JOURNAL OF ENTOMOLOGICAL SOCIETY OF IRAN
2021, 41 (2), 105–121
نامه انجمن حشره‌شناسی ایران ۱۲۱– ۱۰۵ ,(۲)۴۱ ,۱۴۰۰

JESI

DOI: 10.22117/JESI.2021.341497.1359

Research Article

Lethal and sublethal effects of three insecticides on green lacewing, *Chrysoperla carnea* (Neuroptera: Chrysopidae) under laboratory conditions

Gholamreza Golmohammadi[1,*], Hossein-Reza Rezaei Torshizi[2], Reza Vafaei- Shooshtari[2], Leila Faravardeh[1] & Zahra Rafei-Karehroudi[3]

1. Iranian Research Institute of Plant Protection, Agricultural Research, Education, and Extension Organization (AREEO), Tehran, Iran, 2. Department of Entomology, Islamic Azad University, Arak Branch, Iran & 3. Amirkabir Building, Islamic Azad University, Arak Branch, Iran.
* Corresponding Author: g.golmohammadi@areeo.ac.ir

Abstract

Chrysoperla carnea Stephens (Neuroptera: Chrysopidae) is an important beneficial predator in agriculture, which is easily reared in laboratory. It is widely used in augmentative biological control programs. Research on sublethal effects, aims to reveal the negative and non-lethal impacts of insecticides on pests and provide practical information for forming effective pest control strategies. The lethal and sublethal effects of tebufenozide, clothianidin, and flupyradifurone on the common green lacewing, *C. carnea* were investigated in laboratory conditions at 25 ± 2°C, 60 ± 5% RH and a photoperiod of 16:8 h. (L:D). The results indicated the oviposition period in insects treated with flupyradifurone (26.62 days) was significantly different from the oviposition period in insects treated with clothianidin (21.90 days) and tebufenozide (21.62 days). Total fecundity in flupyradifurone treatment was significantly higher than the total fecundity in other treatments. The life table experiment of current study showed the values of *r* in control and the populations treated with LC_{30} of clothianidin, tebufenozide and flupyradifurone were 0.15, 0.17, 0.14, 0.15 day^{-1}, respectively. The finite rate of increase (λ) was affected with different treatments; and the values varied from 1.19 to 1.16 day^{-1} for *C. carnea* adults treated with clothianidin and tebufenozide, respectively. The highest survival rate of *C. carnea* was observed in control (58 days). Based on the results, it seems flupyradifurone may have less harmful effects on total lifespan, fecundity rate and bio-characteristics of green lacewing population than clothianidin and tebufenozide.

Key words: *Chrysoperla carnea,* Sublethal effects, Life-table, insecticide

بررسی اثرات کشنده و غیرکشندهٔ سه حشره‌کش روی بالتوری سبز *Chrysoperla carnea* (Neuroptera: Chrysopidae) در شرایط آزمایشگاهی

غلامرضا گل‌محمدی[۱و*]، حسین رضا رضایی ترشیزی[۲]، رضا وفائی شوشتری[۲]، لیلا فراورده[۱] و زهرا رفیعی کرهرودی[۳]

۱- موسسه تحقیقات گیاه‌پزشکی کشور، سازمان تحقیقات، آموزش و ترویج کشاورزی تهران، ایران، ۲- گروه حشره‌شناسی کشاورزی، دانشگاه آزاد اسلامی واحد علوم وتحقیقات اراک، ایران و۳- دانشکده امیرکبیر، دانشگاه آزاد اسلامی واحد علوم وتحقیقات اراک، ایران.
*مسئول مکاتبات، پست الکترونیک: g.golmohammadi@areeo.ac.ir

چکیده

بالتوری سبز، *Chrysoperla carnea* Stephens از دشمنان طبیعی مفید در کشاورزی است که به راحتی در آزمایشگاه قابل پرورش می‌باشد. این گونه در برنامه‌های مهار زیستی به روش رهاسازی اشباعی به طور گسترده استفاده می‌شود. اطلاعات در خصوص اثرات غیرکشندگی، به مشخص شدن اثرات منفی و زیر کشندهٔ حشره‌کش‌ها روی آفات کمک خواهد نمود و اطلاعات کاربردی برای یافتن راه‌کارهای موثر در کنترل آفات را نشان خواهد داد. اثرات کشنده و غیرکشندهٔ حشره‌کش‌های تبوفنوزاید، کلوتیانیدین و فلوپیرادیفورون روی حشـــرات کامل بالتوری سبز *C. carnea* در شرایط آزمایشگاهی در دمای ۲ ± ۲۵ درجهٔ سلسیوس، رطوبت نسبی ۵ ± ۶۰٪ درصد و دوره نوری ۸:۱۶ ساعت (روشنایی: تاریکی) مورد بررسی قرار گرفت. نتایج نشان داد، دورهٔ تخم‌ریزی در تیمار فلوپیرادیفورون (۲۶/۶۲ روز در مقایسه با تیمارهای کلوتیانیدین (۲۱/۹۰

Received: 11 January 2020, *Accepted:* 6 April 2021
Subject Editor: Mir Jalil Hejazi

روز) و تبوفنوزاید (۲۱/٦۲ روز) تفاوت معنی‌داری دارند و میزان باروری کل نیز در تیمار فلوپیرادیفوران به طور معنی داری بیشتر از سایر تیمارها بود. نتایج آزمایش‌های مربوط به جدول زندگی نشان داد که مقدار پراسنجۀ *r* در شاهد و تیمارهای کلوتیانیدین، تبوفنوزاید و فلوپیرادیفوران به ترتیب ۰/۱۵، ۰/۱۷، ۰/۱٤ و ۰/۱۵ برروز بود. نرخ متناهی افزایش جمعیت (λ) در تیمارهای مختلف تحت تاثیر قرار گرفت، به طوری که از ۱/۱۹ تا ۱/۱٦ بر روز در افراد بالغ *C. carnea* به ترتیب برای تیمارهای کلوتیانیدین و تبوفنوزاید متغیر بود. همچنین بیشترین میزان زنده‌مانی *C. carnea* (۵۸ روز) در شاهد مشاهده شد. با توجه به نتایج به دست آمده در خصوص طول دوره زندگی، میزان باروری و پراسنجه‌های مهم زیستی بالتوری سبز، به نظر می‌رسد فلوپیرادیفوران نسبت به کلوتیانیدین و تبوفنوزاید، روی جمعیت *C. carnea* زیان کمتری داشته باشد.

واژه‌های کلیدی: *Chrysoperla carnea*، اثرات غیرکشندگی، جدول زندگی، حشره کش

دریافت: ۱۳۹۸/۱۰/۲۱، پذیرش: ۱٤۰۰/۰۱/۱۷.

Introduction

The green lacewing, *Chrysoperla carnea* Stephens (Neuroptera: Chrysopidae), is considered as an important and widely distributed natural predator of insect herbivores in many different crop and non-crop habitats (Geetha & Swamiappan, 1998; McEwen *et al*., 2007; Meissle *et al.*, 2012; Romeis *et al*., 2014). The lacewing is regarded as a main generalist biological control agent by high adaptability to various systems, which is used primarily through additive periodic releases of larvae for control of several species (Azema & Mirabzadae, 2004; Turquet *et al*., 2008). Application of chemical control is the primary and effective strategy for pest control in IPM (integrated pest management) programs due to its rapidity, cost-effectiveness and ease of use (Zhao, 2000). By definition, IPM is a pest management strategy that uses a combination of methods to manage pests without solely on chemical pesticides (Kovach *et al*., 1992). Natural enemies and pesticides in combination with each other can be effectively integrated with adequate knowledge of the pesticides to be used and their effects on populations of natural enemies (Bartlett, 1964; Newsom *et al.*, 1976; Jepson, 1989; Croft, 1990, Greathead, 1995; Biondi *et al.*, 2012; Roubus *et al*., 2014).

Various studies have focused on assessing toxicity of different pesticides on beneficial organisms (Nasreen *et al.*, 2005; Preetha *et al.*, 2009; Golmohammadi *et al.*, 2009, 2014; Hussain *et al.*, 2012; Garzón *et al.*, 2015). Biological control has been known as one of the most valuable pest control methods (Doue, 2009). Therefore, knowledge of the effects of pesticides which are compatible with biological control agents is necessary for successful implementation of integrated pest management (IPM) programs (Sa´enz-de-Cabezo´n *et al.*, 2006; Hamedi *et al.*, 2010). Studies that only evaluate the lethal effects may underestimate the negative effects of pesticides on natural enemies (Galvan *et al*., 2005).

One of the generally applied methods to evaluate the side effects of pesticides on natural enemies is to study their sublethal effects recommended by the International Organization of Biological Control (IOBC). This approach primarily screens the pesticides in the laboratory, semi-field and field tests (Dohmen, 1998; Hassan, 1998). The studies conducted on sublethal effects revealed that the negative and non-lethal impacts of insecticides on pests could provide practical information for forming effective pest control strategies (Wang *et al*., 2009). The life-table technique has been used as an appropriate method for assessing population dynamics in the studies related to several target and non-target insects (Biondi *et al*., 2013; Cira *et al*., 2017; Nawaz *et al*., 2017).

Life tables and demographic toxicology which evaluate the total effects of a toxicant in pest management, merge data on all life history parameters, including survival, stage differentiation, and reproduction (Stark *et al*., 2004; Huang *et al*., 2017). flupyradifurone, tebufenozide and clothianidin which were used in this research, affect the central nervous system, act as molting hormone and affect postsynaptic receptors, respectively (Matsumura, 2012). Previously, no study has addressed the sublethal effects of flupyradifurone, tebufenozide and clothianidin on *C. carnea*. Thus, the present study aimed to address the potential of sublethal concentrations of these insecticides on pre-imaginal developmental period, adult longevity, fecundity and demographic parameters of *C. carnea*, using the age-stage, two-sex life table to predict their potential in combination with one of the effective natural enemies.

Materials and Methods

Insect Rearing

The Mediterranean flour moth, *Ephestia kuehniella* Zell (Lepidoptera: Pyralidae) was collected from of the Iranian Research Institute of Plant protection (IRIPP). To rear *E. kuehniella*, plastic containers with a net cloth (70 cm in diameter × 25 cm high) were used. In each glass petri dish, a layer of mixture of wheat flour, wheat bran plus bakery yeast (2.5: 0.5: 40; kg: kg: g) was added, then 1g of *E. kuehniella* eggs was spread uniformly on it. After oviposition, the eggs were collected and refrigerated to feed the green lacewings. The initial population of green lacewing, *C. carnea* adults was obtained from of the Agriculture and Natural Resources Research Center of Khorasan Razavi Province. Adult insects were kept in plastic containers with 16 cm diameter and 24 cm height, covered with a piece of cloth screen and fed on artificial diet consisted of 4 g brewer’s yeast, 7 g honey and 5 ml water. The larvae of green lacewing, fed on eggs of *E. kuehniella.* The adults of green lacewing were fed with artificial diet which consisted of yeast, honey and distilled water (4:7:5 g/g/ml. After formation of pupae of *C. carnea*, they were collected and transferred to another container. Rearing containers was maintained in growth chamber with the temperature and humidity of 25±2℃, 60±5 % RH, and a photoperiod of 16: 8 (L: D) h.

Insecticides

In order to conduct the experiments, flupyradifurone (Sivanto® 48 SC), tebufenozide (Mimic® 20 SC), and clothianidin (20 WG) were applied in these experiments (Table 1).

Concentration-Response Bioassays

After the initial experiments, the range of concentrations resulting in 10-90% mortality were 30- 1800 mg ai/l for tebufenozide, 20 – 50 mg ai/l for flupyradifurone and 10- 80 mg ai/l for clothianidin. Distilled water was used in controls. Abbott's formula was used to estimate the corrected mortality (Abbott, 1925). After preparing of insecticide solutions, 2 ml from each concentration was sprayed at a pressure of 0.5 bar using Potter tower (68.1 $\mu l/cm^2$) into Petri-dishes (10 cm diameter). The Petri dishes were let to dry for 30 minutes. Then 10 *C. carnea* (24-h old-male and female) adults (fed on *E. kuehniella* eggs and artificial diet consisted of yeast, honey and distilled water (4:7:5 g/g/ml was transferred into each Petri-dish. Mortality was assessed 48 h, after treatment.

Effect of sublethal concentrations on biological parameters of *C. carnea*

In order to evaluate the sublethal effects of flupyradifurone, tebufenozide and clothianidin, a fertility life table was constructed using an insect cohort with 100 pairs of same-aged adult green lacewings (male and female), and the fate of the cohort was pursued until the last female died. Adults from the initial cohort were treated with LC_{30} of each insecticide (table 1). Forty eight hours after treatment, the surviving adults were transferred to plastic Petri dishes 60 mm in diameter, and kept in pairs of male and female. The eggs were collected and counted daily. After oviposition of adults, the petri-dishes were replaced daily, and this trend was continued until the death of last individual. Fecundity of females was recorded daily; also population parameters were calculated for both male and females until the death of the last sample. All experiments were conducted at controlled conditions of 25±2℃, 60±5 % RH and a photoperiod of 16: 8 (L: D) hours. In this study there were five replicates for each treatment.

Statistical Analysis

In order to estimate the LC values and sublethal concentrations, SPSS ver 19.0 was used. The population growth parameters (net reproductive rate [R_0], intrinsic rate of natural increase [r], finite rate of increase [λ], and mean generation time [T]) (Fathipour & Maleknia, 2016) of green lacewing, *C. carnea* were analyzed according to the theory of age stage, and two-sex life table (Chi & Liu, 1985; Chi, 1988) by using the computer program of TWO-SEX_Ms Chart Chi (2019). Paired bootstrap test was employed for estimation of the variances and standard errors of the population growth parameters (Efron & Tibshirani, 1993). Furthermore, the paired bootstrap (×100,000) test was applied for the statistical differences among the means of parameters related to development, fecundity, as well as population parameters of different treatments (Efron & Tibshirani, 1993; Huang & Chi, 2012). Excel ver. 2013 was used to draw the charts.

Results

Bioassay of insecticides

Results of the acute toxicity testing of insecticides to estimate LC_{50}, on the 1st instar *C. carnea* are shown in table 1. Based on LC_{50} values and their 95% confidence limits, it was concluded that susceptibility to the three insecticides were different.

Table 1. Probit analysis for the concentration–mortality response of clothianidin, tebufenozide and flupyradifurone on adult females and males of *Chrysoperla carnea*

Insecticide	Category	n	df	LC_{30} (Lower-Upper) 95% CL	LC_{50} (Lower-Upper) 95% CL	X^2	*P-value*
clothianidin	Neonicotinoids	300	3	14.7 (1.9-23.0)	38.4 (30.8-46.6)	2.78	0.42
tebufenozide	Carbohydrazides	300	3	397.8 (129.2-573.7)	885.5 (727.3-1048.4)	2.33	0.50
flupyradifurone	Butenolides	300	3	222.4 (162.5-260.0)	322.3 (288.8-354.7)	0.96	0.81

* 20 individuals per replicate, five replicates per concentration, six concentrations per assay

Development time, longevity and total life span

Table 2 presents the effects of different insecticides on development time of both sexes of *C. carnea*. Based on the results, difference was observed among duration of eggs, larvae, as well as pupae in males and females treated with different insecticides, compared to the results in control. However, as shown in Table 3, the duration of different immature stages, adult longevity, along total life span for both sexes were significantly affected by different concentrations. Based on the obtained results, sublethal concentration (LC_{30}) of clothianidin caused a significant reduction in the longevity and total lifespan of males, compared to control. Also treatment with clothianidin led to a significant difference in total lifespan of females in comparison with the other treatments. The longest and the lowest total life spans for female adults were observed in flupyradifurone and clothianidin treatments, respectively (Table 2).

Table 2. Mean (±SE) of the female and male developmental times (days) of *Chrysoperla carnea* treated with sublethal concentrations of clothianidin, tebufenozide and flupyradifurone.

Parameter	CK	clothianidin	tebufenozide	flupyradifurone
Male				
Egg (days)	3.98 ± 0.11^{a}	3.35 ± 0.1^{b}	4.03 ± 0.11^{a}	3.1 ± 0.11^{b}
Larvae (days)	8.55 ± 0.32^{b}	9.82 ± 0.18^{a}	8.05 ± 0.18^{b}	7.25 ± 0.17^{c}
Pupae (days)	7.38 ± 0.22^{b}	6.08 ± 0.14^{c}	8.07 ± 0.16^{a}	7.05 ± 0.17^{b}
Adult longevity (days)	28.1 ± 0.46^{b}	20.05 ± 0.21^{d}	23.88 ± 0.29^{c}	30.55 ± 0.27^{a}
Total life span (days)	48.00 ± 0.75^{a}	39.33 ± 0.35^{b}	44.02 ± 0.37^{b}	47.95 ± 0.32^{a}
Female				
Egg (days)	4.05 ± 0.1^{b}	3.05 ± 0.1^{c}	4.85 ± 0.13^{a}	4.03 ± 0.16^{b}
Larvae (days)	8.68 ± 0.22^{a}	7.00 ± 0.16^{c}	8.5 ± 0.11^{a}	8.03 ± 0.15^{b}
Pupae (days)	8.35 ± 0.23^{b}	7.03 ± 0.19^{c}	9.00 ± 0.14^{a}	8.03 ± 0.18^{b}
Adult longevity (days)	28.85 ± 0.26^{b}	27.98 ± 0.33^{c}	23.8 ± 0.29^{d}	30.9 ± 0.28^{a}
Total life span (days)	49.92 ± 0.39^{b}	45.02 ± 0.03^{d}	46.15 ± 0.08^{c}	50.98 ± 0.03^{a}

The standard errors were calculated using the bootstrap procedure with 100,000 samples. The means followed by different letters in the same row are significantly different using paired bootstrap test at 5% significance level. CK is the check treatment (water control).

Total effect

The results are evaluated and summarized according to the international rating scheme suggested by the IOBC. Comparing the total effects of the pesticides (Table 3) revealed that tebufenozide and flupyradifurone could be classified as harmless compounds, but clothianidin was slightly harmful based on the IOBC classification.

Table 3. Total effect and hazard classes of the pesticides for *C. carnea* according to the IOBC evaluation categories.

Pesticide	Concentration LC_{30} (mg/lit)	Total effect (%)	Classification [a]
clothianidin	14.73	70.61	2
tebufenozide	397.8	15.74	1
flupyradifurone	222.41	17.52	1

a: 1. harmless, and 2. slightly harmful.

Reproduction Parameters

Table 4 displays the reproductive periods and total fecundity of offspring of the treated females. The results indicated that, in the treatments involving insecticides played significant effect on the adult pre-oviposition period (APOP) as well as total pre-oviposition period (TPOP) of *C. carnea* (Table 4). The mean total fecundity in flupyradifurone was 303.8 offspring/individual. It was significantly upper than those (286.52, 258.38 and 246.62 offspring/individual for control, tebufenozide and clothianidin treatment respectively). The data reveals a dramatically significant decrease in the oviposition period to compare with control that was varied from 21.62 to 26.62 days on tebufenozide and flupyradifurone treatment (Table 4).

Table 4. Mean (±SE) reproductive period and total fecundity of offspring of *Chrysoperla carnea* in control, and sublethal concentrations of clothianidin, tebufenozide, and flupyradifurone treatments.

Parameter	CK	clothianidin	tebufenozide	flupyradifurone
Oviposition period (days)	25.57 ± 0.23^{b}	21.90 ± 0.23^{c}	21.62 ± 0.29^{c}	26.62 ± 0.25^{a}
[1]APOP (days)	2.48 ± 0.08^{a}	2.62 ± 0.07^{a}	2.17 ± 0.02^{ab}	2.88 ± 0.07^{a}
[2]TPOP (days)	23.55 ± 0.29^{a}	19.68 ± 0.34^{c}	24.27 ± 0.27^{a}	22.95 ± 0.29^{b}
Total fecundity (offspring/individual)	286.52 ± 2.81^{b}	246.62 ± 2.56^{d}	258.38 ± 3.48^{c}	303.8 ± 2.86^{a}

The standard errors were calculated using the bootstrap procedure with 100,000 samples. The means followed by different letters in the same row are significantly different using the paired bootstrap test at 5% significance level. CK is the check treatment (water control).
1. APOP= adult pre-oviposition period (the duration from adult emergence to the first oviposition), and 2. TPOP = total pre-oviposition period (the duration from egg to the first oviposition).

Population Parameters

Table 5 represents population growth parameters of *C. carnea* after treatment with the evaluated insecticides. Based on the table 5, the lowest and the highest values of *GRR* were observed in clothianidin and distilled water, respectively. The R_0 values decreased in clothianidin and tebufenozide treatments (Table 5). In addition, the *r* value in clothianidin treatment was significantly higher than the other treatments (0.148, 0.150 and 0.155 day^{-1} for tebufenozide, control and flupyradifurone respectively). The highest λ was recorded for clothianidin (1.190 day^{-1}) compared to the other treatments. Mean generation time (*T*) ranged from 27.61 to 32.93 days for the green lacewings treated with clothianidin and control, respectively (Table 5).

Table 5. Mean comparison of the life table parameters (mean ±SE) of *Chrysoperla carnea* among sublethal concentrations of clothianidin, tebufenozide, and flupyradifurone, control treatments.

Parameters	CK	clothianidin	tebufenozide	flupyradifurone
r (day^{-1})	0.150±0.004^{b}	0.174±0.005^{a}	0.148±0.004^{b}	0.155±0.004^{b}
λ (day^{-1})	1.162±0. 004^{b}	1.190± 0.006^{a}	1.160±0.004^{b}	1.167±0.005^{b}
R_0 (offspring/individual)	143.26 ± 16.07^{b}	123.31 ± 14.01^{d}	129.18±14.69^{c}	151.9±17.26^{a}
GRR (offspring/individual)	164.35±17.97^{a}	134.07 ± 13.99^{c}	144.32 ±15.07^{b}	159.41±17.17^{a}
T (days)	32.93±0.35^{a}	27.61± 0.36^{b}	32.63±0.23^{a}	32.40±0.33^{a}

The standard errors were calculated using the bootstrap procedure with 100,000 samples. The means followed by different letters in the same row are significantly different using the paired bootstrap test at 5% significance level. CK is the check treatment (water control).

Survival and Fecundity

Figure 1 demonstrates the daily survival of both untreated and treated individuals of *C. carnea* with different insecticides. Exposure to sublethal concentration of the insecticides led to reduction in survival. The total lifetime for the untreated *C. carnea* (controls) was 58 days; while, it was 53, 49 and 48 days for flupyradifurone, clothianidin, and tebufenozide treatments, respectively. In addition, the maximum value of m_x was 6.60 eggs/female/day for untreated green lacewing, which was in day 46 of the lifespan (Fig. 2). However, The peak values of m_x for flupyradifurone, clothianidin and tebufenozide treatments were 7.20, 5.83 and 9.16 eggs/female/day, respectively, which occurred on days 48, 32 and 45 (Fig. 2). The age stage-specific survival rate (S_{xjj}) curve indicated the chance that a green lacewing egg will survive to age x and stage j (Fig. 3). Age-stage life expectancy (e_{xj}) curve of *C. carnea* is shown in Figure 4. The highest amounts of this parameter recorded for clothianidin, flupyradifurone and tebufenozide treatments in the female sex were 32.05, 35.97 and 27.92 days, on the 13th, 15th and 18th days, respectively. Based on the e_{xj} curve, these values demonstrated a downward trend. In the male sex, these values were 24.33, 33.95 and 28.02 days, on the 15th, 14th and 16th day, respectively (Fig. 4). The life expectancy in males and females in control were 32.02 and 32.95 days on 16th and 17th day, respectively (Fig. 4).

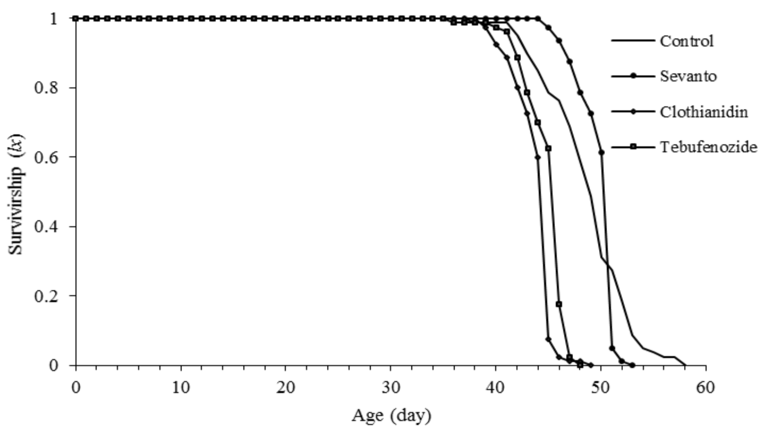

Fig. 1. Age-specific survivorship (l_x) of *Chrysoperla carnea* for control and different insecticides

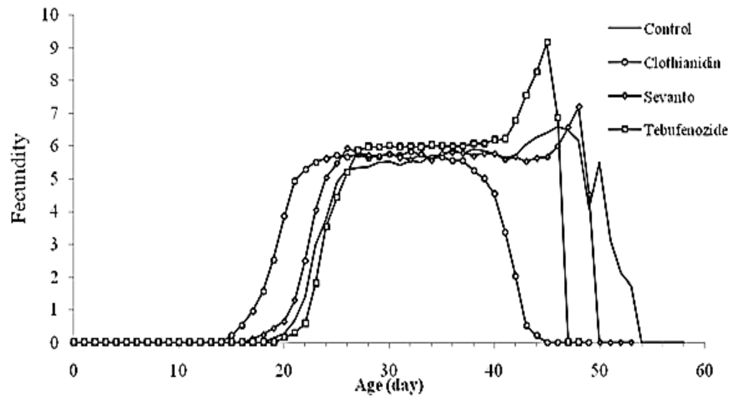

Fig. 2. Age-specific fecundity (m_x) *Chrysoperla carnea* for control and different insecticides

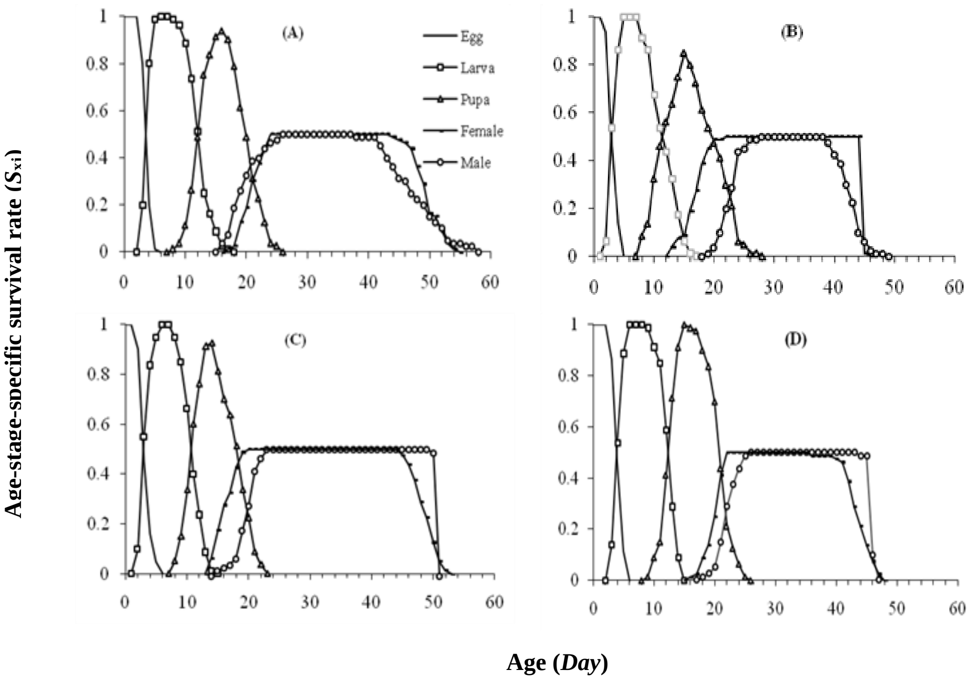

Fig. 3. Age-stage specific survival rate (s_{xj}) of *Chrysopa carnea* for control and different insecticides: control (A), clothianidin (B), flupyradifuron (C), tebufenozide

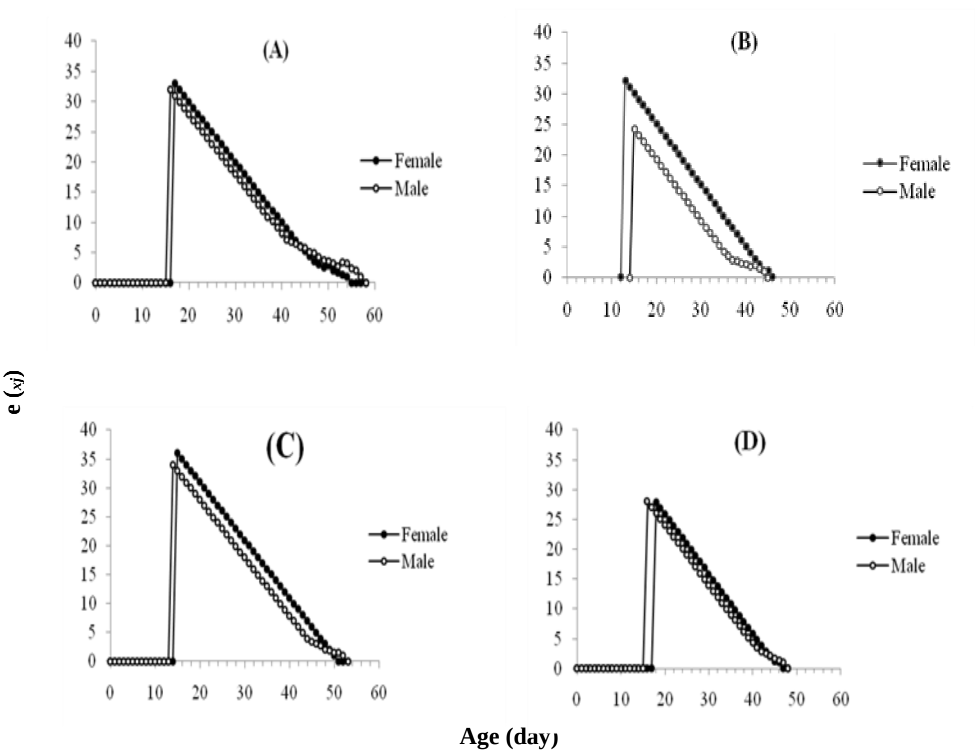

Fig. 4. Age-stage life expectancy (e_{xj}) curve of *Chrysopa carnea* for control and different insecticides: control (A), clothianidin (B), flupyradifuron (C), tebufenozide (D)

Discussion

Generally, a single chemical control strategy against pests cannot be successful, especially when the pesticides are not selected to have minimal effects on natural enemies and the environment, as well as limited effects on specific pest species (Kaplan *et al*., 2012). A various studies represent the effect of the sublethal effects of different pesticides on biological parameters of various natural enemies (Corrales & Campos, 2004; Sabry & El-Sayed, 2011; Amarasekare & Shearer, 2013). The current study provided the population parameters and demographic data related to offspring of *C. carnea* that treated with sublethal (LC_{30}) concentration of three insecticides (clothianidin, flupyradifurone and tebufenozide). Based on the results of this study, sublethal concentration (LC_{30}) of these insecticides had a significant effect on developmental time of both sexes in *C. carnea*. The highest longevity of males and females were observed in flupyradifurone treatment. Results of present study indicated that clothianidin treatment resulted in the lowest total life span at both sexes, compared with the other treatments. These findings are consistent with those in other studies which found the lowest life span period for the adult of *C. carnea* treated with fipronil and imidacloprid (Kumar & Santharam, 1999; Medina *et al*., 2003a). That is while Elzen (2001) showed a shorter life-span for *Orius insidiosus* (Say) treated with endosulfan.

Acquired analysis showed that different treatments had significant effects on pre-oviposition and total pre-oviposition periods and decreased the oviposition period. The results are in line with those from other studies which focused on the effects of pyriproxyfen, permethrin and fenvalerate on *C. carnea* adult individuals (Grafton-Cardwell and Hoy 1985; Medina *et al*., 2003b). Contrarily, Viñuela *et al*. (2001), reported that tebufenozide did not affect fecundity of *C. carnea* adults by residual assay. Fecundity of *C. carnea* individuals was considerably affected by tebufenozide and clothianidin in the current study. However, flupyradifurone treatment caused a significant increase in fecundity of *C. carnea* adults. In agreement with this result, Rezaei *et al*. (2007) and Golmohammadi & Hejazi (2014), indicated a significant reduction in fecundity of *C. carnea* when it was treated with propargite, pymetrozine and indoxacarb.

Life table analyses are considered as significant and outstanding tools in population ecology and pest management, because they combine data on all life history parameters, including survival, stage differentiation, and reproduction (Huang *et al*., 2017). Analogically speaking, demographic toxicology has been recognized as a better measure of response to toxicants, compared with the individual life history traits (Forbes & Calow, 1999). The r (intrinsic rate of increase) parameter is the most important parameter that describing the growth potential of a population (Li *et al*., 2017). The demographic parameters of the current study demonstrated that the highest r and λ (finite rate of increase) values of *C. carnea* was observed when treated with clothianidin. While, that was the lowest values for net reproduction rate (R_0), gross reproductive rate (*GRR*) and mean generation time (*T*) occurred with clothianidin compared with other treatments. These findings are in agreement with the study of Rezaei *et al*. (2007), which showed of *C. carnea* have the lowest population parameters, when treated by pymetrozine, compared to control treatment. In other study Golmohammadi *et al*. (2013) reported that the lowest values for R_0 and *GRR* parameters was observed in green lacewing treated with indoxacarb (LC_{25} concentration). Regarding the curves of survival and age-specific fecundity, a green lacewing treated with insecticides, has a downward trends in l_x and m_x values. Godoy *et al.* (2004) also reported reductions in fertility of adult female *Chrysoperla externa* (Hagen) after topical applications of lufenuron. The reduction value for fecundity were reported in previous studies for *C. carnea* and *Ceraeochrysa cuban* (Hagen) respectively, when treated by fipronil, imidacroprid, pymetrozin and diflubenzuron respectively (Huerta *et al.,* 2003; Rezaei *et al*., 2007; Ono *et al.,* 2017).

In another study, Mizell & Schiffhauer (1990) showed pyrethroids were not toxic to adults of *Chrysoperla rufilabris*. Also, the adult survivorship of *C. carnea* was significantly lower in endosulfan and cypermethrin, (Rimoldi *et al*., 2008); that these results are in agreement with our data for clothianidin and tebufenozide. The age-specific fecundity, survival, and life-expectancy curves demonstrated that sublethal concentrations of clothianidin, flupyradifurone and tebufenozide caused significant reduction in these parameters of *C. carnea*. Barbosa *et al.* (2017), in line with the results of the present study, reported that application of flupyradifurone at 0.22 and 2.19 g a.i./L reduced the population of *C. carnea* drastically compared with untreated check. Similar to our finding, significantly higher toxicity of emamectin benzoate on adults was reported 7 and 14 days after treatment (Khan *et al.,* 2015).

Using the IOBC (International Organization of Biological Control) method, it is feasible to determine the hazard classes of tested compounds (Rezaei *et al*., 2007). In current study, the assessment was made based on the statistical comparisons with no hazard class determination. Similar to our data, imidacloprid was slightly harmful (Group II) against *C. carnea* in the laboratory (Talebi *et al*., 2008). However, pesticides are considered as economical and effective tools for pest management with large generality in most sectors of agricultural production, which should be selected from products with minimum effect on environment, and natural enemies (Damalas & Eleftherohorinos, 2011; Havasi *et al*., 2020).

The stability of resistance in the absence of exposure to insecticides is very crucial in the utilization of natural enemies in IPM (Shankarganesh *et al.,* 2017). Natural enemies play a fundamental role in any IPM program, and the use of insecticides in the ipm system must be done carefully. Therefore, the main challenge is maximize the role of natural enemies (Shankarganesh *et al.,* 2017; Ullah & Lim, 2017). In conclusion, clothianidin and tebufenozide, were toxic to adults of *C. carnea*. In contrast, flupyradifurone may be effectively utilized in IPM programs with a view of safety to the natural enemy, *C. carnea*.

References

Abbott, W. S. (1925) A method of computing the effectiveness of an insecticide. *Journal of Economic Entomology* 18, 265–267.

Amarasekare, K. G. & Shearer, P. W. (2013) Comparing effects of insecticides on two green lacewings species, *Chrysoperla johnsoni* and *Chrysoperla carnea* (Neuroptera: Chrysopidae). *Journal of economic entomology* 106 (3), 1126-1133**.**

Azema, M. & Mirabzadeh, A. (2004) *Issues on dif erent aspects of applying natural enemies for biological control of insect pests*. 213 pp. Markaze Nashre Sepehr Publication

Bartlett, B. R. (1964) Integration of chemical and biological control. pp. 489-514 In: P. DeBach (Ed.), *Bi- ological Control of Insect Pests and Weeds. Reinhold*, New York.

Barbosa, P. R., Michaud, J. P., Bain, C. L. & Torres, J. B. (2017) Toxicity of three aphicides to the generalist predators *Chrysoperla carnea* (Neuroptera: Chrysopidae) and *Orius insidiosus* (Hemiptera: Anthocoridae). *Ecotoxicology* 26(5), 589-599.

Biondi, A., Mommaerts, V., Smagghe, G., Viñuela, E., Zappalà, L. & Desneux. N. (2012) The non-target impact of spinosyns on beneficial arthropods. *Pest management science* 68(12), 1523-1536.

Biondi. A., Zappalà, L., Stark, J. D. & Desneux, N. (2013) Dobiopesticides affect the demographic traits of a parasitoid wasp and its biocontrol services through sublethal effects? *PloS one*. 8: e76548.

Chi, H. (2019) TWO SEX-MSChart: a computer program for the age-stage, two-sex life table analysis.

Chi, H. (1988) Life-table analysis incorporating both sexes and variable development rates among individuals. *Environmental Entomology* 17(1), 26-34.

Chi, H. S. I. N. & Liu, H. (1985) Two new methods for the study of insect population ecology. *Bulletin of the Institute of Zoology, Academia Sinica* 24 (2), 225-240.

Cira, T. M., Burkness, E. C., Koch, R. L. & Hutchison, W. D. (2017) Halyomorpha halys mortality and sublethal feeding effects following insecticide exposure. *Journal of Pest Science* 90, 1257–1268.

Croft, B. A. (1990) *Arthropod biological control agents and pesticides*. John Wiley, New York.

Corrales, N. & Campos, M. (2004) Populations, longevity, mortality and fecundity of *Chrysoperla carnea* (Neuroptera, Chrysopidae) from olive-orchards with different agricultural management systems. *Chemosphere* 57(11), 1613-1619.

Damalas, C. A. & Eleftherohorinos, I. G. (2011) Pesticide exposure, safety issues, and risk assessment indicators. *International journal of environmental research and public health* 8(5), 1402–1419.

Dohmen, G. P. (1998) Comparing pesticide effects on beneficials in a sequential testing scheme. *In Ecotoxicology*, 191-201.

Doue (2009) Directive 2009/128/EC on the sustainable use of pesticides. Doue 24-nov-2009 L309: 71-86.

Efron, B. & Tibshirani, R. J. (1993) *An introduction to the bootstrap*. Springer, US, 436 pp.

Elzen, G. W. (2001) Lethal and sublethal effects of insecticide residues on *Orius insidiosus* (Hemiptera: Anthocoridae) and *Geocoris punctipes* (Hemiptera: Lygaeidae). *Journal of Economic Entomology* 94(1), 55-59.

Fathipour, Y. & Maleknia, B. (2016) Mite predators. In *Ecofriendly pest management for food security*, 329-366.

Forbes, V. E. & Calow, P. (1999) Is the per capita rate of increase a good measure of population-level effects in ecotoxicology?. *Environmental Toxicology and Chemistry* 18(7), 1544-1556.

Garzón, A., Medina, P., Amor, F., Viñuela, E. & Budia, F. (2015) Toxicity and sublethal effects of six insecticides to last instar larvae and adults of the biocontrol agents *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae) and *Adalia bipunctata* (L.)(Coleoptera: Coccinellidae). *Chemosphere* 132, 87-93.

Galvan, T. L., Koch, R. L. & Hutchison, W. D. (2005) Effects of spinosad and indoxacarb on survival, development, and reproduction of the multicolored Asian lady beetle (Coleoptera: Coccinellidae). *Biological Control* 34(1), 108-114.

Geetha, B. & Swamiappan, M. (1998) Improved adult rearing cages for the predator, *Chrysoperla carnea*. *Madras Agricultur Journal* 85, 333-334.

Godoy, M. S., Carvalho, G. A., Moraes, J. C., G. Júnior, M., Morais, A. A. & Cosme, L. V. (2004) Selectivity of insecticides used in citrus crops to eggs and larvae of *Chrysoperla externa* (Hagen) (Neuroptera: Chrysopidae). *Neotropical Entomol*ogy 33, 639–646.

Golmohammadi, G. & Hejazi, M. (2014) Toxicity and side effects of three insecticides on adult *Chrysoperla carnea* (Neu.: Chrysopidae) under laboratory conditions. *Journal of Entomological Society of Iran* 33(4), 23-28.

Golmohammadi, G., Hejazi, M., Iranipour, S. & Mohammadi, S. A. (2009) Lethal and sublethal effects of endosulfan, imidacloprid and indoxacarb on first instar larvae of *Chrysoperla carnea* (Neu.: Chrysopidae) under laboratory conditions. *Journal of Entomological Society of Iran* 28(2), 37-47.

Golmohammadi, G. R., Hejazi, M., Iranipour, S. & Mohammadi, S. S. (2013) Sublethal Effects of three insecticides on adults green lacewing *Chrysoperla carnea* Stephens with demographic toxicology method. *Applied Entomology and Phytopathology* 81 (1).

Grafton-Cardwell, E. E. & Hoy, M. A. (1985) Short-term effects of permethrin and fenvalerate on oviposition by *Chrysoperla carnea* (Neuroptera: Chrysopidae). *Journal of Economic Entomology* 78(4), 955-959.

Greathead, D. J. (1995) Benefits and risks of classical biological control. *In:* Hokkanen HMT, Lynch JM (eds) *Biological control: Benefits and risks.* Cambridge University Press, Cambridge, 53–63.

Havasi, M., Kheradmand, K., Mosallanejad, H. & Fathipour, Y. (2020) Life history traits and demographic parameters of *Neoseiulus californicus* McGregor (Acari: Phytoseiidae) treated with the Biomite®. *Systematic and Applied Acarology* 25(1), 125-138.

Hassan, S. A. (1998) The initiative of the IOBC/WPRS working group on pesticides and beneficial organisms. *Ecotoxicology* 22-27.

Hamedi, N., Fathipour, Y. & Saber, M. (2010) Sublethal effects of fenpyroximate on life table parameters of the predatory mite *Phytoseius plumifer*. *BioControl* 55, 271–278.

Huang, Y. B. & Chi, H. (2012) Assessing the application of the jackknife and bootstrap techniques to the estimation of the variability of the net reproductive rate and gross reproductive rate: a case study in *Bactrocera cucurbitae* (Coquillett)(Diptera: Tephritidae). *Journal of Agriculture Forest* 61, 37–45.

Huang, H. W., Chi, H. & Smith, C. L. (2017) Linking Demography and Consumption of *Henosepilachna vigintioctopunctata* (Coleoptera: Coccinellidae) Fed on *Solanum photeinocarpum* (Solanales: Solanaceae): With a New Method to Project the Uncertainty of Population Growth and Consumption. *Journal of economic entomology* 111(1), 1-9.

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. *Journal of Agriculture Research* 50(4), 509-515.

Huerta, A., Medina, P., Castañera, P. & Viñuela, E. (2003) Residual effects of some modern pesticides on *Chrysoperla carnea* (Stephens) adults under laboratory conditions. *IOBC wprs Bulletin* 26(10), 165-170.

Jepson, P. C. (1989) The temporal and spatial dynamics pesticide side effects on non-target invertebrates. pp 95–128. In: Jepson P. C. (Ed) *Pesticides and non-target invertebrates*. Intercept, Wimborne.

Kaplan, P., Yorulmaz, S. & Ay, R. (2012) Toxicity of insecticides and acaricides to the predatory mite *Neoseiulus californicus* (McGregor)(Acari: Phytoseiidae). *International Journal of Acarology* 38(8), 699-705.

Khan, S. Z., Ullah, F., Khan, S., Khan, M. A., & Khan, M. A. (2015) Residual effect of insecticides against different stages of green lacewing, *Chrysoperla Carnea* (Neuroptera: Chrysopidae). *Journal of Entomology and Zoology Studies* 3, 114-119.

Kovach, J., Petzoldt, C., Degni, J. & Tette, J. (1992) *A method to measure the environmental impact of pesticides.* New York's Food and Life Sciences Bulletin no. 139: IPM Program, Cornell University, New York Agricultural Experiment Station.

Kumar, K. & Santharam, G. (1999) Laboratory evaluation of imidacloprid against *Trichogramma chilonis* Ishii and *Chrysoperla carnea* (Stephens*). Journal of Bioogical Control* 13, 73–78.

Li, Y. Y., Fan, X., Zhang, G. H., Liu, Y. Q., Chen, H. Q., Liu, H. & Wang, J. J. (2017) Sublethal effects of bifenazate on life history and population parameters of *Tetranychus urticae* (Acari: Tetranychidae). *Systematic and Applied Acarology* 22(1), 148-158.

Matsumura, F. (2012) *Toxicology of insecticides*. Springer Science & Business Media.

McEwen, P. K., New, T. R. & Whittington, A. E. (2007) *Lacewings in the crop environment*. Cambridge University Press.

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. *Annals of Applied Biology* 142, 55-61.

Medina, P., Budia, F., del Estal, P., Adán, A. & Viñuela, E. (2003b) Side effects of six insecticides on different developmental stages of *Chrysoperla carnea* (Neuroptera: Chrysopidae). *IOBC WPRS BULLETIN* 26(5), 33-40.

Meissle, M., Álvarez-Alfageme, F., Malone, L. A. & Romeis, J. (2012) Establishing a database of bio-ecological information on non-target arthropod species to support the environmental risk assessment of genetically modified crops in the EU. *EFSA Supporting Publications* 9(9), 334E.

Mizell, R. F. & Schiffhauer, D. E. (1990) Effects of pesticides on pecan aphid predators *Chrysoperla rufilabris* (Neuroptera: Chrysopidae), *Hippodamia convergens*, Cycloneda sanguinea (L.), *Olla v-nigrum* (Coleoptera: Coccinellidae), and *Aphelinus perpallidus* (Hymenoptera: Encyrtidae). *Journal of Economic Entomology* 83(5), 1806-1812.

Nasreen, A., Mustafa, G. & Ashfaq, M. (2005) Mortality of *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae) after exposure to some insecticides; laboratory studies. *South Pacific Studies* 26(1), 1-6.

Nawaz, M., Cai, W., Jing, Z., Zhou, X., Mabubu, J. I. & Hua, H. (2017) Toxicity and sublethal effects of chlorantraniliprole on the development and fecundity of a nonspecific predator, the multicolored Asian lady beetle, *Harmonia axyridis* (Pallas). *Chemosphere* 178, 496–503.

Newsom, L. D., Smith, R. F. & Whitcomb, W. H. (1976) *Selective pesticides and selective use of pesticides. Theory and practice of biological control.* Academic Press, New York, 565-591.

Ono, É. K., Zanardi, O. Z., Santos, K. F. A., & Yamamoto, P. T. (2017) Susceptibility of *Ceraeochrysa cubana* larvae and adults to six insect growth-regulator insecticides. *Chemosphere* 168, 49-57.

Preetha, G., Johnson, S., Manoharan, T., Chandrasekaran, S. & Kuttalam, S. (2009) Toxicity of imidacloprid and diafenthiuron to *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae) in the laboratory conditions. *Journal of plant protection research* 49(3), 290-296.

Rezaei, M., Talebi, K., Naveh, V. H. & Kavousi, A. (2007) Impacts of the pesticides imidacloprid, propargite, and pymetrozine on *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae): IOBC and life table assays. *BioControl* 52(3), 385-398.

Rimoldi, F., Schneider, M. I. & Ronco, A. E. (2008) Susceptibility of *Chrysoperla externa* eggs (Neuroptera: Chrisopidae) to conventional and biorational insecticides. *Environmental entomology* 37(5), 1252-1257.

Roubos, C. R., Rodriguez-Saona, C. & Isaacs, R. (2014) Mitigating the effects of insecticides on arthropod biological control at field and landscape scales. *Biological control 75*, 28-38.

Romeis, J., Meissle, M., Álvarez-Alfageme, F., Bigler, F., Bohan, D. A., Devos, Y., Malone, L. A., Pons, X. & Rauschen, S. (2014) Potential use of an arthropod database to support the non-target risk assessment and monitoring of transgenic plants. *Transgenic research* 23(6), 995-1013.

Sabry, K. H. & El-Sayed, A. A. (2011) Biosafety of a biopesticide and some pesticides used on cotton crop against green lacewing, *Chrysoperla carnea* (Stehens) (Neuroptera: Chrysopidae). *Journal of Biopesticides* 4(2), 214-218.

Sáenz-de-Cabezón, F. J., Martínez-Villar, E., Moreno, F., Marco, V. & Pérez-Moreno, I. (2006) Influence of sublethal exposure to triflumuron on the biological performance of *Tetranychus urticae* Koch (Acari: Tetranychidae). *Spanish Journal of Agricultural Research* 4(2), 167-172.

Shankarganesh, K., Naveen, N. C. & Bishwajeet, P. (2017) Effect of Insecticides on Different Stages of Predatory Green Lacewing, *Chrysoperla zastrowi* sillemi (Esben.-Petersen). *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences* 87 (4), 1415-1422.

Stark, J. D., Banks, J. E. & Acheampong, S. (2004) Estimating susceptibility of biological control agents to pesticides: influence of life history strategies and population structure. *Biological control* 29(3), 392-398.

Statistic, IS. (2011) IBM SPSS STATISTIC program, version 19 statistical software packages. IBM Corporation, New York.

Talebi, K., Kavousi, A. & Sabahi, Q. (2008) Impacts of pesticides on arthropod biological control agents. *Pest Technology* 2(2), 87-97.

Turquet, M., Pommier, J. J., Piron, M., Lascaux, E. & Lorin, G. (2008) March. Biological control of aphids with *Chrysoperla carnea* on strawberry. In *VI International Strawberry Symposium* 842, 641-644.

Ullah, M. S. & Lim, U. T. (2017) Synergism of *Beauveria bassiana* and *Phytoseiulus persimilis* in control of *Tetranychus urticae* on bean plants. *Systematic and Applied Acarology* 22(11), 1924-1935.

Viñuela, E., Medina, M. P., Schneider, M., González, M., Budia, F., Adán, A. & del Estal, P. (2001) Comparison of side-effects of spinosad, tebufenozide and azadirachtin on the predators *Chrysoperla carnea* and *Podisus maculiventris* and the parasitoids *Opius concolor* and *Hyposoter didymator* under laboratory conditions. *IOBC/WPRS Bulletin* 24, 25-34.

Wang, D., Gong, P., Li, M., Qiu, X. & Wang, K. (2009) Sublethal effects of spinosad on survival, growth and reproduction of *Helicoverpa armigera* (Lepidoptera: Noctuidae). *Pest Management Science*: *Formerly Pesticide Science* 65, 223–227.

Zhao, Sh. (2000) *Plant Chemical Protection.* 337 pp. Beijing (China): China Agriculture Press. (in Chinese).