Control of *Spodoptera frugiperda* in different larval ínstars in soybean crops

Controle de *Spodoptera frugiperda* em diferentes ínstares larvais na cultura da soja

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ABSTRACT
Spodoptera caterpillars are emerging as significant defoliators in the soybean crop, causing significant yield losses. Among the species, *Spodoptera frugiperda* (Smith, 1797) (Lepidoptera: Noctuidae) stands out among the species due to its strong ability for polyphagy and migratory habits. This study sought to assess the efficacy of chemical insecticides in the control of *S. frugiperda* in soybean crops. The experiment was conducted in a laboratory setting with a completely randomized design using seven treatments. The applications were carried out in the field, using the soybean cultivar BMX Icon. After the natural drying of the insecticides, leaves were collected from the upper part of the plants, and these were supplied to the caterpillars in the laboratory. For lab

infestations, three larval instars were used to determine mortality and leaf consumption (cm²). The results indicated that insecticides chlorfenapyr, spinetoram, chlorantraniliprole, indoxacarb + novaluron and thiamethoxam + lambda-cyhalothrin are efficient for the control of 1st instar caterpillars. Moreover, the insecticides chlorfenapyr, spinetoram, chlorantraniliprole and indoxacarb + novaluron are efficient for the control of 3rd and 5th instar caterpillars. There was no residual effect at 14 days after insecticide application.

Keywords: integrated pest management, chemical control, fall armyworm, noctuidae.

RESUMO
As lagartas do gênero *Spodoptera* estão se destacando como desfolhadoras importantes na cultura da soja, podendo ocasionar perdas notáveis na produção. Entre as espécies, se ressalta a *Spodoptera frugiperda* (Smith, 1797) (Lepidoptera: Noctuidae) com o seu alto potencial de polifagia e hábitos migratórios. O presente trabalho objetivou avaliar a eficiência de inseticidas químicos no controle de *S. frugiperda* na cultura da soja. O experimento foi conduzido no laboratório em delineamento inteiramente casualizado, com sete tratamentos. As aplicações foram realizadas no campo, utilizando a cultivar de soja BMX Ícone e após a secagem natural dos inseticidas, foram coletadas folhas do terço superior das plantas, e essas fornecidas as lagartas em laboratório. Para as infestações em laboratório foram utilizadas lagartas de três ínstares larvais, analisando a mortalidade e o consumo foliar (cm²). Os resultados comprovaram que os inseticidas clorfenapir, espinetoram, clorantraniliprole, indoxacarbe + novalurom e tiametoxam + lambda-cialotrina são eficientes para o controle de lagartas de 1° ínstar. Os inseticidas clorfenapir, espinetoram, clorantraniliprole e indoxacarbe + novalurom são eficientes para o controle de lagartas de 3° e 5º instares. Não foi verificado efeito residual aos 14 dias após a aplicação dos inseticidas.

Palavras-chave: manejo integrado de pragas, controle químico, lagarta-militar, noctuidae.

1 INTRODUÇÃO

Soybean (*Glycine max* (L.) is one of the world's main agricultural crops, with Brazil being the top producer, producing 136 million tons, in an area of 38.5 million hectares, with an average productivity of 3,529 kg ha-1 (CONAB, 2021). However, pest attacks on agricultural crops generate an average loss of up to 7.7% of grain production, or 25 million tons per year, resulting in significant economic losses (CZEPAK et al., 2019a).

Several insect and mite species feed on soybean plants. *Spodoptera* caterpillar occurrence levels in soybean have been growing in recent years, causing producers concern due to severe productivity losses (BUENO et al., 2012). *Spodoptera frugiperda* has a high degree of polyphagy, and when it attacks the soybean crop in the early stages, it cuts small seedlings at its base, damaging the crop's first stand (ARAÚJO et al. 2021). It can also feed on the leaves and later begins to consume the pods in the early stages of development, and this direct damage to the grains is what causes the majority of productivity losses (BARROS et al., 2010).

The importance of this pest stems from the difficulties in controlling it, which is due to its resistance or insensitivity to several pesticides and Bt protein technologies in corn and soybean crops, as well as a plentiful supply of hosts throughout the year. As a result, the producer resorts to indiscriminate pesticide application, which pressures Spodoptera populations and leads to the emergence of various cases of resistance to the main insecticide groups and modes of action (BARROS et al., 2010; CARVALHO et al., 2013; OMOTO, 2021).

The widespread use of caterpillar-resistant materials in Bt crops has resulted in the abandonment of many integrated pest management strategies, leaving the task of controlling caterpillars to genetic resistance alone.

In contrast, resistance to carbamate, spinosin, avermectin, pyrrole, diacylhydrazine, oxadiazine, and semicarbazone insecticides was relatively low (20%) in 2019/2020 crops, compared to pyrethroid insecticides and chitin synthesis inhibitors, where high resistance (>40%) was observed in some regions of the country (OMOTO, 2021). Thus, the alternation of insecticides with different modes of action must be considered, as this is an important strategy in insecticide resistance management programs aimed at preventing resistance emergence (SOSA-GÓMEZ, 2010).

Updating insecticide performance information becomes valuable knowledge for each crop season. This study was conducted in soybean crops with the purpose of determining the efficacy of different chemical insecticides for the control of *S. frugiperda*.

2 MATERIAL E MÉTODOS

Three experiments were carried out in the laboratory (25 ± 2 ºC, relative humidity of 60 ± 10% and photophase 12 h), from March to May 2021. Caterpillars from the rearing maintained on an artificial diet by Greene et al (1976) were used.

Soybean was cultivated in the field, soybean, cv. BMX Icon, following the technical recommendations for the crop, without receiving insecticide applications. At full flowering, insecticides were applied to shoots, with a backpack sprayer pressurized by CO_2, with a spray volume of 150 L ha^{-1}. After the natural drying of the products, the trifoliates from the apical part of the soybean plants were collected and used in laboratory tests.

In a completely randomized design, seven treatments were evaluated: six chemical insecticides on shoots and control (without insecticide). The insecticides evaluated (active ingredient, commercial product and dose in a.i./150 liters of water) were: a) chlorfenapyr (Pirate®, 800 ml/ha), b) teflubenzuron (Nomolt®, 150 ml/ha), c) spinetoram (Exalt®, 75 ml/ha), d) chlorantraniliprole (Premio®, 50 ml/ha); e) indoxacarb + novaluron (Plethora BR®, 200 ml/ha); f) thiamethoxam + lambda – cyhalothrin (Engeo Pleno®, 150 ml/ha).

The treatments were evaluated with caterpillar infestations in two stages, the first was with the trifoliates collected soon after spraying the insecticides in the field, and the second with the trifoliates collected 14 days after application, to verify the residual effect of the products. Evaluated from infestations in Petri dishes, using Petri dishes, 4.5 cm in diameter for 1st instar caterpillars (neonates), with five caterpillars per plate, with ten replications. Providing a 4 cm² disk of soybean leaf area. For 3rd and 5th instar caterpillars, Petri dishes of 15 cm in diameter were used, with five caterpillars per plate, with five replications, providing a soybean trifoliate. The plates were lined with filter paper moistened with distilled water, to maintain the turgor of the leaves, and whenever necessary, the replacement of discs and/or soybean leaflets was performed.

Mortality assessments of caterpillars were performed on the first, third and seventh day after infestations (DAI), the definition of death was verified by the criterion of the absence of movement of the caterpillars when touched with a brush. Final leaf consumption (cm²) was evaluated on the seventh day with a leaf area meter, model LI-3100C, for the trifoliates and leaf discs visually evaluated based on damage scale. The data were submitted to analysis of variance and when a significant difference was observed, the means were compared using the Tukey test ($p \leq 0.05$).

3 RESULTADOS E DISCUSSÃO

On the first day following application, 1st instar caterpillars showed 98% and 90% mortality rates with spinetoram and chlorfenapyr, respectively, which is considerably different from the other treatments (Table 1). On the third day, maximum control was verified with chlorfenapyr (100%), without differing from spinetoram (98%). The greatest control remained with chlorfenapyr on the seventh day, varying significantly only from teflubenzuron (44%), and the control (0%). In terms of consumption, the amount of leaf area consumed by the caterpillars was greater in the control, differing from the other treatments. There was no consumption, that is, only one test bite, in the chlorfenapyr and spinetoram treatments, which did not differ from chlorantraniliprole and indoxacarb + novaluron, demonstrating outstanding control efficiency.

Table 1. Mortality and consumption *of Spodoptera frugiperda* 1st instar caterpillars on different days after infestation (DAI), in soybean leaves from soybean plants treated with insecticides (25 ± 2ºC; 60 ± 10% RH; 12 h of photophase).

Treatments	Mortality (%)						Consumption (cm²)	
	1st DAI		3rd DAI		7th DAI			
Control (water)	0	d	0	e	0	c	6.55	a
Chlorfenapyr	90	a	100	a	100	a	0	d
Teflubenzuron	14	cd	26	d	44	b	1.70	b
Spinetoram	98	a	98	ab	98	a	0	d
Chlorantraniliprole	32	bc	50	cd	98	a	0.05	cd
Indoxacarb + novaluron	28	bc	42	d	88	a	0.28	cd
Thiamethoxam + lambda-cyhalothrin	52	b	70	bc	78	a	0.36	c
CV (%)	41.89		29.03		26.37		47.70	

Means followed by the same lowercase letter in the column do not differ by Tukey's test at 5% error probability. CV: coefficient of variation.

On the first and seventh days of assessment, the mortality of third-instar caterpillars was considerably higher with chlorfenapyr than with thiamethoxam + lambda-cyhalothrin, teflubenzuron, and control (Table 2). On the third day it differed from thiamethoxam + lambda-cyhalothrin, indoxacarb + novaluron, teflubenzuron. The control had the highest consumption, with no difference from the thiamethoxam + lambda-cyhalothrin treatment. Consumption was reduced by the treatments chlorfenapyr, spinetoram, chlorantraniliprole, and indoxacarb + novaluron.

In comparison to the other treatments, fifth-instar caterpillars had increased mortality at 1 DAI when chlorfenapyr was used (Table 3). At 3 DAI, chlorfenapyr stood out with the maximum percentage of control, without differing from spinetoram. At 7 DAI, the mortality rates for chlorfenapyr and indoxacarb + novaluron were higher, but not substantially different from the spinetoram and chlorantraniliprole treatments. In terms of consumption, chlorfenapyr had the lowest value, which was comparable to the treatments spinetoram, chlorantraniliprole, and indoxacarb + novaluron.

Results of infestations after 14 days of insecticide application revealed no residual effect for 1st, 3rd and 5th instar caterpillars (data not shown).

Table 2. Mortality and consumption of *Spodoptera frugiperda* 3rd instar caterpillars on different days after infestation (DAI), in soybean leaves from soybean plants treated with insecticides (25 ± 2ºC; 60 ± 10% RH; 12 h of photophase).

Treatments	Mortality (%)						Consumption (cm²)	
	1st DAI		3rd DAI		7th DAI			
Control (water)	0	c	0	d	4	b	167.86	a
Chlorfenapyr	48	a	92	a	100	a	9.20	d
Teflubenzuron	0	c	4	d	20	b	61.94	bc
Spinetoram	28	abc	72	ab	84	a	18.20	d
Chlorantraniliprole	36	ab	52	ab	84	a	15.70	cd
Indoxacarb + novaluron	16	abc	40	bc	92	a	30.33	cd
Thiamethoxam + lambda-cyhalothrin	8	bc	8	cd	12	b	92.27	ab
CV (%)	81.72		47.02		33.96		27.20	

Means followed by the same lowercase letter in the column do not differ by Tukey's test at 5% error probability. CV: coefficient of variation.

The chemical insecticides investigated in this study demonstrated differences in control efficiency for *S. frugiperda* caterpillars. On the seventh day of evaluation during the first infestation, the insecticides chlorfenapyr, spinetoram, chlorantraniliprole, and indoxacarb + novaluron demonstrated good control efficiency, creating a mortality rate equal to or greater than 80% for 1st, 3rd, and 5th instar caterpillars. According to the Ministry of Agriculture, Livestock, and Supply (MAPA), for a pesticide to be declared efficient, positive control values greater than 80% as compared to the control are required (GONÇALVES et al., 2016).

The insecticide chlorfenapyr stood out because it was the only one to achieve a 100% mortality rate during the first infestation, on the third day for 1st and 5th instar larvae and on the seventh day for 3rd instar larvae. It also distinguished itself from the others by exhibiting the lowest consumption of leaf area between the treatments, which was sufficient to cause insect intoxication and death. Corroborating with data already obtained in works with 1st and 3rd instar caterpillars of *Spodoptera frugiperda*, regardless of the use of adjuvant (FORMENTINI et al., 2022).

Table 3. Mortality and consumption of *Spodoptera frugiperda* 5th instar caterpillars on different days after infestation (DAI), in soybean leaves from soybean plants treated with insecticides (25 ± 2ºC; 60 ± 10% RH; 12 h of photophase).

Treatments	Mortality (%)						Consumption (cm²)	
	1st DAI		3rd DAI		7th DAI			
Control (water)	0	c	0	d	0	b	297.06	a
Chlorfenapyr	76	a	100	a	100	a	11.20	c
Teflubenzuron	4	c	20	bcd	20	b	141.74	b

Spinetoram	16	bc	52	ab	80	a	37.04	c
Chlorantraniliprole	32	b	48	b	80	a	11.90	c
Indoxacarb + novaluron	8	bc	44	bc	96	a	24.37	c
Thiamethoxam + lambda-cyhalothrin	4	c	8	cd	8	b	243.28	ab
CV (%)	69,90		46,37		32,84		29,22	

Means followed by the same lowercase letter in the column do not differ by Tukey's test at 5% error probability. CV: coefficient of variation.

The pesticide chlorfenapyr belongs to the same chemical category as pyrazole and works by contact and ingestion. It acts as an uncoupler of oxidative phosphorylation in the mitochondria, causing a blockage of ATP generation, energy loss, suspension, and cellular malfunction, ultimately leading to the caterpillar's death (SILVA & SOSA-GOMEZ, 2017). When applied to the adaxial face of the leaf, it has great translaminar mobility and can enter plant tissue to reach the abaxial face (BIALOZOR, 2017). These elements, as well as the agile method of operation, clarify the shock effect (BARBOZA, 2015).

In terms of mortality rate, the insecticides spinetoram and chlorantraniliprole produced similar results: during the first infestation, a minimum of 80% efficiency in 5th instar caterpillars and 98% efficiency in 1st instar caterpillars. Regarding consumption, 1st instar caterpillars did not consume the insecticide spinet-+oram, making it equal to the insecticide chlorfenapyr. In the 3rd and 5th instars, caterpillars treated with the insecticide chlorantraniliprole consumed less than those treated with the other insecticides.

When compared to its precursor spinosad, the insecticide spinetoram exhibits improved efficiency and effective toxicological properties (LIRA, 2018). The results for caterpillar mortality by the insecticide spinetoram are similar with research conducted on corn crops, with control efficacy greater than 80% (GRIGOLLI, 2017).

The insecticide chlorantraniliprole belongs to the chemical group anthranilamide and works by contact and ingestion. The insecticide, known as ryanodine receptor modulators, directly activates these receptors, causing continuous muscular contractions until the sudden interruption of regurgitation, lethargy, and tetany (BIALOZOR, 2017). Grigolli (2017) found a mortality rate of 74% on the seventh day after application during research on the control of S. frugiperda in corn, which support the findings of the current investigation, with an efficacy of 80% mortality on the seventh day for caterpillars of 5th instar.

The insecticide indoxacarb + novaluron was effective, with mortality rates of 88% in 1st instar caterpillars, 92% in 3rd instar caterpillars, and 96% in 5th instar caterpillars. There is an inverse relationship between mortality and consumption, which means that the higher the mortality, the lower the consumption. Teflubenzuron and thiamethoxam + lambda-cyhalothrin did not show satisfactory control efficiency. Martins (2006) found an efficiency of 71% for small caterpillars on the second day after applying the product to the corn crop, which differs from the results found in this study.

There are several research with varied results on mortality caused by the insecticide thiamethoxam + lambda-cyhalothrin. After two days of infestation in soybean and corn, some studies demonstrate 100% mortality for 1st and 3rd instar caterpillars (GONÇALVES et al., 2016). Other investigations with corn found an 87.5% mortality rate three days after infection (SILVA, 2014). The insecticides chlorfenapyr, spinetoram, chlorantraniliprole, and indoxacarb + novaluron reduced consumption of 1st instar caterpillars by 98.7%, 89% of 3rd instar caterpillars, and 92.9% of 5th instar caterpillars.

For the control of 1st instar caterpillars, the insecticides chlorfenapyr, spinetoram, chlorantraniliprole, indoxacarb + novaluron, and thiamethoxam + lambda-cyhalothrin were effective.

4 CONCLUSÃO

For 1st, 3rd, and 5th instar caterpillars, the insecticides chlorfenapyr and spinetoram act faster and with a shock effect.

The insecticides chlorfenapyr, spinetoram, chlorantraniliprole, and indoxacarb + novaluron diminish caterpillar consumption in the first, third, and fifth instars.

For 1st, 3rd, and 5th instar caterpillars, there was no residual effect 14 days after insecticide application.

Chlorfenapyr, spinetoram, chlorantraniliprole, and indoxacarb + novaluron were effective insecticides for controlling 3rd and 5th instar caterpillars.

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