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Effects of insecticides on adults and eggs of *Drosophila suzukii* (Diptera, Drosophilidae)

Efecto de insecticidas sobre adultos y huevos de *Drosophila suzukii* (Diptera, Drosophilidae)

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Abstract: *Drosophila suzukii* (Diptera, Drosophilidae) is an exotic species, endemic to Asia and currently a pest to small and stone fruits in several countries of North America and Europe. It was detected in 2013 for the first time in South America, in the south of Brazil. Unlike most drosophilids, this species deserves special attention, because the females are capable of oviposit inside healthy fruits, rendering their sale and export prohibited. Despite the confirmed existence of this species in different states of Brazil, this insect is yet been to be given the pest status. Nevertheless, the mere presence of this species is enough to cause concern to producers of small fruits and to justify further investigation for it's control, especially chemical control for a possible change in status. Therefore, the goal of this work was to evaluate, in laboratory, mortality of *D. suzukii* adults and ovicidal effect when exposed to different insecticides registered for species of the Tephritidae and Agromyzidae families in different cultures. The insecticides deltamethrin, dimethoate, spinosad, fenitrothion, phosmet, malathion, methidathion, and zeta-cypermethrin resulted in mortality to 100 % of the subjects three days after the treatment (DAT). Regarding the effects over eggs, it was established that the insecticides fenitrothion, malathion, and methidathion deemed 100 % of the eggs not viable, followed by phosmet and diflubenzuron, which also caused elevated reduction in the eclosion of larvae two DAT.

Key words: Chemical control, ovicidal activity, spotted wing *Drosophila*.

Resumen: *Drosophila suzukii* (Diptera, Drosophilidae) es una especie exótica, endémica del Asia y actualmente considerada plaga de pequeños frutos y frutas con hueso en varios países de Norteamérica y Europa. En 2013 fue detectada por primera vez en América del Sur, en el sur de Brasil. A diferencia de la mayoría de drosofílidos, esta especie merece mucha atención debido a que las hembras son capaces ovipositar dentro de frutos sanos, tornando imposible su comercialización y exportación. A pesar que la presencia de esta especie ya fue confirmada en diferentes estados de Brasil, aún no alcanza la condición de plaga. Sin embargo, la simple presencia de esta especie provoca preocupación a los productores de pequeños frutos y justifica la investigación de métodos de control, especialmente el control químico, el cual ayudaría a los fruticultores en caso que el insecto se torne una plaga. Con estos antecedentes, el objetivo de este trabajo fue evaluar, en laboratorio, el efecto ovicida y la mortalidad de adultos *D. suzukii* a diferentes insecticidas registrados para especies de la familia Tephritidae y Agromyzidae en varios cultivos. Los insecticidas deltametrina, dimetoato, spinosad, fenitrotion, fosmet, malatión, metidation y zeta-cipermetrina provocaron 100 % de mortalidad de adultos tres días después de la aplicación (DDA). Se constató que los insecticidas fenitrotion, malatión y metidation inviabilizaron 100 % de los huevos, seguidos por fosmet y diflubenzuron, que causaron una considerable reducción de eclosión de larvas dos DDA.

Palabras clave: Control químico, efecto ovicida, *Drosophila* de alas manchadas.

Introduction

Brazil is the third largest producer of fruit, only surpassed by China and India. However, production of small fruits is still low in relation to other fruit crops. Nevertheless, the interest in strawberry, blueberry, and blackberry production, for instance, has been increasing due to the great value associated to the products and easy placement in internal markets (Agrianual 2015), as well as the possibility of exporting in order to supply the off season demand in North American countries (Fachinello *et al*. 2011).

Drosophila suzukii is currently distributed in the Asian, European, and North and South American continents (Deprá *et al.* 2014) and distribution models indicate areas with high environmental suitability for the occurrence of this species in the continents of Oceania and Africa, even though no records of the occurrence of the species exist (Dos Santos *et al.* 2017). The emergence of this new species, which has as its main hosts fruits with thin skin and soft pulp, causes concern to producers of small fruits. This pest is considered one of the worst threats to the production of thin skin fruits, such as blueberries, raspberries, cherries, grapes, and strawberries in the USA. Total production and marketing of these fruits brings in approximately US$ 2.6 billion a year. Losses estimated for the tri-state area in the 2008 harvest season reached US$ 421.5 million, whereas the backlash for strawberry crops reached US$ 33.4 million, US$ 56.7 million for blueberry, and for raspberry and blackberry crops US$ 174.8 million (Bolda *et al*. 2010). In Brazil, the first estimates of damage due to *D. suzukii* attacks took place in the municipality of Vacaria, Rio Grande do Sul. Nearly 30 % of the strawberries were infested with the pest, although economic losses generated by this attack were not evaluated (Santos 2014).

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The spotted-wing drosophila presents certain peculiarities that allow easy identification. Adult males have a small dark spot on the leading edge of the wing near the tip, a striking characteristic of this species, which originated its popular name. Furthermore, the species also has a row of spines on the first and second tarsal segments, on the first pair of legs. On the other hand, females do not present such spots, but they feature a narrow double-row serrated ovipositor with a series of sclerotized teeth, which allow its insertion in healthy fruits and consequent oviposition within the fruits (Hauser 2011; Walsh *et al*. 2011; Cuthbertson *et al*. 2014). The main damages are a result of the pulp consumption by the larvae, besides the puncture opening doors for secondary infections caused by filamentous fungi, yeast, and bacteria (Schlesener *et al*. 2015).

Countries wherein this pest is already established have a zero tolerance policy regarding the presence of infested fruits, due to its aggressiveness, major biotic potential and restrictions in both internal and external markets (Bruck *et al*. 2011; Cuthbertson *et al.* 2014). There are many works which have as their goal to find viable alternatives for the control of the spotted wing drosophila in conventional and organic systems (Beers *et al.* 2011; Gabarra *et al.* 2014; Cuthbertson and Audsley 2016; Daane *et al.* 2016). However, the first alternative has been insecticides, which are already used for the management of other pests on these crops and that are effective in the control *D. suzukii.*

In Brazil, the difficulty is increased as a result of the lack of available chemical molecules for the management of small fruit pests and due to the non-existence of products registered for *D. suzukii*. Studies on insecticides must be a part of a more elaborated management program, with monitoring protocols, treatment thresholds, alternative methods and efficient chemical control. In this context, the goal of this study was to evaluate in laboratory the mortality of *D. suzukii* adults and ovicidal effect when exposed to insecticides used for the control of pests to different crops, with intent to provide alternatives for the management of this exotic species.

Materials and methods

The experiments were performed in the Integrated Pest Management Laboratory, in the "Eliseu Maciel" School of Agronomy, Pelotas Federal University, Capão do Leão, RS, Brazil. The insecticides used in the trials are registered for different Diptera, Lepidoptera, and Hemiptera pests, and for Tetranychidae mite in different crops. They were: Actara® (strawberry, *Capitophorus fragaefolii* (Cockerell, 1901) (Hemiptera, Aphididae); Altacor® (apple, *Grapholita molesta* (Busk, 1916) (Lepidoptera, Tortricidae)); Decis® 25 EC (peach, *Anastrepha fraterculus* (Wied. 1830) and *Ceratitis capitata* (Wied. 1824) (Diptera, Tephritidae)); Imidan® 500 WP (apple, *G. molesta* and *A. fraterculus*); Malathion® 500 EC (apple and citrus, *A. fraterculus*); Mospilan® (apple, *A. fraterculus*); Mustang® 350 EC (potato, *Liriomyza huidobrensis* (Blanchard, 1926) (Diptera, Agromyzidae)) Perfekthion® (apple, *A. fraterculus* and *C. capitata*); Sumithion® 500 EC (apple, *A. fraterculus*); Supracid® 400 EC (apple, *A. fraterculus*); Suprathion® 400 EC (apple, *A. fraterculus*); Tracer® (apple, *G. molesta*); Vertimec® 18 EC (strawberry, *Tetranychus urticae* (Koch, 1836) (Acari, Tetranychidae)). The dosages utilized were the largest recorded (Table 1) and the control treatment for both bioassays was distilled water. The Pre-Harvest Interval (PHI) was also checked for each crop. For the attainment of the ovicidal effect essays, two products were added (Difluchen® 240 CS and Match® EC) which are growth regulators, with known ovicidal effect. Insects originated from laboratory stock colony were used.

Laboratory colony. A *D. suzukii* stock colony is established in the Insect Ecology Laboratory, at the Biology Institute, Federal University of Pelotas, Capão do Leão, RS, Brazil, originated from flies collected from infested fruits gathered in the Pelotas city, Rio Grande do Sul, Brazil, between March and May, 2015. The subjects were properly identified and conditioned inside flat bottomed glass tubes (27 ml) containing artificial diets based on corn flour (80 g), yeast (40 g), powdered glucose (100 g), agar (8 g), propionic acid (3 ml), Nipagin (8 ml, in a 10 % alcohol dilution) and 1 L of distilled water, plugged with hydrophillic cotton. The breeding tubes were kept in acclimatized chamber under 22 ± 1 ºC, 70 ± 5 % RH and 12 h photofase.

Adult mortality. For the study of *D. suzukii* adult mortality, ripe strawberries (*Fragaria* x *ananassa*) were used. They had been previously treated with a 2 % propionic acid solution, deposited over absorbent paper, and dried under room temperature. After, the fruits were immersed in slurries made from the different insecticides been tested (Table 1) for five seconds, deposited over absorbent paper and once more dried under room temperature. Next, the fruits were placed in plastic containers (250 ml) with a perforated cover (4 cm diameter) and covered with *voile* fabric. On the bottom of each arena, approximately 1 cm of vermiculite, in order to prevent the fruits rolling over and to absorb the liquids from fruit decomposition. Each arena was considered a repetition, which was composed of one fruit and five *D. suzukii* couples (ten adults), inserted with the aid of an entomological vacuum. The arenas were placed in an acclimatized room, under 22 ± 2 ºC temperature, 70 ± 5 % RH and 14 h photofase. The evaluations were performed one, two, and three days after treatment (DAT), when the number of dead subjects was counted. It was not possible to perform evaluation for a longer period of time after subjects' exposure, due to how quickly the fruits decomposed. The averages were subjected to Shapiro-Wilk normality test and homogeneity of variances of Bartlett. Data not following the normality assumptions or homogeneity of variance were submitted to Kruskal-Wallis non parametric analysis of variance (ANOVA). In the event of difference between treatments, the averages were compared by Dunn test at 5 % level of error probability. The control efficiency was calculated according to Abbott's formula (Abbott 1925).

Ovicidal effect. For this study to be perfor/med, two more growth regulating insecticides were added to the list, Difluchem® 240 SC and Match® EC. As a substrate to *D. suzukii's* oviposition, "artificial fruits" were used, made from agar (17 g), distilled water (425 ml), raspberry gelatin (10 g), and Nipagin (4 ml in a 10 % alcohol dilution). The ingredients were mixed and boiled, and this solution was poured into plastic molds. The artificial fruits dried under room temperature and removed from the plastic molds after hardening (modified from Salles 1992). Each fruit was placed inside a 250 ml plastic container, with a perforated

Table 1. Insecticides used in the adult mortality and ovicidal effect over *Drosophila suzukii* in laboratory conditions.

Active ingredient	Insecticide	Chemical group	Recorded dosage	PHI*
Chlorantraniliprole[12]	Altacor®	Anthranilic diamide	10 g / 100 L-1	14
Abamectin[12]	Vertimec® 18 EC[12]	Avermectins	70 mL / 100 L-1	3
Acetamiprid[12]	Mospilan®[12]	Neonicotinoids	40 g / 100 L-1	7
Thiamethoxam[12]	Actara® 250 WG[12]	Neonicotinoids	10 g / 100 L-1	1
Dimethoate[12]	Perfekthion®[12]	Organophosphorus	80 mL / 100 L-1	3
Fenitrothion[12]	Sumithion® 500 EC[12]	Organophosphorus	200 mL / 100 L-1	14
Malathion[12]	Malathion® [12]	Organophosphorus	350 mL / 100 L-1	7
Methidathion[12]	Supracid® 400 EC[12]	Organophosphorus	100 mL / 100 L-1	21
Methidathion[12]	Suprathion® 400 EC[12]	Organophosphorus	100 mL / 100 L-1	21
Phosmet[12]	Imidan® 500 WP[12]	Organophosphorus	200 g / 100 L-1	14
Deltamethrin[12]	Decis® 25 EC[12]	Pyrethroid	40 mL / 100 L-1	5
Zeta-cypermethrin[12]	Mustang® 350 EC[12]	Pyrethroid	60 mL / 100 L-1	7
Spinosad[12]	Tracer®[12]	Spinosyns	15 mL / 100 L-1	14
Diflubenzuron[2]	Difluchem® 240 SC[2]	Benzoylurea	25 mL / 100 L-1	30**
Lufenuron[2]	Match® EC[2]	Benzoylurea	100 mL / 100 L-1	28**
Control	–	–	–	–

[1] Insecticides used in the adult mortality experiment. [2] Insecticides used in the ovicidal effect experiment. * PHI in days for the cultures described in materials and methods. ** PHI in days for citrus.

cover (4 cm diameter), wherein five couples (ten adults), approximately eight days old were added. For the following 24 h oviposition was permitted. The insects were removed from the arenas and, afterward, immersion of the fruits in insecticides (Table 1) was conducted for five seconds. The fruits recently treated were deposited over absorbent paper in order to dry under room temperature. With the aid of a scalpel, ten eggs were removed from each fruit, deposited over Petri dish with humid filtering paper, with daily humidity restitution.

The experimental design was entirely randomized, with five repetitions for each treatment, and each repetition comprised of one Petri dish containing ten eggs previously treated. With the aid of a stereomicroscope, the counting of the ecloded larvae was performed one and two DAT. The averages were subjected to Shapiro-Wilk normality test and homogeneity of variances of Bartlett. Data not following the normality assumptions or homogeneity of variance were submitted to Kruskal-Wallis non parametric analysis of variance (ANOVA). In the event of difference between treatments, the averages were compared by Dunn test at 5 % level of error probability.

Results

***Drosophila suzukii*'s adult mortality.** *Drosophila suzukii*'s adult mortality one, two, and three days after exposure to insecticides is expressed by table 2. Fenitrothion (Sumithion® 500 EC; 200 mL / 100 L-1), phosmet (Imidan® 500 WP; 200 g / 100 L-1), malathion (Malathion®, 350 mL / 100 L-1) and methidathion (Suprathion® 400 EC, 100 mL / 100 L-1) displayed 100 % mortality at the end of one DAT, and spinosad (Tracer®, 15 mL / 100 L-1), deltamethrin (Decis® 25 EC, 40 mL / 100 L-1), and dimethoate (Perfekthion® 80 mL / 100 L-1) also obtained high control indexes, with the recorded mortality of 96 %, 90 %, and 90 %, respectively, significantly differing from the control treatment. Methidathion (Supracid® 400 EC; 100 mL / 100 L-1) and zeta-cypermethrin (Mustang® 350 EC; 60 mL / 100 L-1) reached average mortality of 78 % and 74 %, respectively, not attaining a satisfactory control within the first 24 h of evaluation. Abamectin (Vertimec® 18 EC; 70 mL / L-1), acetamiprid (Mospilan® 40 g / 100 L-1), chlorantraniliprole (Altacor®; 10 g / 100 L-1), and thiamethoxam (Actara® 250 WG; 10 g / 100 L-1) did not cause significant mortality *D. suzukii*'s adults, relative to the control treatment.

At the end of two DAT, the insecticides deltamethrin, dimethoate, and methidathion (Supracid® 400 EC) also caused 100 % mortality to subjects and zeta-cypermethrin caused 98 % mortality to adult subjects, with a significant difference in relation to other treatments. The insecticides acetamiprid and chlorantraniliprole resulted in 46 %, differing significantly from the control treatment. Despite the increase in mortality caused by thiamethoxam (36 %), no significant difference was verified relative to the control treatment, the same was observed for abamectin (4 %).

At three DAT, the insecticides abamectin and acetamiprid displayed results identical to the former evaluations. There was an increase in mortality in the treatment with chlorantraniliprole (60 %). Despite no significant difference found in the performance of this product in relation to the ones that caused 100 % mortality in the insects, the result was not considered to be satisfactory. Abamectin and thiamethoxam were inefficient, equal to the control treatment. The treatments deltamethrin, dimethoate, spinosad, fenitrothion, phosmet, malathion, methidathion, and zeta-cypermethrin caused 100 % mortality in *D. suzukii* adults at three DAT.

Ovicidal effect. The eclosion of *D. suzukii* larvae after treatment with insecticides is expressed in table 3. It was observed that 98 % of the larvae subjected to control treatment (distilled water) ecloded within the first 24 hours of evaluation. The growth regulating insecticide lufenuron (Match® EC; 100 mL / 100 L-1) did not differ significantly from the control treatment, resulting in ecloding to approximately 86 % of the larvae one DAT. The eggs treated with fenitrothion, phosmet, malathion, methidathion (Supracid® 400 EC) and methidathion (Suprathion ® 400 EC) with no larval eclosion was observed at the end of 1 DAT. The insecticides diflubenzuron (Difluchem® 240 SC; 25 mL / 100 L^{-1}) and dimethoate also caused adverse effects during *D. suzukii* embryonic period, with only 8 % and 26 % eclosion of larvae been observed in the respective treatments. Larval eclosion recorded for treatments with deltamethrin, chlorantraniliprole, spinosad, zeta-cypermethrin, and thiamethoxan vary between 42 % and 62 %, wherein all the treatments presented a significant difference in relation to the control treatment.

At the end of two DAT, 100 % of the larvae in the control treatment had ecloded, thus demonstrating that the time of evaluation and methodology are suitable to such essays. No egg eclosion was observed in the eggs treated with fenitrothion, malathion, methidathion (Supracid® 400 EC), methidathion (Suprathion® 400 EC), and under treatment with phosmet only 4 % of larvae ecloded. All treatments differed from the control treatment. Physiological insecticide diflubenzuron also presented high ovicidal effect, resulting in the mortality of 80 % of embryos, which did not differ significantly from the aforementioned treatments and from dimethoate which lead to a 64 % control of the eggs, with both significantly more efficient than the control treatment. Abamectin and chlorantraniliprole provided 46 % and 42 % control, respectively, differing significantly from the control treatment. The other treatments, acetamiprid, deltamethrin, spinosad, thiamethoxam, zeta-cypermethrin, and lufenuron produced embryo mortality between 4 % and 24 %, not presenting a significant performance in relation to the control treatment. Insecticides fenitrothion, phosmet, malathion, methidathion (Supracid® 400 EC), methidathion (Suprathion® 400 EC), and diflubenzuron obtained satisfactory control, above 80 %.

Discussion

The first tests on chemical control of *D. suzukii* with insecticides registered for other insects and pests to other crops in Brazil, demonstrate that the insecticides belonging to the pyrethroid, spinosyns, and organophosphorus chemical groups were efficient in the control of *D. suzukii* adults (Table 2), in addition to most organophosphorus also presenting ovicidal effect (Table 3) due to its in depth or systemic action, which provides greater efficiency in the control of eggs and larvae within the fruits. The high mortality of adults occasioned by some of the organophosphorus insecticides was also verified by other authors (Bruck *et al*. 2011; Haviland and Beers 2012; Cuthbertson *et al*. 2014; Cowles *et al*. 2015). The conscious use of those chemical groups provides five to fourteen days of residual control in the field, on the condition of few occurrences of rain (Bruck *et al*. 2011), furthermore permitting the resistance management and assuring the trade with most of the foreign consuming markets (Haviland and Beers 2012).

Spinosad (Tracer®) demonstrated great efficiency in the control of adult insects when exposed to previously treated strawberries. Similar results were observed by Cuthbertson *et al*. (2014), when the insects were subjected to contact with blueberries which had previously been treated with Converse® (spinosad; 0.096 a.i./L), reaching 100 % mortality after 24 hours. Nevertheless, mortality for adult insects directly pulverized by the same insecticide was notably inferior, probably due the lesser ingestion of the product

Table 2. Average number (± standard error) of *Drosophila suzukii* adult subjects after exposure to strawberries (*Fragaria* x *ananassa*) treated with insecticides in laboratory bioassays.

Treatment	Dosage[1]	Days after treatment (DAT)					
		1 DAT		2 DAT		3 DAT	
		m ± EP*[2]	EC %[#]	m ± EP[3]	EC %	m ± EP[4]	EC %
Abamectin	70.00	10.00 ± 0.00 a	0.00	9.60 ± 0.24 ab	4.00	9.60 ± 0.24 ab	4.00
Acetamiprid	40.00	9.60 ± 0.24 a	4.00	5.40 ± 2.22 b	46.00	5.40 ± 2.22 bc	46.00
Chlorantraniliprole	10.00	8.60 ± 0.24 a	14.00	5.40 ± 0.60 b	46.00	4.00 ± 0.31 cd	60.00
Deltamethrin	40.00	1.00 ± 0.54 bc	90.00	0.00 ± 0.00 c	100.00	0.00 ± 0.00 d	100. 00
Dimethoate	80.00	1.00 ± 0.31 bc	90.00	0.00 ± 0.00 c	100.00	0.00 ± 0.00 d	100.00
Fenitrothion	200.00	0.00 ± 0.00 c	100.00	0.00 ± 0.00 c	100.00	0.00 ± 0.00 d	100.00
Phosmet	200.00	0.00 ± 0.00 c	100.00	0.00 ± 0.00 c	100.00	0.00 ± 0.00 d	100.00
Malathion	350.00	0.00 ± 0.00 c	100.00	0.00 ± 0.00 c	100.00	0.00 ± 0.00 d	100.00
Methidathion (Supracid)	100.00	2.20 ± 0.58 b	78.00	0.00 ± 0.00 c	100.00	0.00 ± 0.00 d	100.00
Methidathion (Suprathion)	100.00	0.00 ± 0.00 c	100.00	0.00 ± 0.00 c	100.00	0.00 ± 0.00 d	100.00
Spinosad	15.00	0.40 ± 0.40 c	96.00	0.00 ± 0.00 c	100.00	0.00 ± 0.00 d	100.00
Thiamethoxam	10.00	9.80 ± 0.20 a	2.00	6.40 ± 2.20 ab	36.00	6.20 ± 2.33 abc	38.00
Zeta-cypermethrin	60.00	2.60 ± 0.81 b	74.00	0.20 ± 0.20 c	98.00	0.00 ± 0.00 d	100.00
Control	–	10.00 ± 0.00 a	–	10.00 ± 0.00 a	–	10.00 ± 0.00 a	–
CV %		19.88	72.50	77.24			

[1] Dosages expressed in mL or g per 100 L of water. [*] Average and standard error for the average number of live *D. suzukii*'s adult insects found the day after treatment (DAT). Results compared by Kruskal-Wallis non parametric analysis of variance (ANOVA): [2] H= 63.8700, p-value = < 0.0000; [3] H = 60.7436, p-value = < 0.0000 and; [4] H = 59.075, p-value = < 0.0000, followed by Dunn's test (P < 0.05); [#] Control efficiency according to Abbott's formula (Abbott 1925).

by the insects. An increase on the ingestion of the product can be improved with the addition of a phagostimulant, such as sucrose (0.3 %) to the spinosad slurry (Entrust®; 0.12 g a.i./L). This addition promoted an increase on the interaction of insects with the residue of the product, leading to a consequent increase and acceleration on the mortality of insects (Cowles *et al.* 2015). The satisfactory performance of spinosad in the control of *D. suzukii* adults is extremely important, since this insecticide has been used as a possible substitute for malathion in toxic baits for the control of flies belonging to the Tephritidae genus, such as *A. fraterculus*, with potential to be of use in the development of baits for *D. suzukii*. The insecticides belonging to the spinosyns chemical group are environmentally safer and less toxic than the organophosphorus (Harter *et al*. 2015). It was also verified that the application of spinosad over infested blueberries completely prevented the emergence of adults (Cuthbertson *et al*. 2014). In the present study, no observation was made regarding a significant effect of this insecticide over eclosion of *D. suzukii* larvae (Table 3).

Other insecticides present a behavior similar to the one observed for spinosad, were the pyrethroids (deltamethrin and zeta-cypermethrin), which caused mortality to all adults at the end of three DAT, due the “knock down” action characteristic to this group of insecticides. However, no significant adverse effects in the embryonic period were observed, for the pyrethroids, like the Decis® insecticide, do not present in depth action (Monnerat *et al.* 2000). Nevertheless, the same was not observed for deltamethrin (Decis®; 0.018 g a.i./L) in immersion tests with fruits (blueberries) that had been previously infested (Cuthbertson *et al.* 2014), wherein 72 h of oviposition were permitted before the immersion of the fruits, and the subsequent phases of insect development were evaluated until the emergence of adults. The longest period of oviposition, which probably generated first instar larvae, more susceptible than the eggs, in conjunction with a longer period of contact between eggs and larvae and the active principle, may have provided a more effective control.

The performance of insecticides acetamiprid and thiamethoxam belonging to the neonicotinoids chemical groups were not satisfactory in relation to the other contact action insecticides. Bruck *et al.* (2011) obtained similar results. In the present study, a slight ovicidal effect was observed, probably caused by the penetration of the insecticide in the oviposition substrate and its systemic effect. However, due to the strong restrictions on the use of these products by the fruit market and environmental agencies the use of neonicotinoids is not recommended for the management of the spotted-wing drosophila.

Vertimec® 18 EC (abamectin) displayed medium ovicidal effect. Abamectin is a macrocyclic lactone, which possess translaminar action, allowing for the action over eggs even within the oviposition substrate (Monnerat *et al*. 2000). It is important to highlight that despite no effect being presented by abamectin over *D. suzukii* adults (Table 2), there was consequential mortality of almost half embryos in the present essays (Table 3). Altacor® (chlorantraniliprole) presented medium effect in the control of *D. suzukii* adults and eggs. This effect is somewhat surprising, since this insecticide is registered only for lepidopterans in fruit crops. The insecticide

Table 3. Average number (± standard error) of *Drosophila suzukii* larvae ecloded after exposure to insecticides in laboratory bioassays.

Treatment	Dosage[1]	Days after treatment (DAT)		
		1 DAT	2 DAT	EC %[#]
		m ± EP*[2]	m ± EP[3]	
Abamectin	70.00	3.20 ± 0.58 de	5.40 ± 0.75 bc	46.00
Acetamiprid	40.00	3.20 ± 0.66 de	7.60 ± 1.36 ab	24.00
Chlorantraniliprole	10.00	4.60 ± 0.74 cd	5.80 ± 0.80 bc	42.00
Deltamethrin	40.00	4.20 ± 0.80 cd	7.60 ± 0.51 ab	24.00
Dimethoate	80.00	2.60 ± 0.67 def	3.60 ± 0.81 cd	64.00
Fenitrothion	200.00	0.00 ± 0.00 f	0.00 ± 0.00 e	100.00
Phosmet	200.00	0.00 ± 0.00 f	0.40 ± 0.25 e	96.00
Malathion	350.00	0.00 ± 0.00 f	0.00 ± 0.00 e	100.00
Methidathion (Supracid)	100.00	0.00 ± 0.00 f	0.00 ± 0.00 e	100.00
Methidathion (Suprathion)	100.00	0.00 ± 0.00 f	0.00 ± 0.00 e	100.00
Spinosad	15.00	4.60 ± 0.92 cd	8.80 ± 0.37 a	12.00
Thiamethoxam	10.00	6.20 ± 0.80 bc	9.00 ± 0.44 a	10.00
Zeta-cypermethrin	60.00	5.00 ± 0.54 cd	9.20 ± 0.58 a	8.00
Diflubenzuron	25.00	0.80 ± 0.37 ef	2.00 ± 0.70 de	80.00
Lufenuron	100.00	8.60 ± 0.75 ab	9.60 ± 0.40 a	4.00
Control	–	9.80 ± 0.20 a	10.00 ± 0.00 a	–
CV %		37.80	26.26	

[1] Dosages expressed in mL or g per 100 L of water. * Average and standard error for the average number of ecloded *D. suzukii's* larvae found the day after treatment (DAT). Results compared by Kruskal-Wallis non parametric analysis of variance (ANOVA): [2] H = 70.0960, p-value = < 0.0000; [3] H = 71.6150, p-value = < 0.0000, followed by Dunn's test ($P < 0.05$). [#] Control efficiency according (2 DAT) to Abbott's formula (Abbott 1925).

chlorantraniliprole (Coragen®; 0.0116 g a.i./L) also caused reduction in the emergence of adults in previously treated blueberry fruits (Cuthbertson *et al*. 2014).

The insecticide Difluchem® 240 SC (diflubenzuron) presented high ovicidal effect over eggs of *D. suzukii*, although the efficiency of control over adults, since it is a growth regulator and inhibits syntheses, acts only in immature forms. The insecticide novaluron (Diamond®, 212.5g a.i./ha^{-1}), which presents the same active principle and means of action as the insecticide Difluchem® 240 SC, did not cause an effect on drosophila adults (Bruck *et al*. 2011). Macth® EC (lufenuron), an insecticide that has the same means of action but not the same active ingredient, did not present any effect over this insect's eggs.

Conclusion

The search for insecticides that may be part of an integrated *D. suzukii* management is essential, and they must be not only effective, but act on distinct physiological sites within the insect's organism. Several genes linked to resistance mechanisms to insecticides have already been identified in species from the *Drosophila* genus (Morton 1993). Therefore, to extend the advent of resistances to pyrethroid, spinosyns, and organophosphorus in the search for new means of control, such as biological control, culture management, and alternative products is primordial to the future of small fruit's production in Brazil.

The present work demonstrates the existence of insecticide capable of integrating a *D. suzukii* chemical control program in Brazil. Nevertheless, the action of these products needs further studies and also record keeping in order to be an alternative for small fruit's producers to control of *D. suzukii*.

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