

## Toxic effects of pesticides on the green lacewing, *Chrysoperla zastrowi sillemi* (Esben-Peterson) (Neuroptera, Chrysopidae)

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**ABSTRACT:** The study evaluated the toxic effects of quinalphos 25% EC, deltamethrin 2.8% EC, bifenthrin 8% SC, thiamethoxam 25% WG, thiacloprid 21.7% SC, thiamethoxam 12.6% + $\lambda$ -cyhalothrin 9.5% SC, propargite 57% EC, hexythiazox 5.45% EC, fenpyroximate 5% EC, and spiromesifen 22.9% SC, on various life stages of *Chrysoperla zastrowi sillemi* (Esben-Petersen) under laboratory conditions, including eggs, larvae (1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> instars) and adults. The results showed that quinalphos, deltamethrin and spiromesifen had significantly high ovicidal activity percentages of 56, 43.3 and 42.7 respectively, on *C. z. sillemi* eggs. The toxicity of the pesticides on *C. z. sillemi* larvae gradually increased over time after application and decreased with the increasing life stage of the larvae. Quinalphos and deltamethrin exhibited 100 per cent mortality across all larval stages of *C. z. sillemi*. Similarly, quinalphos and deltamethrin caused 100 per cent adult mortality after 24 hours of application, followed by thiamethoxam +  $\lambda$ -cyhalothrin and thiacloprid, (which showed 92 and 60% mortality, respectively, after 96 hours). However, pesticides such as bifenthrin, thiamethoxam, hexythiazox, fenpyroximate, and propargite did not exhibit significant acute toxicity on eggs, larvae, and adults of *C. z. sillemi*. Furthermore, the pesticide-treated adults were evaluated to determine sub-lethal toxicity effects on the pre-oviposition period, post-oviposition period, fecundity, fertility, adult emergence, and adult longevity. The findings indicated that thiamethoxam +  $\lambda$ -cyhalothrin, spiromesifen, thiacloprid, and propargite-treated adults experienced reduced longevity, fecundity and fertility. © 2025 Association for Advancement of Entomology

**KEY WORDS:** Acute toxicity, sub-lethal toxicity, reduced longevity, fertility, fecundity

### INTRODUCTION

Common lacewings belong to the order Neuroptera, consisting of soft-bodied insects with biting mouthparts and two pairs of similar membranous wings. Lacewings have a long history of biological control and are naturally occurring in all cropping

systems throughout the year. They play a vital role as bio-control agents against various crop pests (Pappas *et al.*, 2011). Lacewing larvae are predators, while adults feed on pollen and nectar (de Oliveira *et al.*, 2016). The *Chrysoperla carnea* group comprises about 20 very similar-looking species of green lacewings. Among them,

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*Chrysoperla zastrowi sillemi*, a sub species of *Chrysoperla* is the most widely distributed lacewing species on Earth (Henry *et al.*, 2013). *C. z. sillemi*, extends its range across central and northern Africa, the Middle East, western Asia, and the Indian subcontinent (Henry *et al.*, 2010). *C. z. sillemi* is an important natural predator of various soft-bodied insects such as aphids, coccids, mealybugs, thrips, psyllids, whiteflies, and eggs and larvae of many lepidopteran pests and mites occurring on various crops (Senior and McEwen, 2001).

Naturally, *C. z. sillemi* is a voracious predator against red spider mites (RSM), *Oligonychus coffeae* (Acari, Tetranychidae), and tea thrips, *Scirtothrips bispinosus* (Thysanoptera, Thripidae) in the South Indian tea ecosystem. In order to keep pest populations below the economic threshold level (ETL), planters have traditionally relied on conventional methods, utilizing synthetic pesticides approved by the Tea Board of India under the Plant Protection Code (PPC v.16, February 2024) (<https://www.teaboard.gov.in/TEABOARDPAGE/ODY=>). Intensive pesticide use has adverse effects, including non-specificity, the development of insecticide resistance in pests, accumulation and persistence of pesticide compounds in the environment, and non-target effects on beneficial insects. The use of synthetic pesticides also negatively affects beneficial insects in the agroecosystem (Ono *et al.*, 2017). The lethal and sub-lethal impacts of pesticides on natural enemies must be evaluated for a better understanding. Sub-lethal effects, which do not kill insects but cause small changes affecting development and reproduction, must be considered, as they impact the demographic parameters of insects (Desneux *et al.*, 2006). To gain a better understanding of the toxic effects of pesticides on *C. z. sillemi*, conducted an evaluation of ten approved and commonly used pesticides on various life stages of *C. z. sillemi* including eggs, larvae (1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> instars), pupae and adults under laboratory conditions.

## MATERIALS AND METHODS

**Experimental conditions:** The experiments were

conducted at the Division of Entomology, UPASI TRF Tea Research Institute (10°16'09.6" N: 76°58'02.6" E), Valparai, Tamil Nadu, India. All experiments took place in a controlled environment with conditions set at 25±2°C, 75±5 per cent relative humidity and a photoperiod of 16:8 (Light: Dark).

**Mass rearing of the study insect:** Newly hatched *C. z. sillemi* larvae were transferred into a plastic container (15cm × 10cm) and fed with the eggs of *Corcyra cephalonica* (Lepidoptera, Pyralidae) until they pupated. The pupae were then carefully transferred to another plastic container (25cm × 10cm) and monitored until they emerged as adults. Once the adults emerged, they were separated and transferred to new plastic containers (25cm × 10cm). The adults were fed an artificial diet containing ground tea pollen and a 30 per cent sugar solution on cotton wool. For the toxicity study, each life stage, including eggs, 3<sup>rd</sup> instar larvae, pupae, and adults, was randomly obtained from the mass-rearing unit.

**Pesticides:** The study focused on commonly used pesticides in tea plantations. The selected pesticides were quinalphos (25% EC), thiamethoxam (25% WG), deltamethrin (2.8% EC), thiamethoxam (12.6%) + λ-cyhalothrin (9.5% SC), propargite (57% EC), hexythiazox (5.45% EC), fenpyroximate (5% EC), spiromesifen and bifenthrin (8% SC). These pesticides were directly purchased from the certified pesticide vendor.

**Effect of pesticides on eggs of *C. z. sillemi*:** The required number of *C. z. sillemi* eggs (<12 hours old) were randomly collected from the laboratory mass-rearing unit and exposed to the selected pesticides by spraying using a Potter tower adjusted to a pressure of 15 lb.pol"2. Subsequently, the treated eggs were individually transferred to Eppendorf tubes (2.0 ml) with small holes made on the cap for aeration. These Eppendorf tubes were then kept under the previously described conditions. The bioassay was conducted in a completely randomized design (CRD), consisting of eleven treatments with three replications, each treatment comprising fifty eggs. Larvae from treated eggs were fed with *C. cephalonica* eggs. The incubation period, larval hatching percentage, 1<sup>st</sup> instar larvae

mortality, and 1<sup>st</sup> instar duration were observed and recorded.

**Effect of pesticides on larvae of *C. z. sillemi*:**

The required number of 1<sup>st</sup>, 2<sup>nd</sup>, and 3<sup>rd</sup> instar larvae (<12 hours old) were randomly collected from the mass-rearing unit and exposed to the pesticides as previously described. The treated larvae were individually transferred to Eppendorf tubes (2.0 ml) and kept under the same conditions. The bioassay was conducted in a completely randomized design (CRD), consisting of eleven treatments with three replications, each treatment containing forty larvae. The larval mortality rate, third instar duration, number of larvae reaching the pupal stage, total pupal period, and number of emerged adults were observed and recorded, with larval mortality being recorded every 24 hours up to 96 hours.

**Effect of pesticides on pupae of *C. z. sillemi*:**

The required number of pupae (<12 hours old) were randomly collected from the laboratory mass-rearing unit and exposed to the pesticides as described earlier. Following the spraying, the treated pupae were individually placed in glass vials (10 cm height × 2cm diameter) covered with cotton cloth. The bioassay was carried out in a completely randomized design (CRD), with eleven treatments and three replications. Each treatment included forty pupae. Pupicidal percentage, pupal duration, and adult emergence percentage were monitored and recorded throughout the study.

**Effect of pesticides on adults of *C. z. sillemi*:**

The necessary number of newly hatched adults (<12 hours old) were randomly selected from the laboratory mass-rearing unit and exposed to the pesticides as described earlier. After spraying, couples were formed and introduced into plastic containers (25cm × 10cm) and fed accordingly. The bioassay was conducted in a completely randomized design with seven treatments and three replications, each treatment containing forty adults. Adult mortality was observed every 24 hours up to 96 hours. To assess adult reproductive characteristics, at least three pairs of insects were separately kept in plastic bottles and fed as previously described. The pre-oviposition period, post-oviposition period, fecundity, fertility, adult emergence, and adult

longevity were observed and recorded throughout the study.

**Statistical analysis:** All collected data were pooled and subjected to Analysis of Variance (ANOVA), with means separated by Duncan's Multiple Range Test (DMRT). All statistical analyses were performed using IBM SPSS v23.0 software.

## RESULTS AND DISCUSSION

**Pesticide toxicity on eggs of *C. z. sillemi*:**

Among the tested pesticides, quinalphos showed significantly higher ovicidal action (56%) followed by deltamethrin and spiromesifen (43.3%) and (42.7%) respectively, against *C. z. sillemi* eggs (Table 1). However, thiacloprid, propargite, thiamethoxam, hexythiazox, and fenpyroximate showed no harm to eggs, yielding results similar to the control. The egg incubation period and 1<sup>st</sup> instar larval duration were not significantly affected by any of the evaluated pesticides. Cumulative mortality at the end of the 1<sup>st</sup> instar larvae stage was significantly high in deltamethrin and quinalphos (62.5 and 61.5% respectively). Similarly, spiromesifen, thiamethoxam +  $\lambda$ -cyhalothrin, and thiacloprid also produced notable mortality in 1<sup>st</sup> instar larvae.

**Pesticide toxicity on larvae of *C. z. sillemi*:**

The evaluated pesticides caused significant mortality in the 1<sup>st</sup>, 2<sup>nd</sup> and third instars of *C. z. sillemi*. After 24 hours of applications, all pesticides showed lower mortality on all three instars, gradually increasing, with the highest observed after 96 hours of application. The 1<sup>st</sup> and 2<sup>nd</sup> instars were highly susceptible to the pesticides, quinalphos and deltamethrin, causing 100 per cent mortality even after 24 hours of application (Tables 2 and 3). Both pesticides were found to be more toxic to both instars. Additionally, thiamethoxam +  $\lambda$ -cyhalothrin also exhibited higher mortality (70 and 66.5% on the 1<sup>st</sup> and 2<sup>nd</sup> instars, respectively). Similarly, thiacloprid and spiromesifen also moderately affected both the 1<sup>st</sup> and 2<sup>nd</sup> instars of *C. z. sillemi*.

In the third instar, quinalphos and deltamethrin exhibited 100 per cent mortality after 48 and 72 hours of application, respectively followed by

**Table 1. Toxic effects of commonly used pesticides on the eggs of *C. z. sillemi***

| Treatments                  | Ovicidal % <sup>1</sup> | Incubation (hrs) | Hatching % <sup>2</sup>  | Larval period <sup>3</sup> (hours) | Accumulated mortality <sup>4</sup>   |
|-----------------------------|-------------------------|------------------|--------------------------|------------------------------------|--------------------------------------|
| Quinalphos                  | 56.0 ± 9.2 <sup>d</sup> | 100.8 ± 8.6      | 44.0 ± 5.29 <sup>a</sup> | 97.6 ± 13.2                        | 61.5 ± 6.4 <sup>d</sup>              |
| Deltamethrin                | 43.3 ± 6.1 <sup>c</sup> | 92.8 ± 6.9       | 56.7 ± 3.53 <sup>b</sup> | 93.6 ± 7.2                         | 62.5 ± 3.9 <sup>d</sup>              |
| Bifenthrin                  | 20.0 ± 5.3 <sup>b</sup> | 96.0 ± 8.3       | 80.0 ± 3.06 <sup>c</sup> | 99.2 ± 8.4                         | 10.1 ± 3.1 <sup>a</sup>              |
| Thiacloprid                 | 4.0 ± 5.3 <sup>a</sup>  | 91.2 ± 8.7       | 96.0 ± 3.51 <sup>d</sup> | 96.8 ± 4.9                         | 32.8 ± 6.8 <sup>b</sup>              |
| Thiamethoxam                | 8.6 ± 6.4 <sup>a</sup>  | 96.8 ± 2.8       | 91.3 ± 3.71 <sup>d</sup> | 99.2 ± 7.7                         | 13.1 ± 1.4 <sup>a</sup>              |
| Thiamethoxam+ λ-cyhalothrin | 8.7 ± 6.4 <sup>a</sup>  | 94.4 ± 8.4       | 91.3 ± 3.6 <sup>d</sup>  | 94.4 ± 1.4                         | 35.9 ± 2.4 <sup>b</sup> <sup>c</sup> |
| Propargite                  | 6.0 ± 2.0 <sup>a</sup>  | 93.6 ± 6.3       | 94.0 ± 1.15 <sup>d</sup> | 96.8 ± 3.7                         | 11.3 ± 1.1 <sup>a</sup>              |
| Hexythiazox                 | 8.0 ± 6.0 <sup>a</sup>  | 91.2 ± 4.8       | 92.0 ± 3.46 <sup>d</sup> | 96.0 ± 7.2                         | 9.5 ± 3.5 <sup>a</sup>               |
| Fenpyroximate               | 2.7 ± 3.1 <sup>a</sup>  | 92.0 ± 9.6       | 97.3 ± 1.76 <sup>d</sup> | 95.2 ± 2.8                         | 8.2 ± 2.1 <sup>a</sup>               |
| Spiromesifen                | 42.7 ± 5.0 <sup>c</sup> | 98.4 ± 2.4       | 58.3 ± 2.91 <sup>b</sup> | 96.8 ± 3.7                         | 42.7 ± 7.7 <sup>c</sup>              |
| Untreated control           | 2.7 ± 3.1 <sup>a</sup>  | 93.6 ± 6.3       | 97.3 ± 1.76 <sup>d</sup> | 92.8 ± 2.8                         | 9.6 ± 3.3 <sup>a</sup>               |

<sup>1</sup>Mean ovicidal percent at the end of the incubation period; <sup>2</sup>Mean larval hatching percent from the treated eggs; <sup>3</sup>larval period of 1<sup>st</sup> instar; <sup>4</sup>Mean mortality at the end of the 1<sup>st</sup> instar; Mean±SD (n=3) followed by the same alphabet in the vertical column are not significantly different at 5% level ( $p < 0.05$ ) as per DMRT.

**Table 2. Toxic effects of commonly used pesticides on 1<sup>st</sup> instar larvae of *C. z. sillemi***

| Treatments                  | Mortality %              |                          |                          |                          | Developmental duration <sup>1</sup> (in hours) |
|-----------------------------|--------------------------|--------------------------|--------------------------|--------------------------|------------------------------------------------|
|                             | 24 HAT                   | 48 HAT                   | 72 HAT                   | 96 HAT                   |                                                |
| Quinalphos                  | 100 ± 0 <sup>j</sup>     | 100 ± 0 <sup>i</sup>     | 100 ± 0 <sup>j</sup>     | 100 ± 0 <sup>h</sup>     | NA                                             |
| Deltamethrin                | 100 ± 0 <sup>j</sup>     | 100 ± 0 <sup>i</sup>     | 100 ± 0 <sup>j</sup>     | 100 ± 0 <sup>h</sup>     | NA                                             |
| Bifenthrin                  | 8.8 ± 0.87 <sup>e</sup>  | 11.5 ± 1.05 <sup>d</sup> | 16.6 ± 0.78 <sup>e</sup> | 24.7 ± 0.78 <sup>d</sup> | 104.5 ± 0.96 <sup>bc</sup>                     |
| Thiacloprid                 | 38.7 ± 0.66 <sup>h</sup> | 42.5 ± 0.66 <sup>g</sup> | 44.4 ± 0.90 <sup>h</sup> | 54.7 ± 0.81 <sup>f</sup> | 107.3 ± 0.90 <sup>d</sup>                      |
| Thiamethoxam                | 16.7 ± 0.06 <sup>f</sup> | 20.6 ± 1.11 <sup>e</sup> | 21.9 ± 1.62 <sup>f</sup> | 24.4 ± 1.01 <sup>d</sup> | 105.4 ± 0.85 <sup>c</sup>                      |
| Thiamethoxam+ λ-cyhalothrin | 55.9 ± 0.5 <sup>i</sup>  | 60.1 ± 1.48 <sup>h</sup> | 63.8 ± 1.48 <sup>i</sup> | 70.0 ± 0.40 <sup>g</sup> | 109.8 ± 0.35 <sup>e</sup>                      |
| Propargite                  | 5.2 ± 0.32 <sup>d</sup>  | 7.6 ± 0.40 <sup>c</sup>  | 9.0 ± 0.44 <sup>d</sup>  | 9.9 ± 0.55 <sup>c</sup>  | 103.7 ± 0.44 <sup>ab</sup>                     |
| Hexythiazox                 | 3.3 ± 0.38 <sup>c</sup>  | 5.2 ± 0.32 <sup>b</sup>  | 7.6 ± 0.35 <sup>c</sup>  | 8.5 ± 0.45 <sup>b</sup>  | 103.2 ± 0.96 <sup>a</sup>                      |
| Fenpyroximate               | 2.4 ± 0.40 <sup>b</sup>  | 4.1 ± 0.15 <sup>b</sup>  | 5.5 ± 0.21 <sup>b</sup>  | 7.2 ± 0.40 <sup>b</sup>  | 102.9 ± 0.38 <sup>a</sup>                      |
| Spiromesifen                | 32.3 ± 0.79 <sup>g</sup> | 36.6 ± 0.92 <sup>f</sup> | 42.7 ± 1.00 <sup>g</sup> | 51.4 ± 0.96 <sup>e</sup> | 104.8 ± 0.30 <sup>bc</sup>                     |
| Untreated control           | 0 ± 0 <sup>a</sup>       | 0 ± 0 <sup>a</sup>       | 0 ± 0 <sup>a</sup>       | 0 ± 0 <sup>a</sup>       | 104.1 ± 0.50 <sup>ab</sup>                     |

<sup>1</sup>Developmental duration of 1<sup>st</sup> instar larvae; Mean ±SD (n=3) followed by the same letter in the column is not significant at the 5% level ( $p < 0.05$ ) as per DMRT; HAT = Hours after treatment; NA = Not Applicable.

thiamethoxam + lambda-cyhalothrin and thiacloprid (61.7 and 29.6%, respectively). However, insecticides including propargite, hexythiazox, fenpyroximate and bifenthrin were found to be less toxic to the 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> instars of *C. z. sillemi* (Table 4).

**Pesticide toxicity on pupae of *C. z. sillemi*:** The evaluated pesticides were found to be non-harmful to the pupae of *C. z. sillemi*. Among the pesticides, quinalphos alone caused a maximum of 5 per cent of pupicidal activity, which is not a promising result, and other pesticides also showed nil mortality on pupae of *C. z. sillemi*.

**Pesticide toxicity on adults of *C. z. sillemi*:** In adults, the pesticides quinalphos and deltamethrin exhibited 100 per cent mortality after 24 hours of application. This was followed by thiamethoxam + lambda-cyhalothrin and thiacloprid, which showed 92.0 and 60 per cent mortality, respectively, after 96 hours of application. Other treatments such as thiamethoxam and fenpyroximate, also showed

approximately 30.6 and 26.6 per cent mortality, respectively after 96 hours of applications. However, pesticides like bifenthrin, propargite, hexythiazox and spiromesifen were less toxic to the adults (Table 5).

Sublethal effects on the reproductive parameters of pesticide-treated adults were assessed. No adults survived after the application of quinalphos and deltamethrin, so both treatments were removed from the biological parameters study. The pre-oviposition and post-oviposition periods of treated females were similar to those of untreated females. Male and female longevity ranged from 23 to 36 days and 31 to 46 days, respectively (Table 6). The shortest male and female longevity was observed in thiacloprid and spiromesifen, with 23.6 and 31.3 days, respectively. The pesticides evaluated had a significant impact on male longevity. Similarly, spiromesifen, thiamethoxam +  $\lambda$ -cyhalothrin, thiacloprid, and propargite-treated females showed lower longevity compared to others. Fecundity among pesticide-treated females ranged from 268.3

**Table 3. Toxicity of commonly used pesticides against the 2<sup>nd</sup> instar larvae of *C. z. sillemi***

| Treatments                              | Mortality %                  |                              |                              |                              | Developmental duration <sup>1</sup> (in hours) |
|-----------------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------------------------|
|                                         | 24 HAT                       | 48 HAT                       | 72 HAT                       | 96 HAT                       |                                                |
| Quinalphos                              | 100 $\pm$ 0 <sup>h</sup>     | 100 $\pm$ 0 <sup>i</sup>     | 100 $\pm$ 0 <sup>i</sup>     | 100 $\pm$ 0 <sup>h</sup>     | NA                                             |
| Deltamethrin                            | 100 $\pm$ 0 <sup>h</sup>     | 100 $\pm$ 0 <sup>i</sup>     | 100 $\pm$ 0 <sup>i</sup>     | 100 $\pm$ 0 <sup>h</sup>     | NA                                             |
| Bifenthrin                              | 3.2 $\pm$ 0.26 <sup>c</sup>  | 6.4 $\pm$ 0.40 <sup>d</sup>  | 8.3 $\pm$ 0.26 <sup>d</sup>  | 10.9 $\pm$ 0.40 <sup>c</sup> | 112.8 $\pm$ 0.30 <sup>b</sup>                  |
| Thiacloprid                             | 25.6 $\pm$ 1.00 <sup>f</sup> | 31.1 $\pm$ 0.55 <sup>g</sup> | 33.4 $\pm$ 0.66 <sup>g</sup> | 41.0 $\pm$ 0.49 <sup>f</sup> | 114.7 $\pm$ 0.46 <sup>c</sup>                  |
| Thiamethoxam                            | 8.1 $\pm$ 0.35 <sup>d</sup>  | 11.0 $\pm$ 0.36 <sup>e</sup> | 12.7 $\pm$ 0.67 <sup>e</sup> | 16.1 $\pm$ 1.18 <sup>d</sup> | 111.9 $\pm$ 0.65 <sup>ab</sup>                 |
| Thiamethoxam+<br>$\lambda$ -cyhalothrin | 50.9 $\pm$ 0.64 <sup>g</sup> | 55.6 $\pm$ 0.92 <sup>h</sup> | 63.2 $\pm$ 0.44 <sup>h</sup> | 66.5 $\pm$ 1.02 <sup>g</sup> | 117.5 $\pm$ 0.52 <sup>e</sup>                  |
| Propargite                              | 2.8 $\pm$ 0.67 <sup>c</sup>  | 7.1 $\pm$ 0.98 <sup>d</sup>  | 8.2 $\pm$ 0.51 <sup>d</sup>  | 9.9 $\pm$ 0.21 <sup>c</sup>  | 112.7 $\pm$ 0.64 <sup>b</sup>                  |
| Hexythiazox                             | 1.3 $\pm$ 0.31 <sup>b</sup>  | 3.3 $\pm$ 0.31 <sup>b</sup>  | 5.8 $\pm$ 0.56 <sup>b</sup>  | 8.7 $\pm$ 0.25 <sup>b</sup>  | 111.2 $\pm$ 0.45 <sup>a</sup>                  |
| Fenpyroximate                           | 2.2 $\pm$ 0.15 <sup>c</sup>  | 5.5 $\pm$ 0.32 <sup>c</sup>  | 7.2 $\pm$ 0.26 <sup>c</sup>  | 7.8 $\pm$ 0.40 <sup>b</sup>  | 112.1 $\pm$ 0.49 <sup>ab</sup>                 |
| Spiromesifen                            | 22.4 $\pm$ 1.11 <sup>e</sup> | 26.2 $\pm$ 0.57 <sup>f</sup> | 31.0 $\pm$ 0.42 <sup>f</sup> | 34.5 $\pm$ 1.10 <sup>e</sup> | 115.9 $\pm$ 0.67 <sup>d</sup>                  |
| Untreated control                       | 0 $\pm$ 0 <sup>a</sup>       | 0 $\pm$ 0 <sup>a</sup>       | 0 $\pm$ 0 <sup>a</sup>       | 0 $\pm$ 0 <sup>a</sup>       | 114.0 $\pm$ 0.50 <sup>c</sup>                  |

<sup>1</sup>Developmental duration of 2<sup>nd</sup> instar larvae; Mean  $\pm$  SD ( $n=3$ ) followed by the same letter in the column is not significant at the 5% level ( $p<0.05$ ) as per DMRT; HAT = Hours after treatment; NA = Not Applicable.

**Table 4.** Toxicity of commonly used pesticides against the third instar larvae of *C. z. sillemi*

| Treatments                   | Mortality %              |                          |                          |                           | Developmental duration <sup>1</sup> (in hours) |
|------------------------------|--------------------------|--------------------------|--------------------------|---------------------------|------------------------------------------------|
|                              | 24 HAT                   | 48 HAT                   | 72 HAT                   | 96 HAT                    |                                                |
| Quinalphos                   | 85.8 ± 0.46 <sup>d</sup> | 100 ± 0 <sup>g</sup>     | 100 ± 0 <sup>i</sup>     | 100 ± 0 <sup>g</sup>      | NA                                             |
| Deltamethrin                 | 86.6 ± 0.90 <sup>d</sup> | 95.8 ± 3.82 <sup>f</sup> | 100 ± 0 <sup>i</sup>     | 100 ± 0 <sup>g</sup>      | NA                                             |
| Bifenthrin                   | 2.3 ± 0.31 <sup>a</sup>  | 3.3 ± 0.21 <sup>b</sup>  | 5.3 ± 0.15 <sup>e</sup>  | 8.1 ± 0.4 <sup>c</sup>    | 118.4 ± 1.04 <sup>ns</sup>                     |
| Thiacloprid                  | 13.2 ± 0.4 <sup>b</sup>  | 15.4 ± 1.11 <sup>d</sup> | 22.3 ± 0.92 <sup>g</sup> | 29.6 ± 0.05 <sup>e</sup>  | 120.8 ± 0.99 <sup>ns</sup>                     |
| Thiamethoxam                 | 0.6 ± 0.1 <sup>a</sup>   | 2.2 ± 0.49 <sup>ab</sup> | 3.8 ± 0.36 <sup>d</sup>  | 6.8 ± 0.3 <sup>bc</sup>   | 118.4 ± 0.66 <sup>ns</sup>                     |
| Thiamethoxam + λ-cyhalothrin | 43.0 ± 0.55 <sup>c</sup> | 46.9 ± 0.53 <sup>e</sup> | 55.4 ± 0.91 <sup>h</sup> | 61.7 ± 0.77 <sup>f</sup>  | 117.6 ± 1.21 <sup>ns</sup>                     |
| Propargite                   | 1.1 ± 0.15 <sup>a</sup>  | 1.4 ± 0.38 <sup>ab</sup> | 2.9 ± 0.61 <sup>cd</sup> | 5.8 ± 0.62 <sup>bc</sup>  | 116.8 ± 0.49 <sup>ns</sup>                     |
| Hexythiazox                  | 1.0 ± 0.25 <sup>a</sup>  | 1.7 ± 0.1 <sup>ab</sup>  | 2.5 ± 0.36 <sup>c</sup>  | 3.2 ± 0.57 <sup>ab</sup>  | 117.6 ± 0.69 <sup>ns</sup>                     |
| Fenpyroximate                | 0 ± 0 <sup>a</sup>       | 0.5 ± 0.06 <sup>b</sup>  | 1.5 ± 0.1 <sup>b</sup>   | 4.2 ± 0.29 <sup>abc</sup> | 119.2 ± 0.57 <sup>ns</sup>                     |
| Spiromesifen                 | 8.5 ± 0.45 <sup>b</sup>  | 9.9 ± 0.61 <sup>c</sup>  | 12.0 ± 1.04 <sup>f</sup> | 14.2 ± 0.71 <sup>d</sup>  | 117.6 ± 0.72 <sup>ns</sup>                     |
| Untreated control            | 0 ± 0 <sup>a</sup>       | 0 ± 0 <sup>a</sup>       | 0 ± 0 <sup>a</sup>       | 0 ± 0 <sup>a</sup>        | 117.6 ± 1.48 <sup>ns</sup>                     |

<sup>1</sup>Developmental duration of third instar larvae; Mean ± SD ( $n=3$ ) followed by the same letter in the column is not significant at the 5% level ( $p<0.05$ ) as per DMRT; HAT = Hours after treatment; NA = Not Applicable; ns = Not significant.

to 377.6. The maximum and minimum fecundity were observed in untreated females and thiacloprid-treated females, respectively. The treatments with hexythiazox, bifenthrin, thiamethoxam, and fenpyroximate-treated females showed fecundity rates similar to untreated females. In terms of fertility, untreated females and thiamethoxam-treated females had the highest fertility percentages at 90.9 and 83.7, respectively (Table 6). The lowest fertility percentage was observed in thiamethoxam + λ-cyhalothrin, spiromesifen, thiacloprid, and propargite-treated females. The adult emergence percentage of thiamethoxam and fenpyroximate-treated females was comparable to untreated females, while in other treatments, the adult emergence percentage was similar across the board.

Pesticides from various chemical groups and modes of action were tested for their toxic effects on *C. z. sillemi*. Among the evaluated pesticides, quinalphos, deltamethrin, spiromesifen, thiacloprid, and thiamethoxam + λ-cyhalothrin were found to

be extremely harmful to third instar larvae, adults, and eggs of *C. z. sillemi*, but harmless to the pupal stage. The same product used at the same dosage showed a range of effects from harmless to harmful, depending on the developmental stages of the natural enemy (Souza *et al.*, 2014). Certain synthetic pesticides cause acute toxicity to various life stages of Chrysopids. In addition to mortality, they can have sublethal physiological effects such as inhibition of development, decreased adult longevity, low immunity, reduced fecundity and fertility, and behavioural effects on mobility and predation rates. Similar observations have been reported in various Chrysopids, including *C. externa* (Desneux *et al.*, 2007), *C. johnsoni* (Amarasekare and Shearer, 2013), *C. carnea* (Garzon *et al.*, 2015), *Ceraeochrysa cubana* (Rugno *et al.*, 2018) and *C. sinica* (Shan *et al.*, 2020).

In the present study, quinalphos was found to be more toxic against larvae and adults of *C. z. sillemi*, with moderate toxicity observed on eggs. Chakraborty *et al.* (2011) reported that quinalphos

caused 89 per cent mortality in eggs and 70 per cent mortality in larvae of *C. z. sillemi*. Similar findings were reported by Darwish and Farghal (1990) and Srinivasan and Babu (2000) in *C. carnea*. Additionally, the eggs, larvae, and adults of *C. z. sillemi* were highly susceptible to deltamethrin and thiamethoxam +  $\lambda$ -cyhalothrin, which are synthetic pyrethroids known for their insecticidal properties. The residual toxicity of deltamethrin was also observed in *C. carnea* by Bigler and Waldburger (1994) and Giolo *et al.* (2009). Larval stages of predators may be more susceptible to pesticides than adults due to their contact with treated surface, as noted by Medina *et al.* 2004. Rugno *et al.* (2018) found that thiamethoxam +  $\lambda$ -cyhalothrin significantly reduced larval survival rates in *Ceraeochrysa cubana* without affecting the total developmental time of surviving larvae.

Among the neonicotinoids tested, thiamethoxam was mildly harmful to adults but harmless to eggs, larvae, and pupae of *C. z. sillemi*. Rugno *et al.*

(2018) reported extreme lethal and sublethal toxicity of thiamethoxam in *C. cubana*, highlighting potential side effects on lacewings that feed on floral nectar. Spiromesifen was found to be extremely harmful to all stages of *C. z. sillemi* except the pupal stage. Limited studies exist on the toxic effects of spiromesifen on green lacewings, but it has been shown to have lethal and sub-lethal effects on other natural enemies, such as *Neoseiulus californicus* (Mollaloo *et al.*, 2016), *Eretmocerus mundus*, *Orius laevigatus* (Bielza *et al.*, 2009), *Serangium parcesetosum*, and *Oxyopes javanus* (Nazli and Butt, 2020).

Propargite, hexythiazox, and fenpyroximate did not show acute lethal effects on *C. z. sillemi*, with propargite exhibiting sub-lethal toxicity in adults, propargite treated females showed low fertility (67.8%) and low adult emergence (69.9%). Rezaei *et al.* (2006) found that propargite was slightly harmful (Class 2) to *C. carnea* according to the International Organization for Biological Control (IOBC) system, reducing fecundity and survival

**Table 5. Acute toxicity of commonly used pesticides on adults of *C. z. sillemi***

| Chemical                                | Adult mortality %             |                               |                               |                               |
|-----------------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
|                                         | 24 HAT                        | 48 HAT                        | 72 HAT                        | 96 HAT                        |
| Quinalphos                              | 100 $\pm$ 0 <sup>e</sup>      | 100 $\pm$ 0 <sup>g</sup>      | 100 $\pm$ 0 <sup>g</sup>      | 100 $\pm$ 0 <sup>i</sup>      |
| Deltamethrin                            | 100 $\pm$ 0 <sup>e</sup>      | 100 $\pm$ 0 <sup>g</sup>      | 100 $\pm$ 0 <sup>g</sup>      | 100 $\pm$ 0 <sup>i</sup>      |
| Bifenthrin                              | 4 $\pm$ 4 <sup>a</sup>        | 8 $\pm$ 4 <sup>bc</sup>       | 8 $\pm$ 4 <sup>c</sup>        | 9.33 $\pm$ 2.31 <sup>c</sup>  |
| Thiacloprid                             | 41.33 $\pm$ 6.11 <sup>c</sup> | 45.33 $\pm$ 4.62 <sup>e</sup> | 52 $\pm$ 4 <sup>e</sup>       | 60 $\pm$ 4 <sup>g</sup>       |
| Thiamethoxam                            | 16 $\pm$ 4 <sup>b</sup>       | 20 $\pm$ 4 <sup>d</sup>       | 24 $\pm$ 4 <sup>d</sup>       | 30.67 $\pm$ 2.31 <sup>f</sup> |
| Thiamethoxam+<br>$\lambda$ -cyhalothrin | 80 $\pm$ 8 <sup>d</sup>       | 84 $\pm$ 4 <sup>f</sup>       | 90.67 $\pm$ 4.62 <sup>f</sup> | 92 $\pm$ 4 <sup>h</sup>       |
| Propargite                              | 0 $\pm$ 0 <sup>a</sup>        | 0 $\pm$ 0 <sup>a</sup>        | 1.33 $\pm$ 2.31 <sup>ab</sup> | 4 $\pm$ 0 <sup>b</sup>        |
| Hexythiazox                             | 4 $\pm$ 4 <sup>a</sup>        | 5.33 $\pm$ 2.3 <sup>ab</sup>  | 6.67 $\pm$ 2.31 <sup>bc</sup> | 9.33 $\pm$ 0 <sup>c</sup>     |
| Fenpyroximate                           | 12 $\pm$ 4 <sup>b</sup>       | 22.67 $\pm$ 6.11 <sup>d</sup> | 24 $\pm$ 4 <sup>d</sup>       | 26.67 $\pm$ 2.31 <sup>e</sup> |
| Spiromesifen                            | 12 $\pm$ 4 <sup>b</sup>       | 12 $\pm$ 4 <sup>c</sup>       | 12 $\pm$ 4 <sup>c</sup>       | 16 $\pm$ 0 <sup>d</sup>       |
| Untreated control                       | 0 $\pm$ 0 <sup>a</sup>        | 0 $\pm$ 0 <sup>a</sup>        | 0 $\pm$ 0 <sup>a</sup>        | 0 $\pm$ 0 <sup>a</sup>        |

HAT=Hours after treatment; Mean $\pm$ SD ( $n=3$ ) followed by the same alphabet in the vertical column are not significantly different at 5% level ( $p<0.05$ ) as per DMRT.

**Table 6. Sub lethal toxicity effects of commonly used pesticides on adults of *C. z. sillemi***

| Treatments                     | Pre-Oviposition period | Post-Oviposition period | Male longevity         | Female longevity       | Fecundity               | Fertility % <sup>1</sup> | Adult emerging % <sup>2</sup> |
|--------------------------------|------------------------|-------------------------|------------------------|------------------------|-------------------------|--------------------------|-------------------------------|
| Bifenthrin                     | 3.5±0.1                | 2.8±0.4                 | 36.6±2.3 <sup>d</sup>  | 42.7±3.5 <sup>cd</sup> | 355.0±13.6 <sup>b</sup> | 79.9±12.5 <sup>c</sup>   | 74.2±9.8 <sup>a</sup>         |
| Thiacloprid                    | 3.3±0.2                | 2.7±0.3                 | 23.6±2.5 <sup>a</sup>  | 33.6±2.1 <sup>ab</sup> | 268.3±19.0 <sup>a</sup> | 67.5±1.4 <sup>ab</sup>   | 64.3±4.4 <sup>a</sup>         |
| Thiamethoxam                   | 3.7±0.2                | 2.9±0.2                 | 35.0±3.6 <sup>cd</sup> | 44.0±4.4 <sup>cd</sup> | 358.7±27.1 <sup>b</sup> | 83.7±2.8 <sup>cd</sup>   | 91.2±3.2 <sup>b</sup>         |
| Thiamethoxam+<br>λ-cyhalothrin | 3.9±0.3                | 2.0±0.9                 | 30.3±5.1 <sup>bc</sup> | 31.6±3.1 <sup>a</sup>  | 274.7±10.7 <sup>a</sup> | 64.7±2.2 <sup>a</sup>    | 71.1±0.9 <sup>a</sup>         |
| Propargite                     | 3.4±0.2                | 2.6±0.3                 | 36.3±2.5 <sup>d</sup>  | 39.7±3.2 <sup>bc</sup> | 286.3±20.7 <sup>a</sup> | 67.8±5.7 <sup>ab</sup>   | 69.9±0.3 <sup>a</sup>         |
| Hexythiazox                    | 3.3±0.3                | 2.8±0.3                 | 34.0±1.0 <sup>cd</sup> | 45.6±5.5 <sup>cd</sup> | 353.3±25.3 <sup>b</sup> | 79.3±4.7 <sup>c</sup>    | 74.5±9.7 <sup>a</sup>         |
| Fenpyroximate                  | 3.4±0.3                | 2.5±0.6                 | 36.0±5.4 <sup>d</sup>  | 46.3±8.1 <sup>cd</sup> | 360.3±21.8 <sup>b</sup> | 78.3±6.8 <sup>bc</sup>   | 91.2±3.4 <sup>b</sup>         |
| Spiromesifen                   | 3.5±0.5                | 3.0±0.4                 | 28.7±2.5 <sup>ab</sup> | 31.3±1.5 <sup>a</sup>  | 269.3±07.6 <sup>a</sup> | 66.6±6.4 <sup>a</sup>    | 65.4±4.3 <sup>a</sup>         |
| Untreated control              | 3.5±0.1                | 2.7±0.5                 | 44.6±3.5 <sup>e</sup>  | 49.3±3.2 <sup>d</sup>  | 377.6±17.9 <sup>b</sup> | 90.9±4.1 <sup>d</sup>    | 90.6±3.7 <sup>b</sup>         |

<sup>1</sup>Mean fertility percent of pesticide treated females; <sup>2</sup>Mean adult emerging percent calculated from the fertility percent; Mean±SD (n=3) followed by the same alphabet in the vertical column are not significantly different at 5% level (p<0.05) as per DMRT.

rates. Abd El-Baset *et al.* (2023) stated that hexythiazox was harmless to 2<sup>nd</sup> instar larvae of *C. carnea*.

Pathan *et al.* (2010) observed higher intrinsic rates, fecundity, adult longevity, doubling time, and predatory potential in insecticide-resistant populations compared to laboratory-susceptible populations. Quinalphos, deltamethrin, spiromesifen, thiacloprid, and thiamethoxam + λ-cyhalothrin were found to cause acute toxicity to *C. z. sillemi*. In addition to acute toxicity, some pesticides produce sub-lethal effects that impact life table parameters. Further laboratory studies are needed to understand these sub-lethal effects. Field studies are also necessary to fully comprehend the selectivity of the tested pesticides on *C. z. sillemi*, especially those that were toxic in the laboratory.

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