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RESEARCH ARTICLE - WASPS

Physiological selectivity of insecticides from different chemical groups and cuticle thickness of *Protonectarina sylveirae* (Saussure, 1854) and *Brachygastra lecheguana* (Latreille, 1824) (Hymenoptera: Vespidae)

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Abstract

The use of insecticides more toxic to pest than to natural enemies may favor the conservation of these beneficial organisms. This study aimed to evaluate the physiological selectivity of insecticides from different chemical groups to Vespidae *Protonectarina sylveirae* (Saussure, 1854) and *Brachygastra lecheguana* (Latreille, 1824) and cuticle thickness in order to evaluate the tolerance between the two species to the same insecticides. We immersed maize leaves (10 x 10 cm) in insecticide solution in dose (100%), subdose (50%) and distilled water (control) for 5 seconds. We dried the leaves in the shade and subsequently packed them in Petri dishes. The 20 wasps, per plate, received 10% honey and the plates were closed with fine organza fabric and elasticated. After 24 hours, we evaluated the percentage of dead wasps. Alpha-cypermethrin insecticide was highly toxic to *P. sylveirae* and *B. lecheguana* in dose (100%) and subdose (50%). Novaluron, chlorantraniliprole, spinosad and indoxacarb insecticides were poorly toxic to *P. sylveirae* and *B. lecheguana* in dose (100%) and subdose (50%). The high toxicity of insecticides methomyl + novaluron, chlorantraniliprole + lambda-cyhalothrin and deltamethrin to *P. sylveirae* corresponded to a smaller cuticle thickness. Therefore, novaluron, chlorantraniliprole, spinosad and indoxacarb insecticides showed physiological selectivity to *P. sylveirae* and *B. lecheguana*.

Introduction

Fall armyworm *Spodoptera frugiperda* (Smith & Abbot, 1797) (Lepidoptera: Noctuidae) is a polyphagous pest capable of causing significant damage in maize, *Zea mays* L., soy, *Glycine max* L. and cotton, *Gossypium hirsitum* L. (Nagoshi, 2009; Bueno et al., 2011; Aguierre et al., 2016). *S. frugiperda* damage has been reported in North America, Central America, Brazil, Argentina, the United States, and recently in Africa (Prowell et al., 2004; Clark et al., 2007; Casmuz et al., 2010; Tindo et al., 2017).

S. frugiperda caterpillars can occur on maize throughout the plant canopy. Hatched caterpillars scrape the leaf limb epidermis and can cut the collar in the next stages. In the late stages, *S. frugiperda* damages the cartridge and may damage the maize ear during severe infestations. Economic damage has already been reported for $ 3 billion a year in Africa (Rodriguez-del-bosque et al., 2011; Jeger et al., 2017; Maiga et al., 2017). Controlling this pest can occur by cultural, chemical and biological (*Trichogramma pretiosum*) methods and using plants with different expressions of *Bacillus thurigiencis* (*Bt*) proteins (Bt) (Capineira, 2005; Balestrin & Bordin, 2016; Bortolotto et al., 2016; Roel et al., 2017). Among the alternative methods, chemical control may be effective to control *S. frugiperda, Helicoverpa zea* (Boddie, 1850) and *Agrotis ipsilon* (Hufnagel, 1766) (Lepidoptera: Noctuidae), as shown by Blanco et al. (2014). However, overuse of insecticides has resulted in the development of resistant populations and negative impacts on natural enemies (Yu et al., 2003; Romeis et al., 2006; Ahmad & Arif, 2010).

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Beneficial organisms of agricultural importance are important for reducing pest population. Biological control with predatory wasps *Polybia ignobolis* (Haliday, 1836), *Vespula shidai* (Linneaus, 1758), *Vespula vulgaris* (Linneaus, 1758) (Picanço et al., 2010), *Protonectarina sylveirae* (Saussure, 1854) and *Brachygastra lecheguana* (Latreille, 1824) (Hymenoptera: Vespidae) is a viable method for controlling Lepidoptera insects (Ross & Matthews, 1991; Miranda et al., 1998; Gonring et al., 2002; Gonring et al., 2003; Pereira et al., 2007a; Fernandes et al., 2008; Picanço et al., 2011; Ghoneim, 2014; Saraiva et al., 2017).

Conservation of predatory wasps in Integrated Pest Management (IPM) programs becomes essential, because this organism has a great importance to regulating the population dynamics of insect pests (Pereira et al., 2007a). The strategies to conserve natural enemies is to use insecticides with physiological selectivity. Selectivity may be physiological when using insecticides more toxic to pest than to natural enemies (Pedigo, 1999).

Physiological selectivity of the insecticides from the anthranilic diamide group (chlorantraniliprole) to *P. sylveirae*, *B. lecheguana* and *Polybia* sp., growth regulator (buprofezin) in hymenoptera insects was observed by Fernandes et al. (2013) and Araujo et al. (2017). High toxicity of pyrethroids (deltamethrin) in dose (100%) and subdose (50%) to *P. sylveirae* and *B. lecheguana* was observed by Bacci et al. (2009). The use of the recommended dose (100%) for pest control allows the evaluation of the impact of these products on predatory wasps. Already the use of the subdose (50%) allows to evaluate the impact of insecticides when half of their concentrations have been decomposed (Suinaga et al., 1996).

The potential toxicity of insecticides against natural enemies may correlate with their physicochemical characteristics as well as thickness and chemical composition of the wasp cuticle (Leite et al., 1998; Gusmão et al., 2000; Katagi, 2001). On the other hand, the tolerance of wasps to insecticides may be associated with the lower penetration rate of these products to the integument (Bacci et al., 2006).

Biochemical and physiological studies to elucidate the mechanism of physiological selectivity to predatory wasps are unknown (Bacci et al., 2006). Thus, this study aimed to evaluate the physiological selectivity of insecticides from different chemical groups, with the respective dose (100%) and subdose (50%) for maize, *P. sylveirae* and *B. lecheguana* wasps, and cuticle thickness of predatory wasps in order to evaluate the tolerance between the two species with the same insecticides.

Material and methods

We conducted the study at the Integrated Pest Management Laboratory of the Federal University of Viçosa (UFV) - Rio Paranaíba Campus from November 2017 to January 2018. *P. sylveirae* and *B. lecheguana* wasps were collected in nests on the campus. The nests were in trees and shrubs. Later the specimens were packed in plastic bags and sent to UFV Campus Viçosa under the care of Dr. Paulo Sérgio Fiuza (curator and taxonomist of the UFV museum – Viçosa) to identify the species.

We used insecticides registered to control *S. frugiperda* in *Z. mays* (Mapa, 2017) (Table 1). The concentration of the active ingredients used in the bioassay corresponds to 100 and 50% of the dose recorded in the Mapa (2017). Subdose (50%) was used to verify whether the insecticide was selective when degraded by half its concentration (100%).

The experimental design was completely randomized, in a 10 x 2 x 2 factorial scheme (insecticide x concentration of active ingredient x species) with 4 replicates. The experimental plots consisted of 20 wasps of each species (*P. sylveirae* and *B. lecheguana*). Insecticides (Table 1) were diluted in distilled water with adhesive spreader (polyester and silicone copolymer 1000 g L^{-1}). Water plus adhesive spreader was the control treatment.

Maize leaves were cut (10 x 10 cm) and immersed in the insecticide broth for five seconds for each treatment (Bacci et al., 2001; Galvan et al., 2002). The leaves were then dried in the shade for thirty minutes and packed in Petri dishes (9 cm in diameter and 2 cm in height). We prepared a solution with 10% honey to feed 20 wasps per dish. The solution with honey was placed in the lateral walls of the dishes to avoid contact with insecticides. The dishes were covered with fine organza fabric and elasticated.

Each Petri dish, containing the insects, was conditioned in B.O.D (Biochemical Oxygen Demand) at 25 ± 1ºC, 70 ± 1% relative humidity and 12-hour photoperiod. After 24 hours, we evaluated the percentage of dead wasps. The wasps were considered dead when they did not move. Subsequently, mortality rates were corrected using the Abbott's formula (Abbott, 1925).

The insecticides were classified as non-selective or highly toxic (mortalities between 100-70%), moderately selective or moderately toxic (mortalities between 69-30%) and selective or poorly toxic (mortality between 29-0%) (Bacci et al., 2006).

Mortality data were transformed into rank noise (Conover & Iman, 1981) to perform analysis of variance at $p \leq 0.05$ and then the means were compared using the Skott-Knott grouping test ap ≤ 0.05 using the program Speed Stat 1.0 (Mundstock, 2017).

Anatomy of the abdomen cuticle of P. sylveirae and B. lecheguana

Wasp species were captured in nests located on the UFV Campus - Rio Paranaíba on banana and hibiscus plants. For the experiments, we used four wasps (*P. sylveirae* and *B. lecheguana*) and two blocks, each block containing two abdomens.

We performed anatomical sections on the abdomens of adult *P. sylveirae* and *B. lecheguana* females to verify, through cuticle thickness, the tolerance of insects to insecticides.

Table 1. Chemical group, commercial dose, concentration of active ingredient, molecular weight and solubility of the insecticides registered for maize crop, in the control of the caterpillar *Spodoptera frugiperda*.

Insecticides	Chemical group	Commercial dose (mL ha^{-1}or g ha^{-1})	Concentration (mg i.a. ha^{-1})	molecular weight (g mol^{-1})	Solubility (mg L^{-1} or g L^{-1})
Indoxacarb 150 CE	Oxadiazines	400	60	527.8	0.2
Alpha-cypermethrin 100 FS	Pyrethroid	50	5	416.3	2.06
Deltamethrin 25 CE		200	5	505.2	1.3 x 10^{-6}
Chlorantraniliprole 200 SC	Anthranilic	125	25	483.15	1.023
methomyl+novaluron 440 + 35 CE	Oxime methyl carbamate + benzoylurea	500	220 + 17,5	162.20 + 492.7	54.7
Novaluron 100 CE	Benzoylurea	400	40	492.7	3 x 10^{-6}
Lambda-cyhalothrin + chlorantraniliprole 50 + 100 SC	Pyrethroid + anthranilamide	150	7,5 + 15	449.9	6.3 x 10^{-6}
Chlorfenapyr 240 SC	Pyrazole analogue	750	180	407,6	5,28
Spinosad 480 SC	Spinosyns	100	48	732.0 (Spinosyn A) +746.0 (Spinosyn D)	235 + 0.332

The integument of the wasps' abdomen was transferred to the Zamboni fixative solution (Stefanini, 1967) remaining for 24 hours in a vacuum chamber. We submitted the collected material to dehydration to the growing series in ethanol (70, 80, 90 and 95%) for 1 hour. After dehydration, the infiltration occurred on leica historesin and kept in the refrigerator for 24 hours. Subsequently, they were added to histomolds with a historesin solution plus leica polymerizer in a 15:1 mL ratio in an oven at 55ºC for 24 hours.

Historesin blocks containing the integument were sectioned at 3 µm thickness using the rotary microtome. Historesin sections were transferred to a vessel with water in order to expand them and avoid historesin overlap over the cuticle coming from the abdomen of the wasps. The sections were collected on 12 glass slides per species, totaling 24 slides. We placed them into the hotplate for slide cutting setting. The tissue attached to the slide was stained with Toluidine Blue. After staining, the coverslips were placed on the cuttings, fixed with Permount, causing permanent slides.

The stained slides were photographed under the microscope Olympus CX 41 coupled to the Nikon D3100 camera. We edited the images (micrographs) and adjusted contrast, white balance, balance and scale insertion in the Photoshop cc program.

Results

Insecticide

Significant interaction for insecticide and species ($F_{9.120} = 2.95$, $p \leq 0.003$) occurred, insecticide and dose (100 and 50%) ($F_{9.120} = 3.79$, $p < 0.001$) for wasp mortality *P. sylveirae* and *B. lecheguana*. Insecticides ($F_{9.120} = 90.11$, $p \leq 0.001$), species ($F_{1.120} = 14.91$, $p < 0.001$) and dose ($F_{1.120} = 120.30$, $p \leq 0.001$) were also significant. Insecticide interaction, dose and species ($F_{9.120} = 0.805$, $p = 0.6127$) and species and dose interaction ($F_{9.120} = 0.223$, $p = 0.6376$) were not significant.

Alpha-cypermethrin insecticide was highly toxic (non-selective) to *P. sylveirae* and *B. lecheguana* wasps in dose (100%) and subdose (50%) (Table 2). Methanyl + novaluron, chlorantraniliprole + lambda-cyhalothrin and deltamethrin were highly toxic to *P. sylveirae* and moderately toxic to *B. lecheguana* in dose (100%). Novaluron, chlorantraniliprole, spinosad and indoxacarb insecticides were poorly toxic (selective) to *P. sylveirae* and *B. lecheguana* in dose and subdose (Table 2 and 3).

Table 2. Mortality (%) of *Protonectarina sylveirae* (P) and *Brachygastra lecheguana* (B) wasps observed after immersion of maize leaves in insecticide broth with the respective doses recommended for maize crop and subdose, in the control of *Spodoptera frugiperda*.

Insecticides	Mortality (%) (Mean ± SE)[1]			
	Species			
	n	*P. sylveirae*	*B. lecheguana*	Means
Methomyl + novaluron	16	80.6 ± 4.9Aa	53.1 ± 6.7Bb	66.9 ± 5.4
Chlorantraniliprole + lambda-cyhalothrin	16	79.4 ± 5.6Aa	53.8 ± 8.2Bb	66.5 ± 5.8
Deltamethrin	16	71.3 ± 5.3Aa	49.4 ± 7.7Bb	60.3 ± 5.3
Novaluron	16	10.0 ± 3.3Ca	4.4 ± 1.7Da	7.2 ± 1.9
Chlorantraniliprole	16	6.3 ± 2.4Ca	13.1 ± 6.4Ca	9.7 ± 3.4
Spinosad	16	15.0 ± 5.4Ca	14.4 ± 5.4Ca	14.7 ± 3.7
Chlorfenapyr	16	25.0 ± 6.4Ba	15.0 ± 5.0Ca	20.0 ± 4.1
Alpha-cypermethrin	16	78.8 ± 5.2Aa	73.5 ± 6.5Aa	76.2 ± 4.1
Indoxacarb	16	13.6 ± 4.3Ca	18.8 ± 8.5Ca	16.2 ± 4.6
Control	16	0.0 ± 0.0Da	0.0 ± 0.0Da	0.0 ± 0.0
Means		38.2 ± 11.0	29.5 ± 8.0	

[1] Means followed by upper case letter in the column (comparison between insecticides) and, lowercase in the line (comparison between species), did not differ by the Skott-Knott skin test $p \leq 0.05$.

B. lecheguana was the most tolerant species to methomyl + novaluron, chlorantraniliprole + lambda-cyhalothrin and deltamethrin. *P. sylveirae* and *B. lecheguana* showed similar tolerance to novaluron, chlorantraniliprole, spinosad, chlorfenapyr, alpha-cypermethrin and indoxacarb (Table 2). Alpha-cypermethrin caused similar mortality among wasp at half the dose. Regarding the other insecticides, dose was more toxic to wasps than subdose (Table 3). Subdose of insecticides resulted in lower wasp mortality in all evaluated treatments compared to the recommended dose (Table 3). Subdoses of ethanyl + novaluron, chlorantraniliprole + lambda-cyhalothrin and deltamethrin were moderately toxic to *P. sylveirae* and *B. lecheguana*.

Anatomy of the abdomen cuticle of P. sylveirae and B. lecheguana

B. lecheguana showed higher cuticle thickness than *P. sylveirae* (Fig 1 A and B). The high toxicity of insecticides methomyl + novaluron, chlorantraniliprole + lambda-cyhalothrin and deltamethrin to *P. sylveirae* corresponded graphically to the smaller cuticle thickness of this species (Fig 1A).

Table 3. Wasp mortality (%) observed after maize leaf immersion in insecticide broth with the respective doses recommended (100%) for maize crop and subdose (50%), in the control of *Spodoptera frugiperda*.

Insecticides	Mortality (%) (Mean ± SE)[1]			
	Dose (%)			
	n	100	50	Means
Methomyl + novaluron	16	79.4 ± 4.9Aa	54.4 ± 7.4Bb	66.9 ± 5.4
Chlorantraniliprole + lambda-cyhalothrin	16	80.0 ± 5.7Aa	53.1 ± 7.8Bb	66.5 ± 5.8
Deltamethrin	16	73.8 ± 5.4Aa	46.9 ± 6.4Bb	60.3 ± 5.3
Novaluron	16	13.1 ± 2.3Ca	1.3 ± 0.8Cb	7.2 ± 1.9
Chlorantraniliprole	16	18.8 ± 5.2Ca	0.6 ± 0.6Cb	9.7 ± 3.4
Spinosad	16	27.5 ± 3.2Ba	1.9 ± 1.3Cb	14.7 ± 3.7
Chlorfenapyr	16	31.3 ± 5.0Ba	8.8 ± 3.6Cb	20.0 ± 4.1
Alpha-cypermethrin	16	79.4 ± 7.4Aa	73.1 ± 3.7Aa	76.2 ± 4.1
Indoxacarb	16	26.3 ± 7.0Ba	6.3 ± 3.7Cb	16.2 ± 4.6
Control	16	0.0 0 ± Da	0.0± 0 Ca	0.0 ± 0
Means		42.9 ± 9.7	24.6 ± 9.0	

[1] Means followed by upper case letter in the column (comparison between insecticides) and lowercase in the line (comparison of recommended dose and subdose for each insecticide), did not differ by the Skott-Knott skin test $p \leq 0.05$.

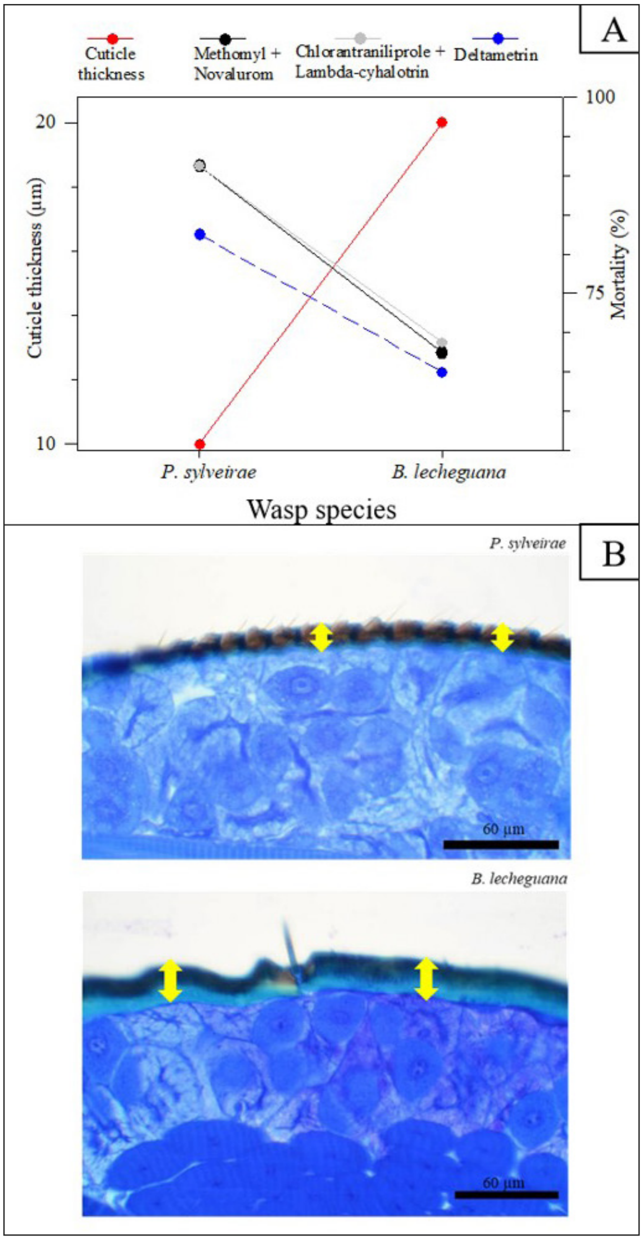

Fig 1. Corrected mortality (%) and cuticle thickness of the *Protonectarina sylveirae* and *Brachygastra lecheguana* wasps at the recommended dose (A) and histological cutting of the abdomen of *P. sylveirae* and *B. lecheguana*, emphasizing the cuticle (B). Yellow arrows in the histological cutting of the abdomen indicate the cuticle thickness of the species.

Discussion

Neurotoxic insecticides showed variable toxicity to *P. sylveirae* and *B. lecheguana* in dose (100%) and subdose (50%). The most toxic insecticides to wasps were alpha-cypermethrin, followed by methomyl + novaluron, chlorantraniliprole + lambda-cyhalothrin and deltamethrin. Deltamethrin was highly toxic in dose (100%) and subdose (50%) to *P. sylveirae* and *B. lecheguana* (100% mortality) in the physiological selectivity study by Galvan et al. (2002). Similarly, this insecticide was toxic to *P. sylveirae* in dose and subdose (Bacci et al., 2009) and highly toxic (84% mortality) to the *Polybia sericea* wasp (Olivier, 1791) (Hymenoptera: Vespidae) (Santos et al., 2003). Few studies have reported the physiological selectivity of methomyl + novaluron to predatory wasps. Liu et al. (2016) observed high toxicity of methomyl to *Telenomus remus* (Nixon, 1937) (Hymenoptera: Scelionidae), parasitoids of *S. frugiperda* eggs. In this study, the high toxicity caused by alpha-cypermethrin to two predatory wasp species continued with half the doses. Therefore, besides the high impact of this insecticide at application, this effect persists even after the decomposition of half of the active principles (Bacci et al., 2006).

The high mortality rate of *P. sylveirae* and *B. lecheguana* caused by alpha-cypermethrin, methomyl + novaluron, chlorantraniliprole + lambda-cyhalothrin and deltamethrin may be due to the penetration rate of the insecticide in the insect integument. This is a result of the relationship between the insecticide affinity with the thickness and chemical composition of the cuticle and the compound solubility (Yu, 2008). Thus, more lipophilic compounds are inversely proportional to solubility and tend to penetrate to a greater extent in the insect's body, given the similarity with the cuticle, which was the insecticide deltamethrin case (less than 0.002 ppm solubility in water) (Leite et al., 1998; Gusmão et al., 2000). However, low penetration rate of insecticides from the diamide group, oxadiazine, spinosyns and pyrazole analogue to wasp cuticle may be the explanation of the physiological selectivity (Salgado et al., 1998; Wing et al., 1998; Jeschke, 2016; Cotton Institute of Mato Grosso do Sul, 2016). The other hypothesis related to physicochemical properties of insecticides (Katagi, 2001). The main physicochemical properties are molecular weight and polarity. The lower the molecular weight and polarity the higher the insecticide penetration in the insect (Stock & Holloway, 1993; Leite et al., 1998; Pereira et al., 2014). This may explain the high mortality rate due to the molecular weight of alpha-cypermethrin (416.3 g mol^{-1}) and deltamethrin (505.21 g mol^{-1}). Spinosad (Spinosad A = 731.98 g mol^{-1}, Spinosad D = 746.0 g mol^{-1}) resulted in lower predatory wasp mortality. (Tomlin, 1995; Thompson et al., 1999; Pesticide Properties Database [PPDB], 2018).

The highest toxicity of the methomyl + novaluron and chlorantraniliprole + lambda-cyhalothrin mixtures occurred due to methomyl and lambda-cyhalothrin in the mixture. These had a synergistic effect. Chlorantraniliprole has higher larvicidal activity and novaluron is a growth regulator of young phases, having little effect on adults (Cordova et al., 2006; Xu et al., 2017). Lambda-cyhalothrin is a pyrethroid of insect contact and has a broad spectrum of action, being toxic to several lepidoptera and coleoptera insect groups and natural enemies (Ruberson & Tilman, 1999; Santos et al., 2007; Palmquist, 2012).

The anthranilic diamide (chlorantraniliprole) was poorly toxic to *B. lecheguana* and *P. sylveirae*, probably due to the greater affinity with the lepidoptera ryanodine receptors, which justifies the selectivity of this group to *B. lecheguana* and *P. sylveirae* adults (Jeschke, 2016; Araujo et al., 2017). In addition, low toxicity may also relate to the increased rate of metabolism of the compound by wasps compared to the pest or target changing of the insecticide against natural enemies (Yu, 1987). Fernandes et al. (2013) observed this response with *P. sylveire*, *B. lecheguana* and *Polybia* sp. The low toxicity of novaluron to the wasps may be because it acts during the young phase, preventing the cuticle formation in the larval stage (Desneux et al., 2007; Jeschke, 2016). This study targeted adult insects.

B. lecheguana and *P. sylveirae* wasps showed low mortality when submitted to the spinosad, chlorfenapyr and indoxacarb treatment. The mechanism that elucidates the physiological selectivity of these insecticides to *P. sylveirae* and *B. lecheguana* wasps are not well understood due to lack of biochemical and physiological studies. Araujo et al. (2017) found that indoxacarb and spinosad caused low mortality of *Solenopsis saevissima* (Smith, 1855) (Hymenoptera: Formicidae). Spinosad selectivity has been reported for most predators. Similarly, the probable physiological selectivity of indoxacarb may be related to the low bioactivation of esterases and/or transferases enzymes in detoxification, which has already been observed in some parasitoids, chrysopodes and coccinellidae (Willian et al., 2003; Zhao et al., 2003; Campos et al., 2011; Pereira et al., 2014).

Anatomy of the abdomen cuticle of P. sylveirae *and* B. lecheguana

B. lecheguana tolerance compared to *P. sylveirae* can be observed with the treatment methomyl + novaluron, chlorantraniliprole + lambda-cyhalothrin and deltamethrin. These insecticides were less toxic (49 – 54%) for *B. lecheguana* and more toxic (71 – 80%) for *P. sylveira*. Deltamethrin was highly toxic to *B. lecheguana* and *P. sylveirae* causing 100% mortality (Galvan et al., 2002). *B. lecheguana* tolerance to deltamethrin compared to *P. sylveirae* differs from that obtained by Galvan et al. (2002) and Crespo et al. (2002). Results show that the cuticle thickness of *B. lecheguana* is twice as thick as *P. sylveirae*. Methomyl + novaluron, chlorantraniliprole + lambda-cyhalothrin, and deltamethrin insecticides applied to *P. sylveirae* wasps showed higher mortality compared to *B. lecheguana*. The greater the thickness the greater the difficulty of penetration, mainly by the physical and chemical barrier that may have higher wax concentration, making it difficult to penetrate insecticides. Several studies have shown lower penetration of β-cypermethrin, permethrin, deltamethrin and lambda-cyhalothrin due to the cuticle thickness of *Bactrocera dorsalis* Hendel (Diptera: Tephritidae), *Anopheles funestus* (Giles, 1900) (Diptera: Culicide), *Helicoverpa armigera* (Hubner, 1827) (Lepidoptera: Noctuidae) *Cimex lectularius* (Linnaeus, 1758) (Hemiptera: Cimicidae) and *Spodoptera litura* (Fabricius, 1775) (Lepidoptera: Noctuidae) (Ahmad et al., 2006; Liu et al., 2009; Wood et al., 2010; Lin et al., 2012; Lilly et al., 2016).

Final remark

The present study provided important practical information to improve IPM systems using insecticides novaluron, chlorantraniliprole, espinosade, clorfernapir and indoxacarbe that presented physiological selectivity to *Protonectarina sylveirae* and *Brachygastra* lecheguana. However, the insecticide alpha-cypermethrin remained highly toxic even in the subdose (50%) and the insecticides methomyl + novaluron, chlorantraniliprole + lambda-cyhalothrin and deltamethrin in the dose (100%) were not selective to the wasps *P. sylveirae* and *B. lecheguana*. which demonstrates the need to develop effective products for pest and less toxic to the natural enemy. On the other hand, *B. lecheguana* wasp showed higher cuticle thickness and was more tolerant to insecticides methomyl + novaluron, chlorantraniliprole + lambda-cyhalothrin and deltamethrin compared to P. sylveirae.

Authors' contribution

Designed the experiments (FL FERNANDES), carried out the fieldwork (SMD JUNIOR and A PLATA-RUEDA), performed the laboratory work (EA SOUZA and IW DA SILVA), carried statistical analysis and wrote the manuscript (WS SOARES).

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