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Efficacy of Insecticides Against *Spodoptera frugiperda* (Smith, 1797)

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Abstract

The Brazil's economy is supported by agribusiness, however, the continuous cycle of food production and favorable climate contributes to the incidence of pest insects all year round. The fall armyworm *Spodoptera frugiperda* (Smith, 1797) (Lepidoptera: Noctuidae) is considered the main insect in the corn crop, due to voracity of the caterpillars and occurrence throughout the crop cycle. Therefore, the chemical control has been demanded considerably, causing emergence of populations resistant to the different products, as well as implications in the environment. Thus, studies are needed to evaluate the efficiency of chemical insecticide control according to the susceptibility and the stages of biological development of the pest. The objective of this work was to evaluate the performance of isolated and combined insecticides for the control of *S. frugiperda* caterpillars under laboratory conditions. In the residual and direct contact bioassays, 8 treatments with 5 replications were used in a completely randomized design, performed with 2nd and 5th instar. The results showed that by residual contact after 72 hours, clofenapir + zeta-cypermethrin treatment had 100% efficacy in the mortality of both instars. When applied via direct contact 72 hours later, the combined treatments showed an efficiency above 80%. However, for an integrated pest management program, where it was recommended the association of different control tactics, the management of insecticides with clofenapir + zeta-cypermethrin was effective with 100% control efficiency in both instars.

Keywords: chemical control, leafhopper caterpillar, insecticide management, insecticide rationing, insect resistance, application technology

1. Introduction

The Brazil's economy is supported by agribusiness, and this fact is attributed to the availability of water, favorable climate, arable land and technology that enables the country to produce all year. However, the continuous cycle of food production and the favorable climate contribute to the incidence of pests which, in view of the circumstance, provides, in many cases, high utilization of chemical control (Belluzzo et al., 2014; Melo et al., 2018). The domestic sales of insecticides in the 2016/2017 harvest reached levels of more than 551 thousand tons of products, with the states of Mato Grosso (104,901.05 tons), São Paulo (76.44,55 tons), Paraná (72,212.38 tons) and Rio Grande do Sul (63,352.27 tons), the largest consumers (IBAMA, 2017).

The corn is the second most representative product in the country (4.967,00 $Kg.ha^{-1}$), providing subsidies to the industry as raw material for human and animal feed, depending on the quantity and nutritional quality of the grain (CONAB, 2018; Rolim et al., 2018). However, in the corn crop, the fall armyworm *Spodoptera frugiperda* (Smith, 1797) (Lepidoptera: Noctuidae) promotes significant losses in production, by voracity of the caterpillars and occurrence throughout the crop cycle. With reductions in productivity around 34% to 40% depending on the stage of development of the plant (Cruz, 2002).

Thus, the control of this insect has demanded a high number of insecticide applications, causing populations resistant to the different products (Diez-Rodríguez & Omoto, 2001; Ahmad et al., 2018; Wang et al., 2018), as well as negative implications for the environment (Michelotto et al., 2017).

Therefore, it is necessary to carry out studies that evaluate the efficiency of control of chemical insecticides on the target insect, since the relative adaptation of a population may vary according to the stages of development

(Cruz, 2002). Studies evaluating *Helicoverpa armigera* (Hübner, 1909) (Lepidoptera: Noctuidae) have demonstrated that newborn caterpillars can be easily killed by insecticides, while efficiency decreases when the application is at an advanced stage of development. In addition, it is necessary to consider that, under field conditions, the generations are not synchronized, occurring, at the same time and place, insects of different stages of development (Lucchini, 1977).

As an alternative, the rotation of active ingredients is a management strategy for insect pest control, however, it is important to consider whether there is cross-resistance and/or incompatibility between insecticides. These studies are important because, in addition to elucidating the basic aspects involved in the resistance to chemical groups of insecticides, they provide important information for the management of the species (Guedes & Oliveira, 2002; Sosa-Gómez & Omoto, 2012).

Considering the importance of the carcass caterpillar, and the lack of studies on the performance of the chemical control used in corn cultivation, the objective of this work was to evaluate the performance of isolated and combined insecticides for the control of *S. frugiperda* caterpillars under laboratory conditions.

2. Materials and Methods

The experiments were conducted at the Embrapa Temperate Weather Bioefficiency Nucleus in an air conditioned room at 25±1 °C, RH of 70±10% and 12 hours of photophase.

2.1 Procurement of Plants

Corn seeds from AG 9045 were planted in 20-liter plastic pots containing natural substrate based on humus, fiber and clay (West Garden®), and then kept in a greenhouse. The corn plants reaching the phenological stage V.4 (approximately 25 days) were used in laboratory experiments as a food substrate of caterpillars.

2.2 Insect Collection and Breeding

The insects were collected at the Terras Baixas Experimental Station in the municipality of Capão do Leão, Rio Grande do Sul, BR. (S 31°49.268′ S, 52°27.472′ W, altitude 7 m) in corn crops in the 2015/2016 harvest, Greene et al. (1976), for 2 generations. From this, 200 eggs of *S. frugiperda* were collected, packed in Petri dishes (9 cm Ø), with filter paper moistened with sterile distilled water at the bottom and at the top perforated plastic film (PVC) with a pin. The material was kept in an air conditioned room at 25±1 °C, RH of 70±10% and photophase of 12 hours until hatching of the caterpillars. Residual contact and direct contact bioassays were used for 2nd and 5th instars caterpillars fed a natural diet.

2.3 Residual Contact Bioassay

The corn leaves were cut into disks (4 cm Ø) and immersed in the treatments for 20 seconds (Table 1). The treatments that presented more than one product after the application of the first product were placed on a bench to wait for the evaporation of excess moisture and after being immersed in another treatment. The leaves submitted to the treatments were conditioned in containers of polystyrene with capacity of 100 ml and inoculated the caterpillars of 2nd or 5th instar, being 5 repetitions with 4 caterpillars, totaling 20 caterpillars per treatment. The treatments were kept in an air conditioned room at 25±1 °C, RH of 70±10% and 12 h of photophase.

2.4 Direct Contact Bioassay

The spray was carried out in a Potter's Tower (Burkard Scientific Uxbridge, UK), calibrated at a pressure of 10 lb.pol-2 with application of 500 µl of insecticidal spray (Table 1) onto 2nd or 5th instar caterpillars. After spraying, the 2nd or 5th instar caterpillars were placed in a polystyrene container with a capacity of 100 ml containing discs (4 cm Ø) of the corn leaf, 5 replicates with 4 caterpillars, totaling 20 caterpillars per treatment. The treatments were kept in an air conditioned room at 25±1 °C, RH of 70±10% and 12h of photophase.

Table 1. Active ingredient, mode of action and dose of insecticides used in corn crop on the control of *Spodotera frugiperda* caterpillars

Active Ingredient	Mode of Action	Dose*
Chlorantraniliprole	Rannodyne receptor modulators	100
Chlorantraniliprole + Zeta-Cypermethrin	Rannodyne receptor modulators + Sodium channel modulators	100 + 80
Flubendiamide	Rannodyne receptor modulators	100
Flubendiamide + Zeta-Cypermethrin	Rannodyne receptor modulators + Sodium channel modulators	100 + 80
Chlorfenapyr	De-couplers of oxidative phosphorylation via disruption of the proton gradient	500
Chlorfenapyr + Zeta-Cypermethrin	De-couplers of oxidative phosphorylation via disruption of the proton gradient + Sodium channel modulators	500 + 80
Zeta-Cypermethrin	Sodium channel modulators	80
Control	Control	-

Note. * mL ha^{-1}.

2.5 Experimental Design

The design used was completely randomized design (CRD) and the evaluations were performed 4, 24, 72, 120, 168 hours after treatment (HAT). The data were submitted to analysis of variance (Anova) and the means were compared by the Tukey test at 5% significance (SAS University, 2014). The control efficiency calculated through corrected mortality, from the Abbott formula (1925) described below:

$$CE\ (\%) = [(nT - nt)/nT] \times 100 \tag{1}$$

where, nT = live insects in the control; nt = live insects in the treatment.

3. Results

3.1 Residual Contact Bioassay

In the experiment applied by residual contact in 2nd instar caterpillars of *S. frugiperda*, treatments chlorfenapyr (100%), chlorfenapyr + zeta-cypermethrin (100%), zeta-cypermethrin (95%) and flubendiamide + zeta-cypermethrin (75%) achieved the best controls differing from the 4 HAT control. Similarly, 24 HAT did not change the efficiency of the applied treatments (Table 2).

In the evaluations carried out 72 HAT it was observed that chlorantraniliprole treatments and the combination of chlorantraniliprole + zeta-cypermethrin promoted an increase of control efficiency in 2nd instar caterpillars. However, when considering the observed observation 120 HAT the chlorantraniliprole treatment presented a significant increase in the control of *S. frugiperda*. To the combined treatment chlorantranilirpole + zeta-cypermethrin there was no significant increase in mortality. In the last performed HAT 168, chlorfenapyr, chlorfenapyr + zeta-cypermethrin and zeta-cypermethrin were the most efficient treatments (100%) (Table 2).

When 5th instar caterpillars of *S. frugiperda* were submitted via residual contact to the chemical treatments, a distinct performance was observed, with chlorantraniliprole controlling only 15% of the 24 HAT target insects. The evaluation performed 72 HAT evidenced the efficiency of the treatment clofernapir + zeta-cypermethrin (100%), differing significantly from the control (Table 2).

In the 168 HAT evaluation, only the flubendiamide treatment obtained the lowest control efficiency, differing from all treatments in *S. frugiperda* 5th instar caterpillars (Table 2).

3.2 Direct Contact Bioassay

In the experiment applied by direct contact in 2nd instar caterpillars of *S. frugiperda*, the results were different from the previous ones (residual contact). The treatment with zeta-cypermethrin reached 55% efficiency in the control of the target insect, differing significantly from the control in 4 and 24 HAT, however, without differing from the combined treatment with flubendiamide + zeta-cypermethrin. The control over 80% occurred in 72 HAT, in the treatments chlorantraniliprole, chlorantraniliprole + zeta-cypermethrin, flubendiamide + zeta-cypermethrin, chlorfenapyr, chlorfenapyr + zeta-cypermethrin and zeta-cypermethrin. In the evaluations performed 120 HAT and 168 HAT, only flubendiamide did not reach 80% of control efficiency (Table 3).

The efficiency of 80% or higher observed when the insecticides were applied via direct contact on *S. frugiperda* 5th instar caterpillars was attributed to the treatments chlorantraniliprole, chlorantraniliprole + zeta-cypermethrin, flubendiamide + zeta-cypermethrin, chlorfenapyr and chlorfenapyr + zeta-cypermethrin 4 HAT (Table 3).

At the end of the evaluation, although all treatments differed significantly from the control, zeta-cypermethrin was below the desired level for control of *S. frugiperda* caterpillars (Table 3).

Table 2. Mean (X±SE) of living caterpillars and control efficiency (CE%) of *Spodotera frugiperda* caterpillars at 4, 24, 72, 120, 168 hours after the treatment (HAT) via residual contact

2nd instar

Treatments	4 HAT	CE (%)	24 HAT	CE (%)	72 HAT	CE (%)	120 HAT	CE (%)	168 HAT	CE (%)
Chlorantraniliprole	4.5±0.05 A[1]	10	4.5±0.05 A	10	3.0±1.22 AB	40	0.3±0.25 BC	95	0.3±0.25 BC	95
Chlorantraniliprole + Zeta-cypermethrin	3.8±1.25 AB	25	3.8±1.25 AB	25	0.7±0.25 BC	85	0.7±0.25 BC	85	0.7±0.25 BC	85
Flubendiamide	3.0±0.91 ABC	40	3.0±0.91 ABC	40	3.0±0.91 AB	40	2.3±1.11 B	55	1.5±0.65 B	70
Flubendiamide + Zeta-cypermethrin	1.3±0.25 BCD	75	1.3±0.25 BCD	75	1.3±0.25 BC	75	0.5±0.29 C	90	0.5±0.29 BC	90
Chlorfenapyr	0.0±0.00 D	100	0.0±0.00 D	100	0.0±0.00 C	100	0.0±0.00 C	100	0.0±0.00 C	100
Chlorfenapyr + Zeta-cypermethrin	0.0±0.00 D	100	0.0±0.00 D	100	0.0±0.00 C	100	0.0±0.00 C	100	0.0±0.00 C	100
Zeta-cypermethrin	0.3±0.25 CD	95	0.3±0.25 D	95	0.3±0.25 C	95	0.3±0.25 C	95	0.0±0.00 C	100
Control	5.0±0.00 A	-	5.0±0.00 A	-	5.0±0.00 A	-	5.0±0.00 A	-	5.0±0.00 A	-
Cv (%)	8.05		10.05		7.78		6.98		8.90	

5th instar

Treatments	4 HAT	CE (%)	24 HAT	CE (%)	72 HAT	CE (%)	120 HAT	CE (%)	168 HAT	CE (%)
Chlorantraniliprole	4.3±0.75 A[1]	15	4.3±0.75 A	15	2.0±0.91 BCD	60	0.0±0.00 C	100	0.0±0.00 C	100
Chlorantraniliprole + Zeta-cypermethrin	5.0±0.00 A	0	5.0±0.00 A	0	3.0±0.41 ABC	40	0.7±0.48 C	85	0.2±0.25 C	95
Flubendiamide	5.0±0.00 A	0	5.0±0.00 A	0	3.5±0.29 AB	30	2.7±0.25 B	45	2.7±0.25 B	45
Flubendiamide + Zeta-cypermethrin	5.0±0.00 A	0	5.0±0.00 A	0	1.8±0.25 BCD	65	0.7±0.25 C	85	0.0±0.00 C	100
Chlorfenapyr	5.0±0.00 A	0	5.0±0.00 A	0	1.3±1.25 BCD	75	0.0±0.00 C	100	0.0±0.00 C	100
Chlorfenapyr + Zeta-cypermethrin	5.0±0.00 A	0	5.0±0.00 A	0	0.0±0.00 D	100	0.0±0.00 C	100	0.0±0.00 C	100
Zeta-cypermethrin	4.0±0.00 A	0	5.0±0.00 A	0	0.2±0.25 CD	95	0.2±0.25 C	95	0.2±0.25 C	95
Control	5.0±0.00 A	-	5.0±0.00 A	-	5.0±0.00 A	-	5.0±0.00 A	-	5.0±0.00 A	-
Cv (%)	5.24		5.24		6.22		7.44		9.69	

Note. [1] (X±SE) = Average number of caterpillars±Standard error. [2] Means followed by the same letter in column do not differ by Tukey test (P < 0.05). CV (%) = Coefficient of variation.

Table 3. Mean (X±SE) of living caterpillars and control efficiency (CE%) of *Spodotera frugiperda* caterpillars at 4, 24, 72, 120, 168 hours after the treatment (HAT) via direct contact

2nd instar

Treatments	4 HAT	CE (%)	24 HAT	CE (%)	72 HAT	CE (%)	120 HAT	CE (%)	168 HAT	CE (%)
Chlorantraniliprole	5.0±0.00 A[1]	0	5.0±0.00 A	0	0.0±0.00 C	100	0.0±0.00 C	100	0.0±0.00 C	100
Chlorantraniliprole + Zeta-cypermethrin	5.0±0.00 A	0	5.0±0.00 A	0	0.3±0.25 C	95	0.3±0.25 BC	95	0.3±0.25 C	95
Flubendiamide	5.0±0.00 A	0	5.0±0.00 A	0	0.3±0.25 B	50	1.5±0.87 B	70	1.3±0.48 B	75
Flubendiamide + Zeta-cypermethrin	4.3±0.75 AB	15	4.3±0.75 AB	15	0.8±0.25 C	85	0.0±0.00 C	100	0.0±0.00 C	100
Chlorfenapyr	5.0±0.00 A	0	5.0±0.00 A	0	0.0±0.00 C	100	0.0±0.00 C	100	0.0±0.00 C	100
Chlorfenapyr + Zeta-cypermethrin	5.0±0.00 A	0	5.0±0.00 A	0	0.0±0.00 C	100	0.0±0.00 C	100	0.0±0.00 C	100
Zeta-cypermethrin	2.3±0.00 B	55	2.3±0.00 B	55	0.0±0.00 C	100	0.0±0.00 C	100	0.0±0.00 C	100
Control	5.0±0.00 A	-	5.0±0.00 A	-	5.0±0.00 A	-	5.0±0.00 A	-	5.0±0.00 A	-
Cv (%)	5.38		5.38		7.34		5.54		7.01	

5th instar

Treatments	4 HAT	CE (%)	24 HAT	CE (%)	72 HAT	CE (%)	120 HAT	CE (%)	168 HAT	CE (%)
Chlorantraniliprole	0.0±0.00 C[1]	100	0.0±0.00 C	100	0.0±0.00 C	100	0.0±0.00 C	100	0.0±0.00 C	100
Chlorantraniliprole + Zeta-cypermethrin	1.0±0.58 BC	80	1.0±0.58 BC	80	0.0±0.00 C	100	0.0±0.00 C	100	0.0±0.00 C	100
Flubendiamide	2.0±0.41 B	60	2.0±0.41 B	60	1.3±0.63 BC	75	1.0±0.41 C	80	1.0±0.41 C	80
Flubendiamide + Zeta-cypermethrin	0.0±0.00 C	100	0.0±0.00 C	100	0.0±0.00 C	100	0.0±0.00 C	100	0.0±0.00 C	100
Chlorfenapyr	0.0±0.00 C	100	0.0±0.00 C	100	0.0±0.00 C	100	0.0±0.00 C	100	0.0±0.00 C	100
Chlorfenapyr + Zeta-cypermethrin	0.0±0.00 C	100	0.0±0.00 C	100	0.0±0.00 C	100	0.0±0.00 C	100	0.0±0.00 C	100
Zeta-cypermethrin	5.0±0.00 A	0	5.0±0.00 A	0	2.3±0.48 B	55	2.3±0.48 B	55	2.3±0.48 B	55
Control	5.0±0.00 A	-	5.0±0.00 A	-	5.0±0.00 A	-	5.0±0.00 A	-	5.0±0.00 A	-
Cv (%)	9.70		9.70		6.62		4.20		4.20	

Note. [1] (X±SE) = Average number of caterpillars±Standard error. [2] Means followed by the same letter in column do not differ by Tukey test (P < 0.05). CV (%) = Coefficient of variation.

4. Discussion

4.1 Residual Contact Bioassay

Chlorfenapyr is one of the insecticides that has been widely used for the control of various insect pests. The active principle is composed of a pro-insecticide and the removal of the N-ethoxymethyl group from the molecule converts it to the toxic form. In this condition, after the compound reaches the mitochondria causes losses of H + protons. As a consequence, the disorder affects the production of ATP resulting in lack of energy and death of the target insect (Roditakis et al., 2015).

The insecticides, with a mode of action in the nervous system, such as zeta-cypermethrin (pyrethroids), present a marked shock action in the different orders of insects (Guedes et al., 2012). However, the present study reveals that, when applied by residual pathway alone, it showed high control efficiency, soon after application.

In general, it was observed that the combination of flubendiamide combined with a pyrethroid showed better efficiency in the control of *S. frugiperda* caterpillars. The mode of action of the insecticides of the group of antranilícas diamides, to which belongs flubendiamide, bind to the rianodine receptors of the insects in the muscular cells, promoting the uncontrolled exit of calcium, due to the opening of the canal, provoking muscular paralysis and death of the insect (Cordova et al., 2006; Lahm et al., 2007; Arrue et al., 2014). When there is a combination with a shock product the efficiency tends to be better, due to the fast action of the product, since the group of diamides does not have this effect. Studies developed by Ebbinghaus et al. (2007) and Gerreiro et al. (30%) and flubendiamide (50%), attributing the fact that they require more time to cause mortality of the target.

The results found applied with residuals with the diamides, prove the difference in susceptibility of the population and can be used as a crucial tool for resistance management programs. In addition, the relevance of this study can contribute to analyze the behavior of genes related to resistance to insecticide through crosses between susceptible and resistant strains (Lima-Neto, 2016).

The diamides have been used in agriculture for several years, so there are reports of resistance to lepidopteran species, including cross-resistance (Thomas, 2013; Roditakis et al., 2015). The results indicate that due to prolonged field use, insects exhibit resistance to both flubendiamide and chlorantraniliprole due to competition for the same site of action and selection pressure (Gonçalves et al., 2016).

The insecticides to be registered in Brazil, the government agencies that regulate the release of chemical and biological products for the control of arthropod pests, require at least 80% efficiency in the control of the target species (Mapa, 2018), since the other 20 % are attributed to the natural mortality of the species (Abbott, 1925). The results obtained in the experiments indicated a certain concern with the product that uses flubendiamide as active principle, since the efficiency was low, especially in the residual contact tests, in the direct contact test, the efficiency of 80% was only obtained at the end of the experiment test.

In order to be successful in controlling insects, integrated pest management (IPM) should be advocated, with one of the actions being the rotation of active ingredients (IRAC, 2018). However, the basic premise is the monitoring of the area, so that the decision is made at the right time, using methods that effectively interrupt herbivory and preserving natural enemies. One strategy that can be used in areas with high rates of infestation is the combination of one insect from the group of pyrethroids (knock down) and another insecticide of slower action and action at another site of action of the insect (Guerreiro et al. 2013). However, it is necessary to consider the variation of the susceptibility of the species when the insecticide is applied (Guedes et al., 2012).

Studies of insecticides for the control of *Grapholita molesta* (Busck, 1916) (Lepidoptera: Tortricidae) found that there is a reduction in insecticide susceptibility (Arioli et al., 2004). Silva (1999) demonstrated in corn cultivation that the control of *S. frugiperda* when it is carried out at the appropriate moment (most of the caterpillars in 2nd instar) the control was of 88%, and in the late form, there was a reduction of 33% in insect control. Therefore, it is evident that control should be directed to first instars caterpillars, not only because of the ease of control, but also because of the reduction of crop damage (Cruz, 2002).

Helicoverpa armigera (Hübner, 1808) (Lepidoptera: Noctuidae) causes damage to several crops in Brazil, with the use of insecticides being the most commonly used control method, which are, in general, the same active ingredients used for caterpillar- cartridge, so care must be taken in the use of these. In lethal concentration (LC_{50}) determinations, *H. armigera* has shown that chlorfenapyr (0.0063 g to L^{-1}) and zeta-cypermethrin (0.0242 g to L^{-1}) are extremely and moderately toxic to caterpillars, respectively. In addition to the mortality test, chlorfenapyr and zeta-cypermethrin applied alone controlled approximately 80% of *H. armigera* caterpillars at 72 hours, both by direct contact and residual contact (Laurenteis, 2017).

In the present study, the combination of the two active principles (chlorfenapyr + zeta-cypermethrin) demonstrated compatibility, due to the increase of the control efficiency in addition, to present a greater range of management, that is, control for both instar caterpillars and of 5th instar.

In some situations, the application of two combined products may lead to the occurrence of interactions that manifest in an additive, antagonistic or synergistic form, which may or may not affect control, as well as producing effects unknown to toxicology (Nash, 1967; Trezzi, 2005). The effects are manifested after the interaction of the active ingredients, which is seldom studied, perhaps due to the high number of products available in the market (Petter et al., 2013).

Factors such as the constant exposure of insect pests to certain active principles, intensive cultivation, expansion of the time and area of planting in traditional areas, emergence of new ecological conditions and niches and cultural practices have increased the cases of resistance in Brazil and in the insecticides (Diez-Rodriguez & Omoto, 2001).

Thus, although diamides constitute a recent and innovative class of insecticides, there are reports of low susceptibility to flubendiamide for several species of Lepidoptera such as *Heliothis virescens* (Fabricius, 1781) (Lepidoptera: Noctuidae), *Agrotis ipsilon* (Hufnagel, 1766) (Lepidoptera: Noctuidae) (Zuo et al., 2018) and *Plutella xylostella* (Linnaeus, 1758) (Lepidoptera: Plutellidae) (Ribeiro et al., 2017).

Although there are significant advances in IPM programs, control of *S. frugiperda* continues to be carried out almost exclusively by chemical methods, which potentiates insect resistance (Diez-Rodriguez & Omoto, 2001; Fazolin et al., 2017). Thus, there is a lack of studies on the mechanism of resistance of *S. frugiperda* in order to define management tactics that delay or even avoid the evolution of resistance (Ribeiro, 2014; Fernandes et al., 2017), since in the present work, flubendiamide presents concern for the low efficiency in the control when applied via residual.

Besides the concern to choose the correct active ingredient and to define the correct moment of application it is necessary to determine which application technology to adopt. In order to achieve adequate placement and distribution of the product in the required quantity, in an economical and minimal environmental contamination (Matuo, 1998; Bonadiman, 2008; Costa et al., 2017). In the results of the present study it was observed that the application form influenced the mortality time observed in the insects.

4.2 Residual Contact Bioassay

Because the 2nd instar caterpillars receive the product via direct contact and are small, the amount of the product on the integument is greater, allowing the insecticides to penetrate through the cuticle, trachea and even pores and/or hair interconnected to the nervous system and , they act in the metabolism until death (Viana & Costa, 1998) faster than in 5th instar caterpillars. The lipophilic character of some insecticides associated with the thickness and lipid composition of the cuticle of the insects is responsible for the greater penetration of the product into the cuticle and its translocation until the action target, observed in the treatments in smaller caterpillars (Gusmão et al., 2000).

The application of flubendiamide + zeta-cypermethrin showed compatibility providing control efficiency of *S. frugiperda* in 2nd instar. The same was observed in the previous experiment, applied by residual path in both 2nd instar and 5th instar caterpillars.

Resistance monitoring should be used to observe the evolution and behavior of insect populations against an active ingredient. Studies carried out in eight Brazilian states showed that *S. frugiperda* populations showed high susceptibility to chlorantraniliprole and flubendiamide in the 2011/2012 crop. However, variations in survival from 0% to 12.7% for chlorantraniliprole and from 1% to 6% for flubendiamide were observed according to the crop and locality (Ribeiro, 2014).

When they reproduce, there is transmission of the genes responsible for the resistance to the offspring and, gradually, the population becomes less susceptible to the active principle. For treatment with flubendiamide, it is expected that there is a greater chance of insects developing resistance, due to the performance in the control of the carcass caterpillar compared to the other products used in the study (Bravo & Soberón, 2008; Huang et al., 2011; IRAC, 2018).

The results evidenced a high mortality, with emphasis on the treatments involving chlorfenapyr, regardless of the mode of application and instar of the insect. Neurotoxic insecticides, when used in combination with other insecticides, have generally increased relative efficacy on *S. frugiperda* mortality in up to 48 hours (Cessa et al., 2013).

However, the study emphasizes the producer's concern with the mode of action of each product, besides equipment calibration, droplet diameter that contribute to uniform distribution and effective control of the target (Souza et al. 2016; Gonçalves et al., 2016). However, the management of insecticides should also be considered, because if the producer does not adopt, there will be selection of resistant individuals and lose efficiency of the active principle. The result is the early withdrawal of technology from the market, with losses for both industry and producers.

5. Conclusion

The best performance is attributed to the treatment using chlorfenapyr, regardless of the mode of application and instar of the target insect.

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