4.71 ^{ab}	47.96 ± 1.76	73.82 ± 1.92 ^a	72.63 ± 2.93
Chlorantraniliprole 50	53.12 ± 4.65 ^b	47.87 ± 2.04	52.93 ± 2.30 ^b	72.52 ± 16.05	74.81 ± 4.15 ^a	64.64 ± 4.1
Chlorantraniliprole 10 + lambda-cyhalothrin 5	66.512 ± 5.35 ^{ab}	45.54 ± 4.16	69.4 ± 2.00 ^{ab}	64.2 ± 9.69	81.66 ± 3.17 ^a	67.68 ± 4.03
Chlorantraniliprole 20 + lambda-cyhalothrin 10	66.742 ± 1.83 ^{ab}	45.7 ± 4.63	59.98 ± 5.20 ^{ab}	67.4 ± 13.49	71.2 ± 3.39 ^a	73.31 ± 1.88
Chlorantraniliprole 30 + lambda-cyhalothrin 15	61.09 ± 4.76 ^{ab}	51.77 ± 2.47	58.28 ± 7.31 ^{ab}	67.92 ± 13.96	82.68 ± 1.37 ^a	63.69 ± 2.1
Water	77.48 ± 1.83 ^a	50.04 ± 3.51	61.91 ± 6.12 ^{ab}	66.91 ± 8.53	71.02 ± 3.48 ^a	71.06 ± 2.45
Chlorpyrifos 960	28.24 ± 3.69 ^c	55.44 ± 4.25	29.12 ± 0.83 ^c	70.15 ± 11.44	16.85 ± 7.11 ^b	73.23 ± 5.1
CV (%)	13.48	18.86	15.46	38.99	12.36	10.49
F	13.63	2.06	7.99	0.36	19.69	1.35
p	< 0.0001	0.0583	< 0.0001	0.945	< 0.0001	0.2433

¹Means (± SE) followed by the same letter in the column do not differ by the Tukey test ($p > 0.05$). ^{ns} ANOVA not significant.

Table 4. Effect of different insecticides and doses on pupae of *Telenomus podisi* and their classification according to the norms of the International Organization for Biological Control (IOBC).

Treatment (g. a.i. ha ⁻¹)	24 h		72 h		120 h	
	E% ¹	Class ²	E% ¹	Class ²	E% ¹	Class ²
Chlorantraniliprole 10	8.3	1	0	1	0	1
Chlorantraniliprole 15	10.6	1	0	1	0	1
Chlorantraniliprole 20	5.1	1	0	1	0	1
Chlorantraniliprole 30	20.8	1	0	1	0	1
Chlorantraniliprole 50	31.4	2	14.5	1	0	1
Chlorantraniliprole 10 + lambda-cyhalothrin 5	14.1	1	0	1	0	1
Chlorantraniliprole 20 + lambda-cyhalothrin 10	13.9	1	3.1	1	0	1
Chlorantraniliprole 30 + lambda-cyhalothrin 15	21.1	1	5.9	1	0	1
Chlorpyrifos 960	63.5	2	52.9	2	76.3	2

1E (%) = $(1 - Vt/Vc) \times 100$; where, E (%) is the percentage of reduction in parasitism or emergence of parasitoids; 2Classes: 1 = innocuous (E < 30%), 2 = slightly harmful (30 ≤ E ≤ 79%), 3 = moderately harmful (80 ≤ E ≤ 99%), and 4 = noxious (E > 99%).

Table 5. Total number of eggs parasitized/female, emergence (%), sex ratio, and longevity (days) of female *Telenomus podisi* adults from pupae sprayed with various concentrations of chlorantraniliprole and chlorantraniliprole + lambda-cyhalothrin.

Treatments (dose/150 L H ₂ O)	Total eggs parasitized/female ¹	Emergence ¹	Sex Ratio ¹	Longevity of female parents ¹
Chlorantraniliprole 10	84.85 ± 7.63a	58.05 ± 3.16a	0.47 ± 0.01a	15.70 ± 1.12ab
Chlorantraniliprole 15	95.07 ± 9.88a	47.93 ± 4.85a	0.45 ± 0.07ab	15.85 ± 1.56ab
Chlorantraniliprole 20	79.20 ± 10.23a	55.04 ± 3.57a	0.58 ± 0.02a	15.75 ± 1.38ab
Chlorantraniliprole 30	102.85 ± 3.86a	55.41 ± 2.99a	0.61 ± 0.04a	14.85 ± 0.80ab
Chlorantraniliprole 50	96.30 ± 3.94a	55.22 ± 2.79a	0.66 ± 0.05a	15.65 ± 1.34ab
Chlorantraniliprole 10 + lambda-cyhalothrin 5	99.95 ± 6.85a	56.15 ± 2.39a	0.49 ± 0.09a	17.85 ± 1.09ab
Chlorantraniliprole 20 + lambda-cyhalothrin 10	93.55 ± 4.10a	53.98 ± 2.96a	0.14 ± 0.05bc	15.55 ± 0.49ab
Chlorantraniliprole 30 + lambda-cyhalothrin 15	92.06 ± 9.51a	58.20 ± 1.59a	0.36 ± 0.03ab	14.20 ± 1.56b
Water	106.60 ± 7.44a	54.81 ± 3.67a	0.40 ± 0.05ab	19.55 ± 0.17a
Chlorpyrifos 960	0.5 ± 0.36b	8.33 ± 8.33b	0c	1.00 ± 0.00c
CV (%)	16.18	14.18	24.44	14.47
F	20.05	13.20	8.67	22.42
p	< 0.0001	< 0.0001	< 0.0001	< 0.0001

¹Means (± SE) followed by the same letter in the column do not differ according to the Tukey test ($p > 0.05$).

The lifetime parasitism decreased over the life of the females. For all treatments, peaks in parasitism occurred on the first and third day of egg exposure (Figures 1 and 2). The maximum amount of parasitized eggs per day was observed for the treatment containing chlorantraniliprole at 30 g a.i. ha⁻¹ (Figures 1 and 2). For the same treatment, a

parasitism rate of 80% was reached between days 8 and 9. The other treatments ranged from the day 9 to 10, as well as having a lower number of parasitized eggs per day (1.2 eggs) on the day 15. For chlorpyrifos, due to the mortality rate of 100% of the parasitoids, it was not possible to assess parasitism capacity.

Figure 1. Parasitism of *Telenomus podisi* on *Euschistus heros* eggs when chlorantraniliprole has been applied; A) 10 g a.i. ha⁻¹ chlorantraniliprole (Premio®); B) 15 g a.i. ha⁻¹ chlorantraniliprole (Premio®); C) 20 g a.i. ha⁻¹ chlorantraniliprole (Premio®); D) 30 g a.i. ha⁻¹ chlorantraniliprole (Premio®); E) 50 g a.i. ha⁻¹ chlorantraniliprole (Premio®). The arrows indicate 80% of lifetime parasitism.

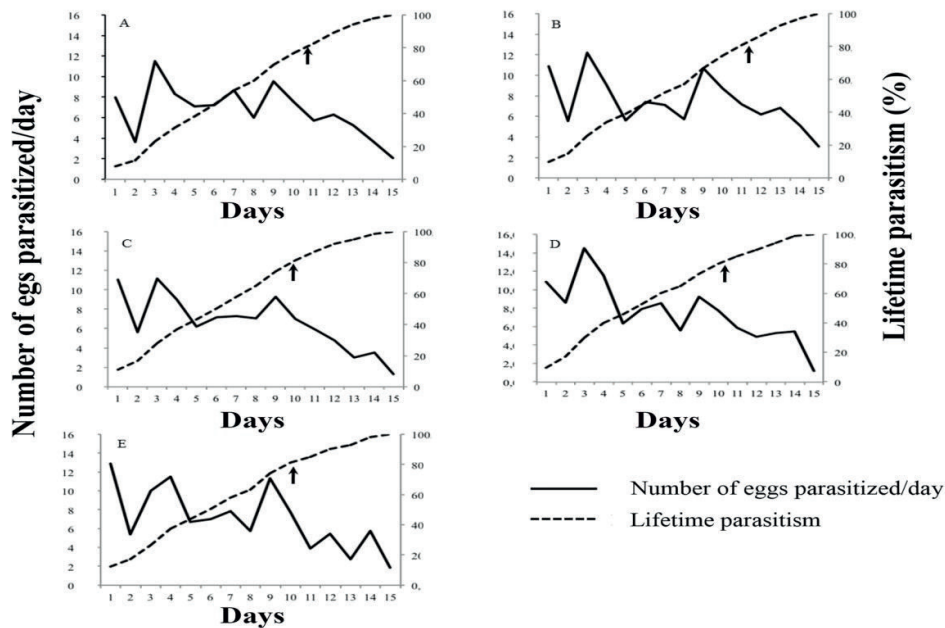
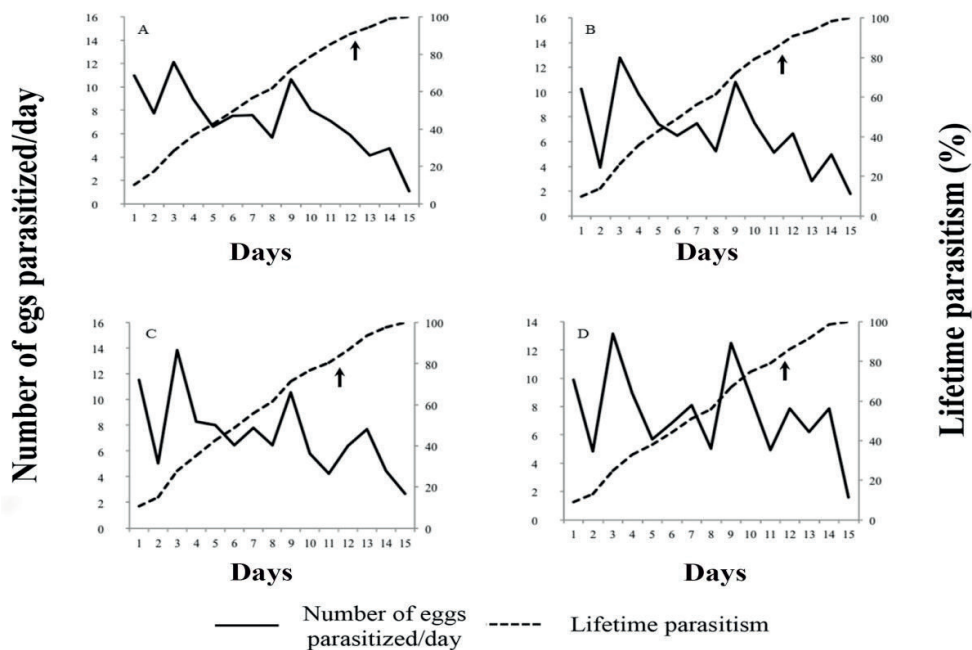


Figure 2. Parasitism of *Telenomus podisi* on *Euschistus heros* eggs where chlorantraniliprole + lambda-cyhalothrin has been applied; A) 10 + 5 g a.i. ha⁻¹ chlorantraniliprole + lambda-cyhalothrin (Ampligo®); B) 20 + 10 g a.i. ha⁻¹ chlorantraniliprole + lambda-cyhalothrin (Ampligo®); C) 30 + 15 g a.i. ha⁻¹ chlorantraniliprole + lambda-cyhalothrin (Ampligo®); D) negative control – water. The arrows indicate 80% of lifetime parasitism.



Selectivity of chlorantraniliprole and chlorantraniliprole + lambda-cyhalothrin to T. podisi adults

The percentage of parasitism varied among treatments in all periods tested and, at 24 hours, did not exceed 47%. The lowest level of parasitism occurred in the treatment with chlorpyrifos (1.27%), followed by the mixture of chlorantraniliprole + lambda-cyhalothrin at 30 + 15 g a.i. ha⁻¹ (15.12%), chlorantraniliprole + lambda-cyhalothrin at 20 + 10 g a.i. ha⁻¹ (28.45%), and chlorantraniliprole + lambda-cyhalothrin at 10 + 5 g a.i. ha⁻¹ (31.15%). Treatments with chlorantraniliprole, as well as with water, had similar percentages. 72 hours after contact between *T. podisi* adults and the respective products, the percentage of parasitism was similar in the concentrations of chlorantraniliprole and water, with values between 63.30% and 82.53% for chlorantraniliprole at 30 g a.i. ha⁻¹ and 10 g a.i. ha⁻¹, respectively. For the chlorantraniliprole + lambda-cyhalothrin mixtures at 10 + 5 g a.i. ha⁻¹ and 20 + 10 g a.i. ha⁻¹, parasitism was lower than for the other treatments, with percentages of 53% and 25.33%, respectively. For the highest concentration of the chlorantraniliprole + lambda-cyhalothrin mixture at 30 + 15 g a.i. ha⁻¹ and the positive control of chlorpyrifos, after 72 hours, there was no parasitism (Table 6). In the last assessment, 120 hours after adult contact with pesticides, parasitism did not differ between chlorantraniliprole and water, with values between 67.04% (30 g a.i. ha⁻¹ chlorantraniliprole) and 83.54% (10 g a.i. ha⁻¹ chlorantraniliprole). The

mixture of chlorantraniliprole + lambda-cyhalothrin at 10 + 5 g a.i. ha⁻¹ showed the lowest percentage of parasitism (11.33%). For the mixtures with the highest doses, as well as the positive control with chlorpyrifos, there was no parasitism observed due to death of the parasitoids (Table 6).

Data on emergence differed only at 24 hours, when the lowest value observed was that of the treatment with chlorpyrifos (25%) and the highest values were for the mixture of chlorantraniliprole + lambda-cyhalothrin at 30 + 15 g a.i. ha⁻¹ (64.63%), chlorantraniliprole at 20 g a.i. ha⁻¹ (61%), chlorantraniliprole at 10 g a.i. ha⁻¹ (60%), and chlorantraniliprole + lambda-cyhalothrin at 10 + 5 g a.i. ha⁻¹ (58.17%). In the other treatments, the percentages of emergence were intermediate (Table 6).

Regarding the classification of toxicity of insecticides according to IOBC parameters, all the concentrations of chlorantraniliprole tested were not toxic to parasitoids at 24, 72, and 120 hours after contact with adult insects. The mixture of chlorantraniliprole + lambda-cyhalothrin 10 g a.i. + 5 ha⁻¹ was not toxic to the parasitoid 24 and 72 hours after contact with adult insects. These concentrations were classified as harmless (class 1) (Table 7). The mixture of chlorantraniliprole + lambda-cyhalothrin at 10 + 5 g a.i. ha⁻¹, 120 hours after contact with the parasitoids, caused an 86.31% reduction in parasitism of adults and was thus classified as moderately harmful (Table 7).

Table 6. Parasitism (%) and emergence (%) of *Telenomus podisi* in *Euschistus heros* eggs after contact between parasitoid adults with chlorantraniliprole and chlorantraniliprole + lambda-cyhalothrin at different doses.

Treatments g. a.i. ha ⁻¹	24h ²		72h ²		120h ²	
	Parasitism ¹	Emergence ¹	Parasitism ¹	Emergence ¹	Parasitism ¹	Emergence ¹
Chlorantraniliprole 10	41.90 ± 1.97a	60.05 ± 5.25a	82.53 ± 1.74a	50.72 ± 10.61 ^{ns}	83.54 ± 2.94a	65.45 ± 3.31 ^{ns}
Chlorantraniliprole 15	43.53 ± 2.62a	46.39 ± 5.48ab	72.62 ± 5.52a	67.68 ± 5.66	79.84 ± 0.28a	64.07 ± 6.17
Chlorantraniliprole 20	42.96 ± 1.05a	61.00 ± 3.70a	67.59 ± 5.69a	61.26 ± 6.10	72.06 ± 7.11a	65.00 ± 5.27
Chlorantraniliprole 30	43.45 ± 3.28a	55.43 ± 5.78ab	63.30 ± 8.40a	74.55 ± 7.17	67.04 ± 4.51a	63.93 ± 9.69
Chlorantraniliprole 50	46.69 ± 1.48a	50.81 ± 5.21ab	71.08 ± 8.65a	53.19 ± 9.43	81.50 ± 5.38	59.70 ± 9.60
Chlorantraniliprole 10 + lambda-cyhalothrin 5	31.15 ± 3.52bc	58.17 ± 4.51a	53.00 ± 6.05ab	64.73 ± 13.30	11.33 ± 11.33b	70.36 ± 4.20
Chlorantraniliprole 20 + lambda-cyhalothrin 10	28.45 ± 1.12c	51.02 ± 6.43ab	25.33 ± 11.0bc	87.83 ± 5.98	. ³	. ³
Chlorantraniliprole 30 + lambda-cyhalothrin 15	15.12 ± 2.10d	64.63 ± 10.39a	0.00 ± 0.00c	. ³	. ³	. ³
Water	41.37 ± 2.10ab	51.42 ± 4.79ab	63.50 ± 11.29 ^a	54.06 ± 12.59	82.81 ± 6.45 a	63.03 ± 4.78
Chlorpyrifos 960	1.27 ± 0.77e	25.00 ± 25.00b	0.00 ± 0.00c	. ³	. ³	. ³
CV (%)	14.34	26.72	30.53	26.63	17.70	21.94
F	45.25	1.69	20.14	2.54	94.75	0.20
p	<0.0001	0.1258	<0.0001	0.0566	<0.0001	0.9720

¹Means (± SE) followed by the same letter in the column do not differ statistically according to the Tukey test (p > 0.05); ²Original data arcsine transformed $\sqrt{X/100}$. ³There were no insects to assess. ^{ns}ANOVA not significant.

Table 7. Effect of different insecticides and doses on adults of *Telenomus podisi* and their classification according to the norms of the International Organization for Biological Control (IOBC).

Treatments g. a.i. ha ⁻¹	24 h		72 h		120 h	
	E% ¹	Class ²	E% ¹	Class ²	E% ¹	Class ²
Chlorantraniliprole 10	0	1	0	1	0	1
Chlorantraniliprole 15	0	1	0	1	3.6	1
Chlorantraniliprole 20	0	1	0	1	12.9	1
Chlorantraniliprole 30	0	1	0.4	1	19.0	1
Chlorantraniliprole 50	0	1	0	1	1.6	1
Chlorantraniliprole 10 + lambda-cyhalothrin 5	24.7	1	19.6	1	86.3	3
Chlorantraniliprole 20 + lambda-cyhalothrin 10	31.2	2	60.1	2	100	4
Chlorantraniliprole 30 + lambda-cyhalothrin 15	63.4	2	100	4	100	4
Chlorpyrifos 960	96.9	3	100	4	100	4

¹E (%) = $(1 - Vt/Vc) \times 100$; where, E (%) is the percentage of reduction in parasitism or emergence of parasitoids; ²Classes: 1 = innocuous (E < 30%), 2 = slightly harmful (30 ≤ E ≤ 79%), 3 = moderately harmful (80 ≤ E ≤ 99%), and 4 = noxious (E > 99%).

The highest concentrations of the mixtures – chlorantraniliprole + lambda-cyhalothrin at 20 + 10 g a.i. ha⁻¹ and 30 + 15 g a.i. ha⁻¹ – reduced parasitism after 24 hours to 31.23% and 63.44%, respectively. These concentrations were classified as somewhat noxious (Table 7). At 72 hours after contact with the parasitoids, the same mixtures reduced parasitism to 60.13% and 100%, respectively, and were considered slightly noxious at 20 + 10 g a.i. ha⁻¹ and noxious at 30 + 15 g a.i. ha⁻¹. After 120 hours, both reduced the parasitism of *T. podisi* by 100% and were classified as noxious (Table 7).

Spraying with chlorpyrifos was classified as moderately harmful 24 hours after contact with parasitoids, with a 96.92% reduction in parasitism (Table 7). For the other periods tested, 72 hours and 120 hours after contact, the reduction in parasitism was 100%, resulting in a classification of noxious to *T. podisi* adults (Table 7).

Discussion

Even with the reported toxicity of chlorantraniliprole in different doses to non-target organisms belonging to various groups, such as *Daphnia magna* (Crustacea) (LAVTIZAR et al., 2015) and to nymphs of *Amphiareus constrictus*

(Stal) and *Blaptostethus pallescens* (Poppius) (Heteroptera: Anthocoridae) (GONTIJO et al., 2015), in general, this study found no significant influence of this product on the development of *T. podisi*. Accordingly, the product shows characteristics that allow us to consider it to be selective (LAHM et al., 2009; SPARKS et al., 2015). In addition, this molecule acts mainly on insects of the order Lepidoptera (IRAC, 2016), which may be related to its low degree of interference in the *T. podisi* parasitoid.

Thus, chlorantraniliprole has been classified as harmless to adult insects and pupae, except at the highest dose tested (50 g a.i. ha⁻¹). Similar results were observed for other species of egg parasitoids of the Trichogrammatidae family (PREETHA et al., 2009; BRUGGER et al., 2010; UMA et al., 2014) and for *T. podisi* in rice (PAZINI et al., 2016), where chlorantraniliprole was classified as innocuous at 31.5 g a.i. ha⁻¹. However, the highest dose of chlorantraniliprole still needs to be assessed in the field, where variables such as rain, wind, sunlight, and others minimize the action of the product on the organism. Additional studies are needed to address these factors.

In tests with *Trichogramma galloi* (Zucchi) (Hymenoptera: Trichogrammatidae),

chlorantraniliprole led to a reduction in mortality of less than 30% and was classified as innocuous at 350 g a.i. ha⁻¹ (OLIVEIRA et al., 2013). For *Trichogramma pretiosum* pupae (Riley) (Hymenoptera: Trichogrammatidae), chlorantraniliprole was considered slightly harmful (BARROS, 2016), which in the present study occurred only with the highest dose of the product, in the first 24 hours of assessment for *T. podisi*. For adult insects, at all concentrations and periods tested, chlorantraniliprole was shown to be innocuous. Generally, the adult phase of the parasitoid is more sensitive to pesticides, compared to the pupal phase, which is considered more tolerant (CARMO et al., 2009). This is because the pupa is protected within the egg of the host during the pupal phase. The chorion of the host egg provides protection to the developing parasitoid, preventing the pesticide from reaching the parasitoid pupa inside the host (BUENO et al., 2017). However, the higher toxicity of chlorantraniliprole on pupae observed in this work can be explained by the penetration of the product through the chorion of host eggs due to their lipophilicity, thus leading to lack of viability of adult emergence (MACBEAN, 2012).

According to Brugger et al. (2010), there is no significant reduction in the emergence of *T. pretiosum* after application of chlorantraniliprole to *H. armigera* eggs. According to those authors, this insecticide can be viably used in IPM programs due to its selectivity with regard to non-target organisms, especially parasitoids. This result was also found in the present study. Thus, chlorantraniliprole-based products may allow for the concurrent use of biological and chemical control, with regard to the use of *T. podisi*.

In this study, the mixture of chlorantraniliprole + lambda-cyhalothrin significantly reduced the parasitism of *T. podisi*. Its negative effect intensified during the assessments, classified at 120 hours as harmful at the highest concentrations tested.

According to Paiva (2016), the effect of the mixture of pyrethroid and neonicotinoid was also harmful to the *T. pretiosum* parasitoid. With the present results, decreased parasitism was also observed under the effect of chlorantraniliprole + lambda-cyhalothrin, demonstrating negative interference in the performance of the insect. This fact can be explained by the different modes of action of the insecticides, which together intensified their effect on parasitoid activity.

Regarding the parasitic capacity of the F₁ generation of *T. podisi*, neither chlorantraniliprole nor the mixture of chlorantraniliprole + lambda-cyhalothrin affected the total number of eggs that were parasitized, the viability of parasitism, or the sex ratio. This demonstrates that the spraying of various products and doses does not affect performance of the second generation of the parasitoid (sublethal effects).

In general, the adult phase of *T. podisi* was more sensitive to the products and doses applied. This pattern was also observed for other species of parasitoids (BUENO et al., 2008). Thus, the present study provides information for making choices about the insecticide to be used in pest management, favoring the integration of chemical and biological control, with the aim of better preserving natural enemies in agroecosystems.

Conclusion

Chlorantraniliprole was selective to *T. podisi* at the doses studied and can be considered a tool in IPM for soybeans, since it demonstrates low or null negative interference in the development of the parasitoid when sprayed on pupae and adults. However, the mixture of chlorantraniliprole + lambda-cyhalothrin should be used with caution in IPM, as it interferes negatively in the development of the parasitoid and should be substituted with a more selective product whenever possible.

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