Demographic Parameters of *Chrysoperla carnea* on the Sublethal Concentration of Endosulfan: Two-Sex Life Table

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Abstract

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The aim of this study is to investigate the sublethal effects (LC_{30}) of endosulfan on *Chrysoperla carnea* adults as an efficient natural enemy against the flour moth *Ephestia kuehniella* Zell (Lepidoptera: Pyralidae) under laboratory conditions: (25±2°C temperature, relative humidity of 60±5% relative humidity, and 16:8 hours (light: dark) photoperiod), in a growth chamber. The results obtained showed a significant decrease in the LC_{30} concentration of Endosulfan during the biological life span of both sexes (male and female) of *C. carnea* compared to the control. The highest fecundity rate obtained for endosulfan treatment was 203.28 offspring/female compared to 316.31 offspring/female for the control treatment. The net reproduction rate (R_0) of females treated with endosulfan was 140.18 offspring/individual/generation and was significantly lower than that of the control-treated females (253.04 offspring/individual/generation). The mean time of one generation (T) varied from 43.12 days in the control treatment to 38.70 days in the LC_{30} endosulfan treatment. Results obtained showed that the use of a sub-lethal concentration of endosulfan affects some biological parameters of the green lacewing predator *C. carnea*, which is useful information to consider when designing IPM programs for the flour moth.

Keywords: Dynamic parameters, Chrysopidae, life history, sublethal concentration.

Introduction

Integrating biological control methods with selective insecticides is a globally adopted strategy for managing destructive plant pests, which are often challenging to control using a singular approach. This approach requires careful considerations to ensure that the biological control of one pest does not interfere with the chemical control of another (Medina *et al,* 2003). The extensive use of synthetic insecticides harms beneficial arthropods, humans and the surrounding environment, as well as pest re-emergence, insecticide resistance (Maia *et al.,* 2016), frequent use, environmental pollution, and the emergence of secondary pests and biodiversity reduction (Antonious & Snyder, 2006).

Natural enemies are one of the most important methods of integrated pest management (IPM) because they reduce agricultural damage caused by primary pests and prevent the spread of secondary pests (Saber *et al.,* 2018). Green lacewings, from the Chrysopidae family, are effective predators in various agricultural environments, and they consume various insect pests (Al-Fatlawi *et al.,* 2021; Fathipour & Jafari, 2004). *C. carnea*, often known as the common green lacewing, is a polygenic predator used in biological control, known for its wide geographical distribution, high level of tolerance to various environments, and their ability to consume a wide range of pest species (Horton *et al.,* 2009; Jones *et al.,* 2011; Zeb Khan *et al.,* 2015). Moreover, the importance of this predator in integrated pest control programs has increased due to its high resistance to traditional insecticides (Alsendi *et al.,* 2023; Pathan *et al.,* 2008; 2010). Currently, agricultural growers are increasingly using integrated pest management programs that usually include environmentally friendly pesticides and biological control agents (Calvo *et al.,* 2012; Mohammed *et al.,* 2022). The lethal consequences of different pesticide doses must be evaluated and sub-lethal concentrations determined before using these pesticides. Low doses effectively manage primary resistance and protect beneficial organisms which are important in IPM programmes (He *et al.,* 2013; Song *et al.,* 2013).

Endosulfan is one of the organochlorine insecticides that US-ATSDR (2013) has estimated to have a half-life of approximately 320 days. This insecticide has been reported as highly toxic and causes the hyperexcitation of the nervous system by antagonizing the inhibitory neurotransmitter gamma-aminobutyric acid (GABA) (Bloomquist, 1996; Chen *et al.,* 2006). Assessing the effect of pesticides under laboratory conditions is useful for obtaining information about potential effects on arthropods (Havasi *et al.,* 2019). In addition, information on life table and population dynamics for determining competence (Chi *et al.,* 2020), side effects of pesticides on the population growth rate and fecundity (Chi, 1990; Kakde *et al.,* 2014; Li *et al.,* 2017; Sakai *et al.,* 2001) are essential to develop improved control applications. Due to the high use and consumption of insecticides such as Endosulfan in various products, it is suggested that this chemical compound's lethal and sublethal effects on this

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widely used biological control agents be investigated to identify find the most appropriate combinations. Furthermore, it is necessary to evaluate the insecticidal effects of the mentioned compound on the demographic parameters of green lacewing *C. carnea* using the age-stage two-sex life table theory to determine the efficiency of the most suitable chemical compound to be able to use it as a component in integrated pest management programs.

Material and Methods

Biological materials

The Mediterranean flour moth, *Ephestia kuehniella* Zell (Lepidoptera: Pyralidae) was obtained from the Iranian Research Institute of Plant Protection (IRIPP). Plastic containers with a net cloth (70 cm in diameter × 25 cm high) were used to rear *E. kuehniella*. A combination of 2.5 kg wheat flour, 0.5 kg wheat bran, and 40 grams of flour yeast were added to each container, and one gram of Mediterranean flour moth was uniformly introduced to each container. Net cloths were used to cover The plastic tray lids were covered with net cloth and placed under controlled conditions (temperature of 25±2°C, relative humidity of 65±5%, and a photoperiod of 16 hours of light and 8 hours of darkness) in a growth chamber (Rezaei Torshizi *et al.,* 2019). Green lacewing was grown in a plastic cylinder (15 cm in diameter and 22 cm in height), with a net fabric covering the lid. According to Golmohammadi & Hejazi (2014), adults were given flour moth eggs every day along with an artificial diet consisting of yeast, honey, and distilled water. Each layer contained 20 green lacewing larvae and enough flour moth eggs. After the appearance of the first instar larvae, second instar larvae, third instar larvae, and pupae were collected and transferred to other containers (with an opening diameter of 17.5 cm and a height of 7.5 cm) and used in the main experiments. The breeding containers were kept under the same conditions above (Rezaei Torshizi *et al*., 2019).

Insecticide used and concentration-response bioassay

The insecticide tested was endosulfan (35EC, Partoenar Company). Male and female green lacewing adults of the same age (less than 24 hours old) were used for bioassays, and their gender was determined under a stereomicroscope according to the shape of the sternite at the end of the abdomen (Rezaei Torshizi *et al*., 2019). Bioassay using the contact toxicity method (Mohammadi *et al*., 2009) in plastic Petri dishes (diameter 6 and height 1 cm) was used under controlled conditions (temperature of 25±2°C, relative humidity 65±5%, and photoperiod 16: 8 hours (light: dark). A preliminary experiment was conducted to determine 10-90% mortality in adult insects (Robertson *et al*., 2007). Then, five concentrations, including 400, 600, 950, 1100, and 1800 ml/l for endosulfan, were prepared and applied using the logarithmic distance. Distilled water was also used as the control treatment. Two milliliters of each concentration were poured on two surfaces of 10 cm diameter Petri dishes (one milliliter on each surface) and kept at room temperature for thirty minutes until their surfaces were completely dry. Then 10 pairs of male and female insects were placed inside each container separately, then the Petri dishes were transferred to an incubator under controlled conditions as described above. 24 hours later, the number of male and female insect deaths was counted separately. The experiments were performed with 5 insecticide concentrations and 4 replicates.

Life-table assay

The sublethal effect of endosulfan on the parameters of the green lacewing *C. carnea* biological table was started by treating whole insects with the LC_{30} insecticide concentration. The LC_{30} concentration was estimated for endosulfan insecticide as shown in Table 1. One hundred pairs of male and female 24 hours old insects were selected for endosulfan treatment, and distilled water was used as control treatment. 24 days later, the treated adults that survived were selected. Then, 10 pairs (10:10, male: female) of adult insects were transferred to containers with an opening diameter of 8 cm (height 16 cm) for spawning. On the wall of each container, a plastic tape was placed attached to the outer wall with an elastic band for insects to lay eggs. Insects diet prepared in advance (mixture of yeast, water, and honey) (Golmohammadi & Hejazi, 2014), was placed on these strips. The lid of these containers was covered with a net cloth and a small piece of sponge, to provide the water needed by the insect (Golmohammadi & Hejazi, 2014). The eggs laid in each container were counted daily and removed until the end of the last green lacewing life. The biological parameters of the adult green lacewing insects were calculated, including the duration of life cycles, life span, and the total life duration of both males and females. In addition, the reproductive and fecundity periods and the mean total reproduction were estimated.

Statistical analysis

The LC_{50} and LC_{30} values and the concentration-mortality regression of biocontrol agent species were obtained using a Probit program of IBM SPSS (version 19.0). The raw life history data were analyzed based on an age-stage, two-sex life table (Chi & Liu 1985; Chi 1988) using the software TWOSEX MSChart program (version 2021) (Chi, 2021). The variances and standard errors of the population growth parameters were estimated by the bootstrap procedure (Efron and Tibshirani 1993). Furthermore, the paired bootstrap (×100,000) test was applied for the statistical differences among the means of life table parameters (Efron & Tibshirani, 1993; Huang & Chi, 2013).

Table 1. Probit analysis for the concentration-mortality response of the adult stage of *Chrysoperla carnea* to endosulfan.

Treatment	Category	N*	LC_{30} (ml/L) (95% confidence intervals)	LC_{50} (ml/L) (95% confidence intervals)	*df*	Slope ± SE
Endosulfan	Organochlorinate	480	632.03 (560.97-695.53)	1946.11 (1675.82-2396.22)	4	3.69 ± 0.35

*20 individuals per replicate, four replicates per concentration, six concentrations per assay.

Results

Bioassay

The estimated LC_{50} for the green lacewing was 1946 ml/l, however, the mortality rate of the control treatment was 0.0. In addition, the value of LC_{30} was 632 ml/l (Table 1).

Determination of development time, longevity, and total lifespan

The results of the effect of the sublethal concentration of endosulfan on the length of different developmental stages of green lacewing *C. carnea* compared to the control are shown in Table 2. There was no significant difference in the length of growth periods of male *C. carnea* treated with the LC_{30} concentration of endosulfan compared to the control. In this study, significant differences were observed in the mean life span of adults males and females compared to controls. The mean length of the longevity period of male (control= 42.51, LC_{30}= 28.72 day) and female (control= 44.25, LC_{30}= 35.67 day) green lacewing *C. carnea* are presented in Table 2. The mean total life span of males and females ranged from 63.42 to 49.33 and from 68.81 to 57.23 days, respectively. The effect of the sub-lethal concentration (LC_{30}) on the life span of the treated green lacewing *C. carnea* was significantly decreased compared to the control.

Table 2. Means (±SE) of the growth duration and survival of *Chrysoperla carnea* treated with sub-lethal concentration (LC_{30}) of endosulfan compared with the control.

Parameter	Control	Endosulfan
Males		
Developmental time (day)	20.90±0.51 a	20.61±0.29 a
Longevity (day)	42.51±1.64 a	28.72±1.51 b
Total life span (day)	63.42±1.73 a	49.33±1.57 b
Females		
Developmental time (day)	24.55±0.24 a	21.55±0.31 b
Longevity (day)	44.25±2.19 a	35.67±2.16 b
Total life span (day)	68.81±2.26 a	57.23±2.22 b

Means followed by the same letters in the same row are not significantly different using the paired bootstrap test at P=0.05.

Reproductive period

The number of eggs laid per female were significantly decreased after the adult females were treated with sublethal concentrations of endosulfan compared to the control. The highest fecundity of *C. carnea* was 316.31 offspring/female was observed in the untreated control (Table 3). Conversely, LC_{30} concentration resulted in the lowest fecundity. The females treated with sublethal concentration significantly differed significantly in adult pre-oviposition period (APOP is the duration from female emergence to first oviposition) compared to the control. Still, post-oviposition periods significantly differed in LC_{30} treated females compared with untreated control. The maximal oviposition period of *C. carnea* was observed in the control and reached 39.83 days, and significantly decreased following LC_{30} treatment (31.23 days). The mean number of eggs per *C. carnea* females showed a declining trend for *C. carnea* exposed to LC_{30} (Table 3).

Population parameters

The growth reproductive rate was significantly reduced under the influence of the experimental concentration. The LC_{30} concentration of Endosulfan reached its lowest value, 218.96 offspring/ individual/ generation. The net reproductive rate of green lacewing *C. carnea* treated with Endosulfan was significantly reduced. So that its lowest value (140/18 offspring/ individual/ generation) was related to LC_{30} concentration of endosulfan, which had a significant difference from the control (253/04 offspring/ individual/ generation). The studied insecticide endosulfan significantly affected the mean generation time of *C. carnea* individuals. The lowest mean generation time of green lacewing *C. carnea* (38.70 days) was obtained for the LC_{30} concentration of Endosulfan. The longest mean generation time (43.12 days) was related to control treatment (Table 4).

Table 3. Insecticidal effect of endosulfan on some biological characteristics (Mean±SE) of *Chrysoperla carnea* compared to control.

Parameter	Control	Endosulfan
Oviposition (days)	39.83±2.17 a	31.23±2.15 b
Adult pre-oviposition period (days)	3.67±0.18 a	3.88±0.19 a
Post oviposition period (days)	28.23±0.28 a	25.43±0.43 b
Total Fecundity (offspring/female)	316.31±20.34 a	203.28±16.59 b

Table 4. Population growth parameters (Mean±SE) of *Chrysoperla carnea* under the influence of sub-lethal concentration (LC_{30}) of the insecticide Endosulfan in comparison with the control.

Population growth parameters	Control	Endosulfan
Gross reproduction rate (*GRR*) (offspring/individual/ generation)	319.08±21.48 a	218.96±15.12 b
Net reproductive rate (R_0) (offspring/individual/ generation)	253.04±24.15 a	140.18±16.76 b
Intrinsic rate of increase (*r*) (per day)	0.1283±0.002 a	0.1277±0.003 a
Finite rate of increase (λ) (per day)	1.1369±0.002 a	1.1362±0.003 a

Survival and fecundity

Figure 1 shows the trend of age-specific survival (mx) changes of progeny obtained from green lacewing treated with a sublethal concentration of endosulfan. The maximum age-specific fecundity (m_x) of female *C. carnea* at LC_{30} concentration of endosulfan was 7.06 eggs/individual on the 52nd day. The highest value of this parameter, 8.61 eggs/individual, was obtained on the 55th day for untreated green lacewing (Figure 1-A).

The trend of changes in age-specific survival (l_x) of progeny obtained from green lacewing treated with sublethal concentration of endosulfan are shown in Figure 1-B. The longest life span in green baltoris in control was 82 days, while this rate was 74 days for Endosulfan at 30% sublethal concentrations (Figure 1-B).

The Age-stage-specific survival rate (s_{xj}) of *C. carnea* for the untreated (control) and LC_{30} treatment of endosulfan is shown in Figure 2. A distinct overlap was observed in the curves at different developmental periods among the individuals.

Discussion

Accomplishing effective bioagent control is considered the first step in developing IPM programs (Fathipour *et al.,* 2020). However, the compatibility of insecticides with natural enemies and plant pests should be considered to develop strategies related to IPM (Biondi *et al.,* 2012; Desneux *et al.,* 2006). In addition, evaluating the toxic effects of insecticides against beneficial insects is important and necessary in developing pest management (Desneux *et al.,* 2007; Golmohammadi & Hejazi, 2014). Sublethal concentrations can affect the pest community below the loss of concentration curve (Stark & Banks, 2003). It should also be noted that many studies have investigated the sublethal effects of different insecticides on the biological parameters of *C. carnea* (Garzón *et al.,* 2015; Maia *et al.,* 2016; Mohammadi *et al.,* 2009; Suárez-López *et al.,* 2020).

Thiacloprid and lambda c-halothrin pesticides cause a considerable reduction in the average lifespan of *Adalia bipunctata* (L.) population (Jalali *et al.,* 2009; Jansen, 2010). The available information showed that the survival of *C. carnea* adults was affected by thiamethoxam pesticide treatment (Gontijo *et al.,* 2014). Adults of *A. bipunctata* exposed to sulfoxafluor and deltamethrin) insecticides caused a significant reduction in survival and offspring production (Garzón *et al.,* 2015). Thiamethoxam is a neonicotinoid insecticide and its mode of action is by activating pest nicotinic acetylcholine receptors (nAChR) in an agonistic manner (Nauen *et al.,* 2003). Kumar & Santharam (1999) indicated that the use of imidacloprid caused a reduction in the lifespan of the *C. carnea*, which is in agreement with this study. Additionally, the study led by Asadi Eeidvand *et al.* (2015) observed that the use of endosulfan pesticide on *C. carnea* reduced the lifespan of common green lacewing adults, which is also in agreement with this study.

Analysis of the results obtained showed that endosulfan treatment had a significant effect on the total pre-oviposition period and led to a decrease in the oviposition period. Such findings are consistent with previous research that examined the effects of pyripoxyphene, permethrin, and fenvalerate on adult individuals infected with *C. carnea* (Grafton-Cardwell & Hoy, 1985; Medina *et al.,* 2003). The results of the current study showed a significant effect of endosulfan on the overall reproductive capacity and timing of egg laying in *C. carnea* females, which are in agreement with previous reports (Amarasekare & Shearer, 2013; Golmohammadi *et al.,* 2021; Maia *et al.,* 2016).

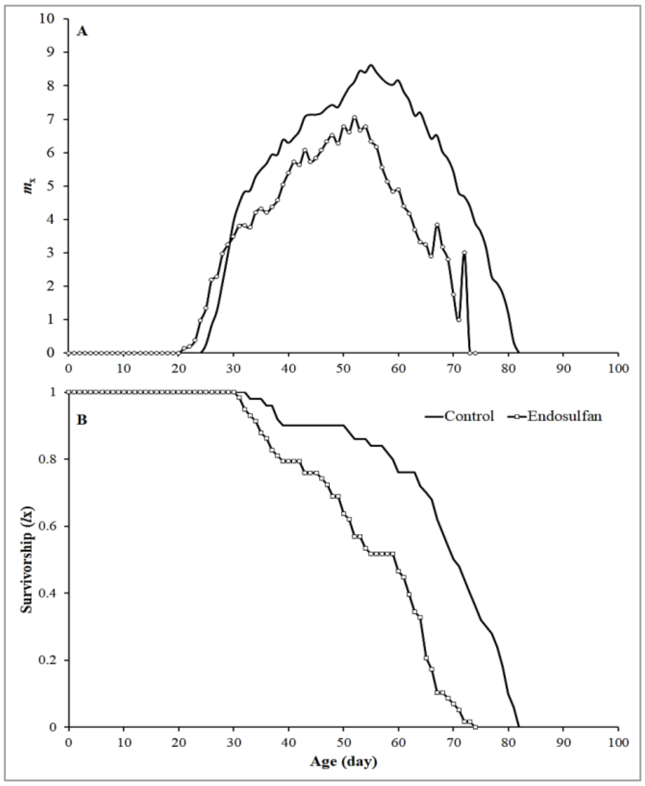

Figure 1. Age-specific fecundity (*mx*) (A) and Age-specific survivorship (l_x) (B) of the offspring of the treated and untreated *C. carnea* by sublethal concentration of Endosulfan.

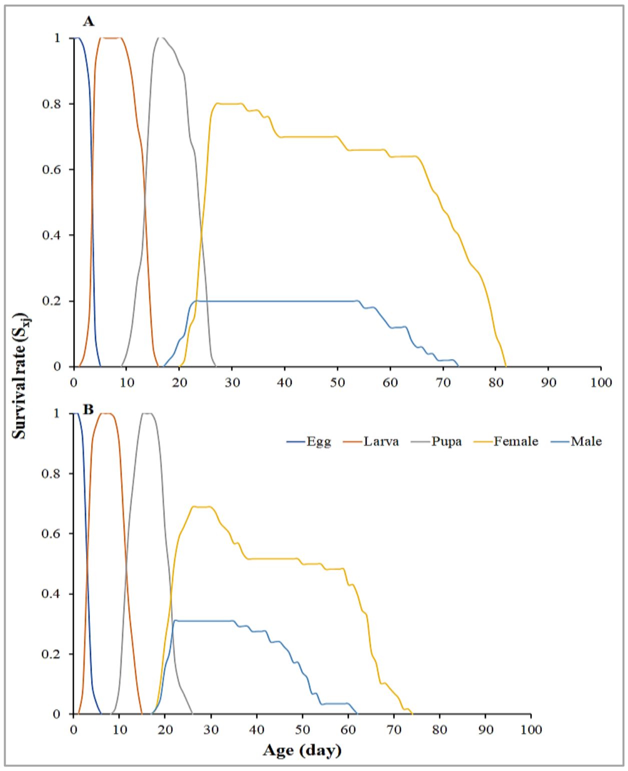

Figure 2. The Age-stage-specific survival rate (S_{xj}) of *C. carnea* untreated control (A) and sublethal concentration treatment of endosulfan (B).

The present study showed that the population parameters (specifically R0 and GRR) of *C. carnea* were significantly reduced when exposed to sublethal concentrations of endosulfan at LC_{30}, compared to the control group, which is in agreement with a previous report (Rugno *et al.,* 2019; Shakoorzadeh *et al.,* 2013). It can be concluded from this study that the use of sub-lethal concentration (LC_{30}) of endosulfan has minimal adverse effects on various biological parameters of *C. carnea*, including age, gross reproductive capacity and population dynamics such as net reproductive rate (R0), and gross reproductive rate (GRR). The average generation time (T), the main parameters that affect the growth rate of future generations. This study suggests that the common green lacewing can be used in the biological control of the flour moth *Ephestia kuehniella* in Iraq. If chemical control is still needed, it is recommended to use endosulfan at sub-lethal concentration. To confirm the laboratory results, it is also necessary to test the lethal and sub-lethal effects of endosulfan on common green lacewing in dry and semi-dry environments.

الملخص

السندي، إياد، سيناء مسلم الزرفي، سروة كريم حمد، أكرم محمد، علي كريم ومحمد شهيد. 2025. المعايير الديموغرافية للمفترس *Chrysoperla carnea* وتأثير التركيز شبه المميت للمبيد إندوسلفان في جدول حياة الإناث والذكور. مجلة وقاية النبات العربية، 43(2): 171–177. https://doi.org/10.22268/AJPP-001312

هدفت هذه الدراسة إلى معرفة التأثيرات غير المميتة (LC_{30}) للمبيد endosulfan على حشرات بالغات أسد المنّ الأخضر (*Chrysoperla carnea*) كعدو طبيعي فعّال ضدّ عثّة الدقيق (*Ephestia kuehniella* Zell) (Lepidoptera: Pyralidae) تحت ظروف المختبر من درجة حرارة 25±2°س، رطوبة نسبية 60±5% وفترة ضوئية 16:8 ساعة (ضوء: ظلام)، في غرفة النمو. أظهرت النتائج التي تمّ الحصول عليها انخفاضاً ملحوظاً في تركيز الجرعة غير المميتة LC_{30} للمبيد endosulfan خلال مدّة الحياة الحيوية لكلا جنسي (الذكور والإناث) الحشرة *C. carnea* مقارنةً بمعاملة الشاهد. تحقق أعلى معدل خصوبة في معاملة المبيد، وبلغ 203.28 ذرية/أنثى مقارنة بـ 316.31 ذرية/أنثى في معاملة المقارنة. وكان صافي معدل التكاثر (R0) للإناث المعاملة بالمبيد 140.18 ذرية/فرد/جيل، وهو أقل بكثير من معدل الإناث في معاملة الشاهد (253.04 ذرية/فرد/جيل). وتراوح متوسط مدّة الجيل الواحد (T) من 43.12 يوماً في معاملة الشاهد إلى 38.70 يوماً في معاملة المبيد بتركيز LC_{30}. أظهرت النتائج المتحصّل عليها أن لاستخدام التركيز شبه المميت للمبيد endosulfan أثر في بعض المعايير الحيوية للمفترس أسد المنّ الأخضر (*C. carnea*)، وهي معلومات مفيدة يجب أخذها في الاعتبار عند تصميم برامج الإدارة المتكاملة لفراشة الدقيق.

كلمات مفتاحية: معايير ديناميكية، Chrysopidae، جدول الحياة، تركيز شبه مميت.

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