Ecotoxicology (2016) 25:940–949
DOI 10.1007/s10646-016-1651-9

Impact of insect growth regulators on the predator *Ceraeochrysa cincta* (Schneider) (Neuroptera: Chrysopidae)

Gabriel Rodrigo Rugno[1] · Odimar Zanuzo Zanardi[1] · Johanna Bajonero Cuervo[1] · Matheus Rovere de Morais[1] · Pedro Takao Yamamoto[1]

Accepted: 26 March 2016 / Published online: 30 April 2016

Abstract The generalist predator *Ceraeochrysa cincta* (Schneider) (Neuroptera: Chrysopidae) is an important biological control agent of several arthropod pests in different agroecosystems. This study assessed the lethal and sublethal effects of six insect growth regulators sprayed on first-instar larvae of *C. cincta*. Lufenuron and diflubenzuron were highly harmful to first-instar larvae of *C. cincta*, causing 100 % of mortality before they reached the second instar. Buprofezin caused ~25 % mortality of the larvae and considerably reduced the fecundity and longevity of the insects, but substantially increased the proportion of females in the surviving population of *C. cincta*. Methoxyfenozide and tebufenozide did not affect the duration and survival of the immature stages, but methoxyfenozide significantly reduced the fecundity and longevity of the insects. Pyriproxyfen reduced the survival of the larval stage by 19.5 %, but did not affect the development, survival and reproduction of the surviving individuals. Based on reduction coefficient, the insecticides diflubenzuron and lufenuron were considered harmful to *C. cincta*, whereas buprofezin and methoxyfenozide were slightly harmful and tebufenozide and pyriproxyfen were harmless. The estimation of life-table parameters indicated that buprofezin and methoxyfenozide significantly reduced the R_o, r and λ of *C. cincta*, whereas pyriproxyfen and tebufenozide caused no adverse effect on population parameters, indicating that these insecticides could be suitable for use in pest management programs towards the conservation and population increase of the predator in agroecosystems. However, more studies should be conducted to evaluate the compatibility of these insecticides with the predator *C. cincta* under semi-field and field conditions.

Keywords Lacewings · Insecticides · Lethal and sublethal effects · Life-table

Introduction

Worldwide, pesticides play an important role in regulating arthropodpest populations that affect agricultural production systems, protecting plants against direct and indirect damage caused by herbivores (Adhikari et al. 2004; Marimuthu et al. 2013; Rugno et al. 2015; Santos et al. 2015). However, although pesticides reduce populations and mitigate the impacts of arthropod pests, they also affect ecological processes, causing mortality of natural enemies, selection of resistant pest populations to the main active ingredients, resurgence of pests targeted for control, and outbreaks of secondary pests (Desneux et al. 2007; Cutler et al. 2009; Szczepaniec et al. 2011; Lu et al. 2012; Biondi et al. 2012a; Cordeiro et al. 2013; Guedes and Cutler 2014; Zhan et al. 2015), increasing production costs and reducing the technical efficacy and environmental sustainability of the system (Ribeiro et al. 2014). Given these problems and the growing consumer demand for healthier food produced in more sustainable environments, new chemical groups of insecticides with different mechanisms of action have appeared on the market and have been used in integrated pest management (IPM) programs as alternatives to neurotoxic insecticides, in order to reduce impacts on non-target organisms.

✉ Gabriel Rodrigo Rugno
gabrielrugno@gmail.com

[1] Department of Entomology and Acarology, "Luiz de Queiroz" College of Agriculture/University of São Paulo (ESALQ/USP), Av. Pádua Dias, 11 – Agronomia, Piracicaba, São Paulo CEP 13418-900, Brazil

Insect growth regulators have been widely used in the control of arthropod pests in many crops, due to their high efficacy, rapid degradation of residues in the environment, and low toxicity to higher animals (Dhadialla et al. 1998; Arthur et al. 2009; Tiwari et al. 2012). These products act by inhibiting chitin biosynthesis or as analogues of juvenile and ecdysteroid hormones, which are involved in ecdysis in insects (Meola and Mayer 1980; Arthur et al. 2009). Despite their high toxicity to arthropod pests, these insecticides have been considered compatible with biological-control agents present in agricultural ecosystems (Liu and Chen 2000). However, studies have shown that exposure to this class of insecticide may cause high mortality of different developmental stages of predators and parasitoids (Hattingh and Tate 1995; Magagula and Samways 2000; Yu et al. 2014), while reducing the development of the immature stage (Liu and Chen 2000), reproduction (Mendel et al. 1994) and longevity of insects (Liu and Stansly 2004), and reduce the biocontrol services provided by natural enemies (Biondi et al. 2015), which may compromise IPM programs that use natural biological control (Castro et al. 2012) as a strategy to reduce the infestation levels of arthropod pests and economic damage to crops.

Among the biological agents that act as natural controls of arthropod pests, lacewings (Neuroptera: Chrysopidae) are one of the most important, due to their high biotic potential, voracity and ecological plasticity (Tauber et al. 2000; Pappas et al. 2011; Khuhro et al. 2014). In Neotropical agroecosystems, the lacewing *Ceraeochrysa cincta* (Schneider) is one of the most important generalist predators found in several crops, including citrus, tree plantations and banana (López-Arroyo et al. 1999; Tauber et al. 2000). *C. cincta* is present in North, Central and South America (Ramírez-Delgado et al. 2007) and its larvae are associated with populations of aphids, lace bugs, scales, whiteflies, psyllids and mites that cause serious crop damage (Tauber et al. 2000). In laboratory conditions, Cardoso et al. (2007) reported that each larva of *C. cincta* consumes 6275 nymphs or 129 adults of *Leptopharsa heveae* Drake and Poor (Hemiptera: Tingidae); Lopez and Freitas (1996) observed that larvae were able to predate 139 aphids [*Rhodobium porosum* (Sanderson) (Hemiptera: Aphididae)] during their development in rose-production systems. In addition, *C. cincta* can be easily multiplied in the laboratory, which allows the establishment of mass-rearing facilities, and inundative releases in crop areas to reduce arthropod pest populations (Tauber and De León 2001), increasing the potential of this biological-control agent in IPM programs (López-Arroyo et al. 1999).

Despite the potential of *C. cincta* as a biological-control agent of arthropod pests, no studies have examined the impacts of insect growth regulators on this predator species. This study evaluated the effects of six insect growth regulators on the development and reproduction of *C. cincta*. Based on these effects, population parameters were estimated to determine the impacts on and the compatibility of these products with the predator. This information will be important for the development of management strategies aiming to conserve and/or increase population levels of *C. cincta*, to ensure the success of biological control in IPM programs.

Materials and methods

Insects

The population was established from *C. cincta* specimens collected on citrus plants managed without pesticide application in the preceding 6 months in Piracicaba, São Paulo, Brazil. The species was confirmed by Dr. Francisco Sosa, Universidad Centroccidental "Lisandro Alvarado", Barquisimetro, Venezuela. The specimens were transferred to rearing cages made of polyvinyl chloride (PVC), 10 cm in diameter × 20 cm high with one end placed on an acrylic dish (15 cm in diameter) containing a filter-paper disc in the base (15 cm in diameter); the other end was closed with a tulle screen (100 μm). The adults were fed with a diet based on brewer's yeast and honey (1:1, v:v) as proposed by Godoy et al. (2004). The food was made available to the insects by means of cotton discs placed on the cages. To obtain eggs, the cages were coated with white paper. The paper was replaced every 24 h and the eggs transferred to plastic pots of 1500 cm^3, with an opening ~7.5 cm in diameter (~41.2 cm^2) sealed with voile fabric. The larvae obtained were kept in the same plastic pots until the adults emerged. During this period, the larvae were fed ad libitum with eggs of *Ephestia kuehniella* (Zeller) (Lepidoptera: Pyralidae) sterilized under a germicidal lamp (UV) as described by Stein and Parra (1987). To perform the bioassays, fifth-generation larvae of *C. cincta* maintained under laboratory conditions were used. The rearing of *C. cincta* and the bioassays were performed in a climate-controlled room with temperature 25 ± 2 °C, relative humidity (RH) 70 ± 10 % and 14L:10D h photoperiod.

Insecticides

Six commercial insecticides were evaluated on *C. cincta*, representing the main active ingredients belonging to the insect growth regulators group recommended by the Ministry of Agriculture, Livestock and Supply [MAPA (Agrofit 2015)] for control of the mite *Phyllocoptruta oleivora* (Ashmead) (Prostigmata: Eriophyidae), scales [*Praelongorthezia praelonga* (Douglas) (Hemiptera: Diaspididae),

Pulvinaria flavescens Brèthes (Hemiptera: Coccidae), *Selenaspidus articulatus* (Morgan) (Hemiptera: Diaspididae), *Parlatoria cinerea* Doane and Hadden (Hemiptera: Diaspididae)], citrus leafminer [*Phyllocnistis citrella* Stainton (Lepidoptera: Gracillariidae)], Asian citrus psyllid [*Diaphorina citri* Kuwayama (Hemiptera: Liviidae)], and *Ecdytolopha aurantianum* Lima (Lepidoptera: Tortricidae) in Brazilian citrus orchards. The insecticides and concentrations (g a.i. L^{-1}) evaluated were: diflubenzuron 0.12 (Micromite 24 SC, Chemtura Indústria Química do Brasil Ltda.), lufenuron 0.25 (Match 5 EC, Syngenta Crop Protection Ltda.), buprofezin 0.50 (Applaud 25 SP, Arysta Lifescience of Brazil Chemical Industry and Agriculture), methoxyfenozide 0.75 (Intrepid 24 SC, Dow Agroscience Industrial Ltda.), tebufenozide 0.48 (Mimic 24 SC, Dow Agroscience) and pyriproxyfen 0.20 (Tiger 10 EC, Syngenta Crop Protection Ltda.). All four companies are located in São Paulo, SP, Brazil.

Bioassay

To assess the lethal and sublethal effects of these insecticides, 40 first-instar larvae (≤24 h old) were used for each treatment. For this purpose, first-instar larvae were anesthetized by 10 s and sprayed with 2 mL of solution in a Potter tower (Burkard Scientific Co., Uxbridge, UK), adjusted to a pressure of 68.6 kPa, resulting in a deposit of 1.8 ± 0.1 mg cm^{-2} of fresh residues, which is consistent with the criteria established by the Pesticides and Beneficial Organisms working group of the International Organization for Biological Control of Noxious Animals and Plants/West Palaearctic Regional Section (IOBC/WPRS) for pesticide toxicity studies on natural enemies (Hassan et al. 1994). Deionized water was used as a control treatment. Immediately after the treatment were applied, the larvae were placed in individual flat-bottom glass tubes (8.5×2.5 cm^2 in diameter), which were sealed with PVC film and kept in a climate-controlled room. During the bioassay evaluation period, the larvae were fed ad libitum with sterilized *E. kuehniella* eggs (Stein and Parra 1987). For each treatment, 40 repetitions were used. The bioassay was repeated thrice over time using a fully randomized design.

Mortality and duration of the larval stage were assessed daily until the pupae were obtained. The pupae were kept in the same tubes used for larval development until the adults emerged. The viability of the pupal stage was determined based on the number of emerged adults. Adults were initially separated by sex, and then couples were formed and transferred to PVC cages (15 cm in diameter × 10 cm high) as described in "Insects" section, to evaluate the pre-oviposition and oviposition periods, fecundity and fertility of females, percentage of deformed eggs (number of eggs dehydrated and absence of pedicel in relation to control treatment) and longevity of females and males. During this period, the adults were fed with a mixture of brewer's yeast and honey (1:1, v:v) available in cotton discs on the cages. Treatments that provided fewer than seven couples were not used in further analyses due to the small number of surviving insects (repetitions). The evaluations were performed every 24 h until all adults died. Female fertility was calculated based on the number of larvae hatched from 100 eggs, due to the smaller number of eggs laid in first oviposition ($n \leq 4$), it was standardized the collection from the second oviposition of each female. For this, eggs of each female were removed from the cages and placed in individual compartments of Elisa plates (EasyPath Ltda., São Paulo, SP, Brazil) as described by Godoy et al. (2004). The plates were sealed with transparent PVC film and kept in a climate-controlled room. The number of hatched larvae in each treatment was evaluated 12 d after the transfer to the plates.

Data analysis

Effect of insecticides on the development and reproduction of C. cincta

Generalized linear models (Nelder and Wedderburn 1972) with quasi-binomial and quasi-Poisson distributions were used to analyze mortality/survival proportion data (larvae and pupae) and counts (number of eggs and duration of larval and pupal stages), respectively. The quality adjustment was determined through a half-normal graph with a simulation envelope (Hinde and Demétrio 1998). In cases of significant differences between treatments, multiple comparisons with the Tukey test ($p < 0.05$) for balanced data and Tukey–Kramer test ($p < 0.05$) for unbalanced data were made through the "*glht*" and "*multcomp*" and "*DTK*" packages, respectively, with adjusted p values. All analyses were performed using the statistical software "*R*", version 3.1.3 (R Development Core Team 2015).

Toxicity class

Based on the lethal (mortality of larvae and pupae) and sublethal effects (fecundity and fertility), the reduction coefficient (E_x) was calculated for each treatment using the formula $E_x = 100 - (100 - M_c) \times E_r$ proposed by Biondi et al. (2012b), where: M_c = corrected mortality calculated with the formula of Abbott (1925), and E_r = effect on reproduction, calculated as: $E_r = R_1 \times R_2$ where: R_1 = ratio of the number of eggs laid by females from first-instar larvae treated with insecticides and control, and R_2 = ratio of the number of hatched larvae for females from first-instar larvae treated with insecticides and control. Based on

reduction coefficient, the insecticides were classified according to the toxicity scale proposed by IOBC/WPRS, which include four categories: I, harmless ($E_x < 30$ %); II, slightly harmful (30 % $\leq E_x \leq$ 79 %); III, moderately harmful (80 % $\leq E_x \leq$ 99 %) and IV, harmful ($E_x > 99$ %) as described by Biondi et al. (2012b).

Estimation of the demographic growth parameters

Based on the data for duration and survival of the immature stages, pre-oviposition period, fecundity and fertility of females, and longevity of females and males of *C. cincta*, life-table parameters were estimated for each treatment. Life tables were constructed based on data for all individuals tested (including females, males and individuals that died during the immature stage development, as proposed by Chi (1988). The original data for all individuals were analyzed according to the theoretical model proposed by Chi and Liu (1985), using the TWOSEXMSChart program (Chi 2014). For each treatment were estimated:The net reproductive rate (R_o):

$$R_o = \sum_{x=0}^{\infty} l_x m_x$$

The intrinsic rate of increase (r):

$$\sum_{x=0}^{\infty} e^{-r(x+1)} l_x m_x = 1$$

The mean generation time (T):

$$T = \ln R_o / r$$

and the finite rate of increase (λ):

$$\lambda = e^r$$

The intrinsic growth rate was estimated by the Euler–Lotka formula (Goodman 1982). The means and standard errors of each parameter were estimated by the bootstrap method, following the procedure of Huang and Chi (2012). During the bootstrap procedure, the data for each population parameter were resampled 40,000 times. The means of each treatment were compared by paired bootstrap test ($p < 0.05$) (Efron and Tibshirani 1993).

Results

The spraying of insect growth-regulator insecticides on first-instar larvae of *C. cincta* showed that lufenuron and diflubenzuron were highly harmful to the predator, causing 100 % mortality of larvae before they reached the second instar, differing significantly from the other treatments (Table 1). Buprofezin and pyriproxyfen reduced *C. cincta* larval survival to 65.2 and 70.5 %, respectively, whereas methoxyfenozide and tebufenozide did not significantly affect the survival of larvae, which was similar to the control (Table 1).

The duration of the larval stage and the duration and survival of the pupal stage were not affected by pyriproxyfen, buprofezin, methoxyfenozide and tebufenozide (Table 1). The pre-oviposition period of females was not affected by any of the insecticides (Table 2). However, the number of eggs laid by females (fecundity) was significantly lower in females from first-instar larvae treated with buprofezin and methoxyfenozide, compared to the other treatments (Table 2). No significant effect was observed on the oviposition period and fertility of females from first-instar larvae treated with insect growth-regulator insecticides (Table 2). The higher percentage of deformed eggs (dehydrated and absence of pedicel) was observed in females from first-instar larvae treated with tebufenozide and pyriproxyfen compared to females from first-instar larvae treated with buprofezin, methoxyfenozide and the control treatment (Table 2). The longevity of females and males was reduced more in the treatments with buprofezin and methoxyfenozide than in the other treatments (Table 2).

Based on mortality of larvae and pupae and sublethal effects (fecundity and fertility) were used to estimate the reduction coefficient for each insecticide. Our results showed that diflubenzuron and lufenuron were harmful ($E_x > 99$ %, class IV) to *C. cincta*, whereas buprofezin and methoxyfenozide were slightly harmful (30 $\leq E_x \leq$ 79 %, class II) and pyriproxyfen and tebufenozide were harmless ($E_x < 30$ %, class I) (Table 3).

The life-table parameters were estimated based on the data for duration and survival of the immature stages, pre-oviposition and oviposition periods, fecundity, fertility, and longevity of males and females obtained in the different treatments (except for diflubenzuron and lufenuron, which caused 100 % larval mortality). Methoxyfenozide and buprofezin considerably reduced the net reproductive rate (R_o), intrinsic rate of increase (r) and finite rate of increase (λ) of *C. cincta* (Table 4). On the other hand, pyriproxyfen and tebufenozide did not affect the R_o, r, and λ and were similar to the control (Table 4). Spraying of methoxyfenozide, buprofezin, pyriproxyfen, and tebufenozide on first-instar larvae of *C. cincta* did not significantly alter the mean generation time (T) (Table 4).

Discussion

The lethal and sublethal effects of six insect growth-regulator insecticides on first-instar larvae of *C. cincta* were evaluated. Our results showed that the toxicity levels of the

Table 1 Duration and survival (mean ± SE) of larvae and pupae of *Ceraeochrysa cincta* when first-instar larvae were treated topically with insect growth-regulator insecticides

Treatment	Larval stage		Pupal stage	
	Duration[a] (d)	Survival[b] (%)	Duration[a] (d)	Survival[b] (%)
Control (deionized water)	11.2 ± 0.31 a	90.0 ± 2.36 a	14.7 ± 0.75 a	92.2 ± 4.19 a
Buprofezin (0.50 g L^{-1})	10.9 ± 0.65 a	65.2 ± 4.90 b	15.0 ± 0.62 a	100.0 ± 0.00 a
Diflubenzuron (0.12 g L^{-1})	–	0.0 ± 0.00 c	–	–
Lufenuron (0.25 g L^{-1})	–	0.0 ± 0.00 c	–	–
Methoxyfenozide (0.75 g L^{-1})	11.5 ± 0.15 a	80.2 ± 3.54 ab	13.8 ± 0.24 a	94.1 ± 2.96 a
Pyriproxyfen (0.20 g L^{-1})	11.6 ± 0.11 a	70.5 ± 3.24 b	14.9 ± 0.66 a	100.0 ± 0.00 a
Tebufenozide (0.48 g L^{-1})	12.1 ± 0.05 a	87.5 ± 7.91 ab	13.5 ± 0.12 a	92.2 ± 4.20 a
	$F = 0.376$	$F = 3.007$	$F = 0.712$	$F = 2.268$
	d.f. = 4, 149	*d.f.* = 6, 199	*d.f.* = 4, 144	*d.f.* = 4, 151
	$p = 0.825$	$p = 0.019$	$p = 0.584$	$p = 0.064$

[a] Means followed by the same letter in a column do not differ significantly (GLM with quasi-Poisson distribution, followed by post hoc Tukey test; $p < 0.05$)

[b] Means followed by the same letter in a column do not differ significantly (GLM with quasi-binomial distribution, followed by post hoc Tukey test; $p < 0.05$)

Table 2 Sublethal effects of pesticides on biological parameters (mean ± SE) of the adult stage of *Ceraeochrysa cincta* when first-instar larvae were treated topically with insect growth-regulator insecticides

Treatment	Pre-oviposition period[a] (d)	Oviposition period[a] (d)	Fecundity[a] (mean number of eggs female^{-1})	Fertility[b] (number of hatched larvae) (%)	Deformed eggs[a] (dehydrated and absence of pedicel) (%)	Longevity[a] (d)	
						Female	Male
Control (deionized water)	14.8 ± 0.72 a	45.0 ± 0.63 a	228.2 ± 28.52 a	90.6 ± 2.43 a	0.1 ± 0.02 d	58.4 ± 3.52 a	49.1 ± 2.47 a
Buprofezin (0.50 g L^{-1})	13.2 ± 1.74 a	43.6 ± 1.68 a	101.6 ± 19.59 b	85.4 ± 2.36 a	3.5 ± 0.21 b	35.5 ± 3.06 b	35.2 ± 4.52 b
Methoxyfenozide (0.75 g L^{-1})	13.7 ± 1.55 a	44.5 ± 1.29 a	106.8 ± 21.35 b	86.5 ± 3.10 a	1.3 ± 0.09 c	38.5 ± 5.23 b	33.6 ± 1.79 b
Pyriproxyfen (0.20 g L^{-1})	16.3 ± 1.89 a	47.1 ± 1.65 a	187.4 ± 27.92 a	89.2 ± 3.30 a	4.5 ± 0.12 a	52.6 ± 2.86 a	45.7 ± 2.74 a
Tebufenozide (0.48 g L^{-1})	18.8 ± 1.64 a	47.6 ± 1.65 a	203.4 ± 30.01 a	85.0 ± 1.73 a	4.4 ± 0.17 a	59.1 ± 2.20 a	53.6 ± 5.04 a
	$F = 1.972$	$F = 1.405$	$F = 3.305$	$F = 1.009$	$F = 3.449$	$F = 3.610$	$F = 3.002$
	d.f. = 4, 55	*d.f.* = 4, 55	*d.f.* = 4, 55	*d.f.* = 4, 15	*d.f.* = 4, 55	*d.f.* = 4, 55	*d.f.* = 4, 55
	$p = 0.112$	$p = 0.244$	$p = 0.041$	$p = 0.634$	$p = 0.041$	$p = 0.011$	$p = 0.034$

[a] Means followed by the same letter in a column do not differ significantly (GLM with quasi-Poisson distribution, followed by post hoc Tukey test; $p < 0.05$)

[b] Means followed by the same letter in a column do not differ significantly (GLM with quasi-binomial distribution, followed by post hoc Tukey test; $p < 0.05$)

insecticides were dependent on the chemical group used in the bioassays. The application of chitin-biosynthesis inhibitors type 0 (lufenuron and diflubenzuron) were highly harmful (class IV) to first-instar larvae of *C. cincta*, causing 100 % mortality before the second instar. These results are similar to those observed in first- and third-instar larvae of *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae) exposed to lufenuron (Hussain et al. 2012; Mohammadi et al. 2014) and diflubenzuron (Medina et al. 2003a). A high mortality rate was also reported by Zotti et al. (2012) in third-instar larvae of *Chrysoperla externa* (Hagen) (Neuroptera: Chrysopidae) treated topically with lufenuron. Bueno and Freitas (2004) demonstrated that the application of lufenuron on eggs of *C. externa* significantly reduced the larval survival rate at the time of ecdysis, whereas Medina et al. (2003a) found lower survival of

Table 3 Reduction coefficient of insect growth-regulator insecticides applied topically on first-instar larvae of *Ceraeochrysa cincta*

Treatment	Cumulative mortality of immature stage (%)	Effect on reproduction (E_r)		Reduction coefficient (E_x)[a]	Toxicity categories[b]
		Fecundity (mean number of eggs laid female^{-1}) (R_1)	Fertility (%) (percent of hatched larvae) (R_2)		
Control (deionized water)	17.0	228.2	90.6	–	–
Buprofezin (0.50 g L^{-1})	35.0	101.6	85.4	65.8	II
Diflubenzuron (0.12 g L^{-1})	100.0	–	–	100.0	IV
Lufenuron (0.25 g L^{-1})	100.0	–	–	100.0	IV
Methoxyfenozide (0.75 g L^{-1})	24.5	106.8	86.5	58.5	II
Pyriproxyfen (0.20 g L^{-1})	29.5	187.4	89.2	29.3	I
Tebufenozide (0.48 g L^{-1})	26.2	203.4	85.0	24.5	I

[a] Reduction coefficient of insecticides calculated by formula proposed by Biondi et al. (2012b)

[b] Toxicity categories proposed by the IOBC/WPRS for pesticide selectivity studies on natural enemies: I, harmless ($E_x < 30$ %); II, slightly harmful (30 % $\leq E_x \leq$ 79 %); III, moderately harmful (80 % $\leq E_x \leq$ 99 %) and IV, harmful ($E_x > 99$ %) as described by Biondi et al. (2012b)

Table 4 Estimates of life-table parameters of *Ceraeochrysa cincta* when first-instar larvae were treated topically with insect growth-regulator insecticides

Treatment	Population parameter (mean ± SE)[a]			
	Net reproduction rate (R_o) (female female^{-1})	Mean generation time (T) (d)	Intrinsic rate of increase (r) (female female^{-1} d^{-1})	Finite rate of increase (λ) (female female^{-1} d^{-1})
Control (deionized water)	80.03 ± 14.63 a	57.66 ± 1.49 ab	0.076 ± 0.006 a	1.08 ± 0.006 a
Buprofezin (0.50 g L^{-1})	27.91 ± 11.01 b	52.84 ± 2.60 b	0.063 ± 0.008 b	1.06 ± 0.009 b
Methoxyfenozide (0.75 g L^{-1})	31.97 ± 14.97 b	57.75 ± 3.01 ab	0.060 ± 0.009 b	1.06 ± 0.010 b
Pyriproxyfen (0.20 g L^{-1})	61.05 ± 12.88 ab	57.11 ± 2.13 ab	0.072 ± 0.008 ab	1.07 ± 0.008 ab
Tebufenozide (0.48 g L^{-1})	51.24 ± 11.43 ab	60.56 ± 1.58 a	0.065 ± 0.007 ab	1.07 ± 0.007 ab

[a] Means followed by the same letter on a line do not differ significantly by the bootstrap paired test ($p < 0.05$)

pupae when third-instar larvae were treated with this insecticide, demonstrating that lufenuron can also affect the survival of subsequent stages of those exposed to the insecticides. The high mortality of first-instar larvae treated with diflubenzuron and lufenuron observed in this study is attributed to inactivation of the enzyme chitin synthase, responsible for chitin biosynthesis in the new integument of insects during ecdysis (Desneux et al. 2007; Castro et al. 2012), and to the low rate of excretion of the products by insects (Medina et al. 2002).

Although not evaluated in this study (due to high mortality of first-instar larvae), previous studies have shown that diflubenzuron and lufenuron can also affect reproduction when applied to adult lacewings. Medina et al. (2002) demonstrated that topical application of diflubenzuron on *C. carnea* adults completely inhibited the larvae hatching, and Godoy et al. (2004) found that spraying of lufenuron on adults of *C. externa* considerably reduced the fecundity and fertility of females. According to the authors, these effects are associated with malformation of the

reproductive cells in females (oogenesis) and/or males (spermatogenesis) in insects exposed to these insecticides. Diflubenzuron can also reduce the deposition of yolk in oocytes and prevent the formation of layers of follicular epithelial and cytoplasmatic cells in females, and cause disruption of spermatocytes in males (Agüero et al. 2014). These results indicate that excessive use of diflubenzuron and lufenuron in agroecosystems can substantially reduce the population levels of predators and compromise the natural biological control exerted by lacewings, specifically *C. cincta*.

On the other hand, the spraying of chitin biosynthesis inhibitor type 1 (buprofezin, 0.50 g L^{-1}) on first-instar larvae of *C. cincta* caused low acute toxicity ($\sim$27 % mortality in relation to the control) for the immature stage of the predator. Similar acute toxicity was observed in larvae of *Chrysoperla rufilabris* (Burmeister) (Neuroptera: Chrysopidae) (Nasreen et al. 2005; Sabry and El-Sayed 2011) and *C. carnea* (Liu and Chen 2000) treated with different concentrations of buprofezin. However, James (2004) reported that buprofezin (0.58 g L^{-1}) caused high mortality of *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae) larvae and *Geocoris pallens* Stål and *Geocoris punctipes* (Say) (Hemiptera: Geocoridae) nymphs exposed to product residues. Likewise, Cabral et al. (2008) reported $\sim$67 % mortality of larvae *Coccinella undecimpunctata* L. (Coleoptera: Coccinellidae) exposed to buprofezin (0.125 g L^{-1}). These results indicate that lacewing larvae are more tolerant to buprofezin than are coccinellid and hemipteran predators. This concord with the findings of Grafton-Cardwell et al. (2005), who reported high activity of buprofezin for larvae of beetle and nymphs of hemipteran pests, and with Vivek et al. (2012), who documented a small effect of this insecticide on lacewing larvae.

Our results demonstrated that females from first-instar larvae treated with buprofezin produced fewer eggs compared to the control treatment. Moreover, buprofezin reduced the longevity of *C. cincta* and increased the proportion of deformed eggs. The lower number of eggs laid by the females may be associated with the shorter oviposition period (low longevity); inhibition of prostaglandin E_2 biosynthesis, one of the main components associated with oviposition (Moreno and Nakano 2002); and changes in oviposition behavior of the predator, as found in females of *Encarsia formosa* (Gahan) (Hymenoptera: Aphelinidae) (Gholamzadeh et al. 2012) and other natural enemies (Desneux et al. 2007). Likewise, the reduced longevity of *C. cincta* could be attributed to increase in 20-hydroxyecdysone hormone levels after apolysis (De Cock and Degheele 1993), causing a hormonal imbalance in adult insects, which affects survival (Moreno and Nakano 2002).

Our results also showed that the toxicity levels of buprofezin were lower than those observed for diflubenzuron and lufenuron. Although the additional action mechanisms of these insecticides are not completely known, the low penetration capacity of buprofezin in the integument and its excretion by insects may be some of the causes for the lower toxicity of buprofezin to *C. cincta* compared to diflubenzuron and lufenuron. Medina et al. (2003a) found that the diflubenzuron penetration rate was 10–20 % 1 h after application of the product on *C. carnea* larvae. Diflubenzuron is also eliminated (excreted) more slowly, which may increase its toxicity and action period. Although the lower impact on survival and reproduction of *C. cincta*, buprofezin considerably reduces the net reproductive rate (R_o), intrinsic rate of increase (r) and the finite rate of increase (λ) of the predator. Therefore, the use of this insecticide can compromise the biological control exerted by predator *C. cincta* in IPM programs.

The exposure of first-instar larvae to ecdysteroid receptor agonists indicated that methoxyfenozide and tebufenozide did not cause significant larval mortality of *C. cincta*. Similar results were obtained for larvae of *C. externa* (Ferreira et al. 2005; Rimoldi et al. 2008) and *C. carnea* (Ferreira et al. 2006) treated with these insecticides. Although considered harmless to the immature stage, methoxyfenozide reduced the R_o, r and λ of *C. cincta* and was considered slightly harmful in the IOBC/WPRS classification. The reduction of population parameters is directly related to the reduction of the oviposition rate of females and the longevity of the insects. The action of methoxyfenozide on ecdysteroid receptors disrupts the reproductive process (vitellogenesis, production of mature eggs and promoting the growth of spermatocytes), reducing the reproductive rate of insects (Desneux et al. 2007). These results indicate that the use of methoxyfenozide in production systems can reduce population growth and the effectiveness of the predator in controlling arthropod pests. It should be emphasized, however, that this study was conducted in the laboratory, where insects are subjected to maximum contact with the insecticide. Probably, under field conditions, the sublethal effects of methoxyfenozide will be lower than those observed here. This hypothesis is supported by the findings of Colomer et al. (2011), who reported no significant effect on population levels of *Orius laevigatus* Fieber (Hemiptera: Anthocoridae) and *Amblyseius swirskii* (Athias-Henriot) (Acari: Phytoseiidae) after application of methoxyfenozide. In the present study, tebufenozide did not alter the survival, reproduction and population parameters of *C. cincta* and was considered harmless ($E_x < 30$ %, class I) to the predator. Similarly, no adverse effects were observed on *C. carnea* (Medina et al. 2002, 2003a, b) and *Micromus tasmaniae* Walker (Neuroptera: Hemerobiidae) (Rumpf et al. 1998) treated with tebufenozide. The safety of tebufenozide is attributed to its low rate of absorption and penetration in the insect

integument, e.g., ~45 % 24 h after application of the product (Medina et al. 2003a). Moreover, tebufenozide can occupy the binding site of ecdysone, preventing any deleterious effects of the product on lacewings (Zotti et al. 2012). Our results indicated that tebufenozide can be used in IPM programs, because it did not affect the biological and population parameters of the predator *C. cincta*.

Similarly, the juvenile hormone analogue (pyriproxyfen) was considered harmless ($E_x < 30$ %, class I) to *C. cincta*, although it slightly reduced the larval survival rate and slightly increased the proportion of deformed eggs. Pyriproxyfen was also judged to be safe for *Ceraeochrysa cubana* (Hagen) (Neuroptera: Chrysopidae) (Godoy et al. 2010), *C. externa* (Godoy et al. 2010; Torres et al. 2013), and *C. carnea* (Medina et al. 2002, 2003a, b). The low toxicity of pyriproxyfen is attributed to its rapid excretion by neuropterans. Medina et al. (2003a) found that most of the insecticide was excreted 48 h after application. In addition to the relatively small lethal effect, pyriproxyfen did not affect the fecundity, fertility or longevity of *C. cincta*. Similarly, no significant effects on reproduction (fecundity and fertility) and on adult survival were observed for *C. cubana* (Godoy et al. 2004), *C. externa* (Medina et al. 2003b; Godoy et al. 2004; Torres et al. 2013) and *C. carnea* (Medina et al. 2003a, b) exposed to pyriproxyfen. In addition to lacewings, pyriproxyfen was also considered safe for fifth-instar nymphs of *O. laevigatus* treated with this insecticide.

On the other hand, pyriproxyfen increased the proportion of deformed eggs in the surviving population. The deposition of inviable eggs and absence of pedicels in these eggs may be associated with hormonal alteration (especially juvenile hormone) caused by this insecticide. During the development of the immature stage, the juvenile hormone is responsible for maintaining the juvenile features of the insects, whereas in adults this hormone acts in the synthesis of vitellogenin, which is secreted into the hemolymph and used in the formation of oocytes (Guo et al. 2014). Thus, the application of pyriproxyfen can cause a hormonal imbalance that affects vitellogenesis, causing abnormalities in the formation, development and viability of eggs (Agüero et al. 2014). Although significant, these effects did not cause any significant alteration in R_o, r and λ of *C. cincta*, demonstrating that pyriproxyfen is selective and can be used in combination with the predator for population management of arthropod pests.

Although the insect growth-regulator insecticides are considered harmless to many species of beneficial arthropods, our results showed that the use of diflubenzuron, lufenuron, buprofezin and methoxyfenozide for the control of insect pests may adversely affect population levels of *C. cincta* and compromise the predator's performance as a biological control agent. However, more studies on the selectivity to *C. cincta* with the tested compound should be conducted using different development stages of the predator as well as other methods of exposure this insecticides. In addition, semi-field and field studies may also contribute to understand the impacts of these compounds on population levels of the predator. On the other hand, pyriproxyfen and tebufenozide did not affected the population parameters of *C. cincta*, suggesting that these insecticides would be highly suitable for use in pest management programs towards the conservation and population increase of the predator. The present study provides useful information for integrated pest-management programs that aim to combine chemical and biological control for suppression of arthropod pest populations.

Acknowledgments The authors thank Dr. Francisco Sosa of the Universidad Centroccidental "Lisandro Alvarado" (Barquisimetro, Venezuela) for his help in the identification of the species (*Ceraeochrysa cincta*), the Brazilian Federal Agency for the Support and Evaluation of Graduate Education (CAPES) and the National Council for Scientific and Technological Development (CNPq—grant number 140651/2013-6) for financial support and award of scholarships. The authors also thank Janet W. Reid for revising the English text.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

Abbott WS (1925) A method of computing the effectiveness of an insecticide. J Econ Entomol 18:265–267

Adhikari S, Sarkar B, Chatterjee A, Mahapatra CT, Ayyappan S (2004) Effects of cypermethrin and carbofuran on certain hematological parameters and prediction of their recovery in a freshwater teleost, *Labeo rohita* (Hamilton). Ecotoxicol Environ Saf 58:220–226

Agrofit (2015) Sistema de Agrotóxicos Fitossanitários—Ministério da Agricultura, Pecuária e Abastecimento, Brasil. http://extranet.agricultura.gov.br/agrofit_cons/principal_agrofit_cons. Accessed 9 Jan 2015

Agüero MAF, Neves PMOJ, Cremonez PSG (2014) Efeito do piriproxifem e diflubenzurom na reprodução de *Nezara viridula* (L.) (Hemiptera: Pentatomidae). Inv Agr 16:99–106

Arthur FH, Liu S, Zhao B, Phillips TW (2009) Residual efficacy of pyriproxyfen and hydroprene applied to wood, metal and concrete for control of stored-product insects. Pest Manag Sci 65:791–797

Biondi A, Desneux N, Siscaro G, Zappalà L (2012a) Using organic-certified rather than synthetic pesticides may not be safer for biological control agents: selectivity and side effects of 14 pesticides on the predator *Orius laevigatus*. Chemosphere 87:803–812

Biondi A, Mommaerts V, Smagghe G, Vinuela E, Zappalà L, Desneux N (2012b) The non-target impact of spinosyns on beneficial arthropods. Pest Manag Sci 68:1523–1536

Biondi A, Campolo O, Desneux N, Siscaro G, Palmeri V, Zappalà L (2015) Life stage-dependent susceptibility of *Aphytis melinus* DeBach (Hymenoptera: Aphelinidae) to two pesticides commonly used in citrus orchards. Chemosphere 128:142–147

Bueno AF, Freitas S (2004) Effect of the insecticides abamectin and lufenuron on eggs and larvae of *Chrysoperla externa* under laboratory conditions. Biocontrol 49:277–283

Cabral S, Garcia P, Soares AO (2008) Effects of pirimicarb, buprofezin and pymetrozine on survival, development and reproduction of *Coccinella undecimpunctata* (Coleoptera: Coccinellidae). Biocontrol Sci Technol 18:307–318

Cardoso ER, Freitas S, Nunes HT, Pessoa LGA (2007) Seletividade de *Lecanicillium lecanii* e *Metarhizium anisopliae* para larvas de primeiro de primeiro ínstar de *Ceraeochrysa cincta* (Neuroptera: Chrysopidae) em laboratório. Acta Sci Agron 29:563–568

Castro AA, Lacerda MC, Zanuncio TV, Ramalho FS, Polanczyk RA, Serrão JE, Zanuncio JC (2012) Effect of the insect growth regulator diflubenzuron on the predator *Podisus nigrispinus* (Heteroptera: Pentatomidae). Ecotoxicology 21:96–103

Chi H (1988) Life-table analysis incorporating both sexes and variable development rates among individuals. Environ Entomol 17:26–34

Chi H (2014) TWOSEX-MSChart: a computer program for the age-stage, two-sex life table analysis. http://www.140.120.197.173/Ecology/. Accessed 15 Nov 2014

Chi H, Liu H (1985) Two new methods for the study of insect population ecology. Bull Inst Zool Acad Sin 24:225–240

Colomer I, Aguado P, Medina P, Heredia RM, Fereres A, Belda JE, Viñuela E (2011) Field trial measuring the compatibility of methoxyfenozide and flonicamid with *Orius laevigatus* Fieber (Hemiptera: Anthocoridae) and *Amblyseius swirskii* (Athias-Henriot) (Acari: Phytoseiidae) in a commercial pepper greenhouse. Pest Manag Sci 67:1237–1244

Cordeiro EMG, Moura ILT, Fadini MAM, Guedes RNC (2013) Beyond selectivity: are behavioral avoidance and hormesis likely causes of pyrethroid-induced outbreaks of the southern red mite *Oligonychus ilicis*? Chemosphere 93:1111–1116

Cutler GC, Ramanaidu K, Astatkie T, Isman MB (2009) Green peach aphid, *Myzus persicae* (Hemiptera: Aphididae), reproduction during exposure to sublethal concentrations of imidacloprid and azadirachtin. Pest Manag Sci 65:205–209

De Cock A, Degheele D (1993) Cytochemical demonstration of chitin incorporation in the cuticle of *Trialeurodes vaporariorum* (Westwood) (Homoptera: Aleyrodidae) after buprofezin treatment. Int J Insect Morphol Embryol 22:119–125

Desneux N, Decourtye A, Delpuech JM (2007) The sublethal effects of pesticides on beneficial arthropods. Annu Rev Entomol 52:81–106

Dhadialla TS, Carlson GR, Le DP (1998) New insecticides with ecdysteroidal and juvenile hormone activity. Annu Rev Entomol 43:545–569

Efron B, Tibshirani RJA (1993) An introduction to the bootstrap. Springer, London

Ferreira AJ, Carvalho GA, Botton M, Mendonça LA, Corrêa ARB (2005) Seletividade de inseticidas usados na cultura da macieira a ovos de *Chrysoperla externa* (Hagen, 1861) (Neuroptera: Chrysopidae). Cienc Rural 35:756–762

Ferreira AJ, Carvalho GA, BottonM Lasmar O (2006) Seletividade de inseticidas usados na cultura da macieira a duas populações de *Chrysoperla externa* (Hagen, 1861) (Neuroptera: Chrysopidae). Cienc Rural 36:378–384

Gholamzadeh M, Ghadamyari M, Salehi L, Hoseininaveh V (2012) Effects of amitraz, buprofezin and propargite on some fitness parameters of the parasitoid *Encarsia formosa* (Hym.: Aphelinidae), using life table and IOBC methods. J Entomol Soc Iran 31:1–14

Godoy MS, Carvalho GA, Moraes JC, Cosme LV, Goussain MM, Carvalho CF, Morais AA (2004) Seletividade de seis inseticidas utilizados em citros a pupas e adultos de *Chrysoperla externa* (Hagen) (Neuroptera: Chrysopidae). Neotrop Entomol 33:359–364

Godoy MS, Carvalho GA, Carvalho BF, Lasmar O (2010) Seletividade fisiológica de inseticidas em duas espécies de crisopídeos. Pesq Agropec Bras 45:1253–1258

Goodman D (1982) Optimal life histories, optimal notation, and the value of reproductive value. Am Nat 119:803–823

Grafton-Cardwell EE, Godfrey LD, Chaney WE, Bentley WJ (2005) Various novel insecticides are less toxic to humans, more specific to key pests. Calif Agric 59:29–34

Guedes RNC, Cutler GC (2014) Insecticide-induced hormesis and arthropod pest management. Pest Manag Sci 70:690–697

Guo W, Wu Z, Song J, Jiang F, Wang Z, Deng S, Walker VK, Zhou S (2014) Juvenile hormone-receptor complex acts on *Mcm4* and *Mcm7* to promote polyploidy and vitellogenesis in the migratory locust. PLoS Genet 10(10):e1004702

Hassan SA, Bigler F, Bogenschütz H, Boller E, Brun J, Calis JNM, Coremans-Pelseneer J, Duso C, Grove A, Heimbach U, Helyer N, Hokkanen H, Lewis GB, Mansour F, Moreth L, Polgar L, Samsøe-Petersen L, Sauphanor B, Stäubli A, Sterk G, Vainio A, Van De Veire M, Viggiani G, Vogt H (1994) Results of the sixth joint pesticide testing programme of the IOBC/WPRS-working group pesticides and beneficial organisms. Entomophaga 39:107–119

Hattingh V, Tate B (1995) Effects of field-weathered residues of insect growth regulators on some Coccinellidae (Coleoptera) of economic importance as biological controls. Bull Entomol Res 85:489–493

Hinde J, Demétrio CGB (1998) Overdispersion: models and estimation. Comput Stat Data Anal 27:151–170

Huang YB, Chi H (2012) Age-stage, two-sex life tables of *Bactrocera cucurbitae* (Coquillett) (Diptera: Tephritidae) with a discussion on the problem of applying female age-specific life tables to insect populations. Insect Sci 19:263–273

Hussain D, Ali A, Tariq R, Mushtaq-Ul-Hassan M, Saleem M (2012) Comparative toxicity of some new chemistry insecticides on *Chrysoperla carnea* (Stephens) under laboratory conditions. J Agric Res 50:509–515

James DG (2004) Effect of buprofezin on survival of immature stages of *Harmonia axyridis*, *Stethorus punctum picipes* (Coleoptera: Coccinellidae), *Orius tristicolor* (Hemiptera: Anthocoridae), and *Geocoris* spp. (Hemiptera: Geocoridae). J Econ Entomol 97:900–904

Khuhro NH, Biondi A, Desneux N, Zhang L, Zhang Y, Chen HY (2014) Trade-off between flight activity and life-history components in *Chrysoperla sinica*. Biocontrol 59:219–227

Liu TX, Chen TY (2000) Effects of a chitin inhibitor buprofezin on immature *Chrysoperla rufilabris* (Neuroptera: Chrysopidae). J Econ Entomol 93:234–239

Liu TX, Stansly PA (2004) Lethal and sublethal effects of two insect growth regulators on adult *Delphastus catalinae* (Coleoptera: Coccinellidae), a predator of whiteflies (Homoptera: Aleyrodidae). Biol Control 30:298–305

Lopez CC, Freitas S (1996) Pulgões associados a roseiras no município de Jaboticabal. Rev Agric 71:104–105

López-Arroyo JI, Tauber CA, Tauber MJ (1999) Comparative life histories of the predators *Ceraeochrysa cincta, C. cubana,* and *C. smithi* (Neuroptera: Chrysopidae). Ann Entomol Soc Am 92:208–217

Lu Y, Wu K, Jiang Y, Guo Y, Desneux N (2012) Widespread adoption of Bt cotton and insecticide decrease promotes biocontrol services. Nature 487:362–367

Magagula CN, Samways MJ (2000) Effects of insect growth regulators on *Chilocorus nigritus* (Fabricius) (Coleoptera: Coccinellidae), a non-target natural enemy of citrus red scale, *Aonidiella aurantii* (Maskell) (Homoptera: Diaspididae), in southern Africa: evidence from laboratory and field trials. Afr Entomol 8:47–56

Marimuthu K, Muthu N, Xavier R, Arockiaraj J, Rahman MA, Subramaniam S (2013) Toxicity of buprofezin on the survival of embryo and larvae of African catfish, *Clarias gariepinus* (Bloch). PLoS One 8(10):e75545

Medina P, Smagghe G, Budia F, Del Estal P, Tirry L, Viñuela E (2002) Significance of penetration, excretion, and transovarial uptake to toxicity of three insect growth regulators in predatory lacewing adults. Arch Insect Biochem Physiol 51:91–100

Medina P, Budia F, Del Estal P, Viñuela E (2003a) Effects of three modern insecticides, pyriproxyfen, spinosad and tebufenozide, on survival and reproduction of *Chrysoperla carnea* adults. Ann Appl Biol 142:55–61

Medina P, Smagghe G, Budia F, Tirry L, Viñuela E (2003b) Toxicity and absorption of azadirachtin, diflubenzuron, pyriproxyfen, and tebufenozide after topical application in predatory larvae of *Chrysoperla carnea* (Neuroptera: Chrysopidae). Environ Entomol 32:196–203

Mendel Z, Blumberg D, Ishaaya D (1994) Effects of some insect growth regulators on natural enemies of scale insects (Hom.: Coccoidea). Entomophaga 39:199–209

Meola SM, Mayer RT (1980) Inhibition of cellular proliferation of imaginal epidermal-cells by diflubenzuron in pupae of the stable fly. Science 207:985–987

Mohammadi M, Dastjerdi H, Golmohammadi GR, Hassanpour M (2014) Investigation on the effects of lufenuron and pyridalyl insecticides on the developmental stages of the green lacewing (*Chrysoperla carnea* Steph.) under laboratory conditions. Pestic Plant Prot Sci 1:30–40

Moreno PR, Nakano O (2002) Atividade de buprofezin sobre a cigarrinha verde do feijoeiro *Empoasca kraemeri* (Ross and Moore, 1957) (Hemiptera, Cicadellidae) em condições de laboratório. Sci Agric 59:475–481

Nasreen A, Ashfaq M, Mustafa G, Rasoolkhan R (2005) Mortality of *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae) after exposure to some insecticides; laboratory studies. J S Pac Stud 26:1–6

Nelder JA, Wedderburn RWM (1972) Generalized linear models. J Roy Stat Soc 135:370–384

Pappas ML, Broufas GD, Koveos DS (2011) Chrysopid predators and their role in biological control. J Entomol 8:301–326

R Development Core Team (2015) R: a language and environment for statistical computing. A foundation for statistical computing, Vienna

Ramírez-Delgado M, López-Arroyo I, González-Hernández A, Badii-Zebeh MH (2007) Rasgos biológicos y poblacionales del depredador *Cereaeochrysa* sp. nr. *cincta* (México) (Neuroptera: Chrysopidae). Acta Zool Mex 23:79–95

Ribeiro LP, Zanardi OZ, Vendramim JD, Yamamoto PT (2014) Comparative toxicity of an acetogenin-based extract and commercial pesticides against citrus red mite. Exp Appl Acarol 64:87–98

Rimoldi F, Schneider MI, Ronco AE (2008) Susceptibility of *Chrysoperla externa* eggs (Neuroptera: Chrysopidae) to conventional and biorational insecticides. Environ Entomol 37:1252–1257

Rugno GR, Zanardi OZ, Yamamoto PT (2015) Are the pupae and eggs of the lacewing Ceraeochrysa cubana (Neuroptera: Chrysopidae) tolerant to insecticides? J Econ Entomol 108:2630–2639

Rumpf S, Frampton C, Dietrich DR (1998) Effects of conventional insecticides and insect growth regulators on fecundity and other life-table parameters of *Micromus tasmaniae* (Neuroptera: Hemerobiidae). J Econ Entomol 91:34–40

Sabry KH, El-Sayed AA (2011) Biosafety of a biopesticide and some pesticides used on cotton crop against green lacewing, *Chrysoperla carnea* (Stehens) (Neuroptera: Chrysopidae). J Biopestic 4:214–218

Santos MS, Zanardi OZ, Pauli KS, Forim MR, Yamamoto PT, Vendramim JD (2015) Toxicity of an azadirachtin-based biopesticide on *Diaphorina citri* Kuwayama (Hemiptera: Liviidae) and its ectoparasitoid *Tamarixia radiata* (Waterston) (Hymenoptera: Eulophidae). Crop Prot 74:116–123

Stein CP, Parra JRP (1987) Uso da radiação ultra-violeta para inviabilizar ovos de *Anagasta kuehniella* (Zeller, 1879) visando estudos com *Trichogramma* spp. An Soc Entomol Bras 16:229–234

Szczepaniec A, Creary SF, Laskowski KL, Nyrop JP, Raupp MJ (2011) Neonicotinoid insecticide imidacloprid causes outbreaks of spider mites on elm trees in urban landscapes. PLoS One 6(5):e20018

Tauber CA, De León CAT (2001) Systematics of green lacewings (Neuroptera: Chrysopidae): larvae of *Ceraeochrysa* from Mexico. Ann Entomol Soc Am 94:197–209

Tauber CA, De León T, Penny ND, Tauber MJ (2000) The genus *Ceraeochrysa* (Neuroptera: Chrysopidae) of America north of Mexico: larvae, adults, and comparative biology. Ann Entomol Soc Am 93:1195–1221

Tiwari S, Clayson PJ, Kuhns EH, Stelinski LL (2012) Effects of buprofezin and diflubenzuron on various developmental stages of Asian citrus psyllid, *Diaphorina citri*. Pest Manag Sci 68:1405–1412

Torres AF, Carvalho GA, Santa-Cecília LVC, Moscardini VF (2013) Selectivity of seven insecticides against pupae and adults of *Chrysoperla externa* (Neuroptera: Chrysopidae). Rev Colomb Entomol 39:34–39

Vivek S, Bishwajeet P, Pirasanna PGG, Shankarganesh K (2012) Relative toxicity of insecticides on larval stages of green lacewing, *Chrysoperla* sp. (*Carnea*-group) (Chrysopidae: Neuroptera). Indian J Entomol 74:394–397

Yu C, Fu M, Lin R, Zhang Y, Yongquan L, Jiang H, Brock TCM (2014) Toxic effects of hexaflumuron on the development of *Coccinella septempunctata*. Environ Sci Pollut Res 21:1418–1424

Zhan Y, Fan S, Zhanga M, Zalom F (2015) Modelling the effect of pyrethroid use intensity on mite population density for walnuts. Pest Manag Sci 71:159–164

Zotti MJ, Grützmacher AD, Lopes IH, Smagghe G (2012) Comparative effects of insecticides with different mechanisms of action on *Chrysoperla externa* (Neuroptera: Chrysopidae): lethal, sublethal and dose-response effects. Insect Sci 20:1–9