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Efficacy of the green lace wing, *Chrysoperla zastrowi sillemi* (Esben-Peterson) (Neuroptera: Chrysopidae), against sucking pests of tomato: an appraisal under protected conditions

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Abstract

Pest infestations in net-houses are not sometimes different from that under open-field conditions, necessitating usage of pesticides. To examine the hypothesis that bioagents may have more potential under restricted plant growing conditions, the predatory potential of green lace wing, *Chrysoperla zastrowi sillemi* Esben-Peterson (Neuroptera: Chrysopidae) was evaluated against the sucking pests of tomato under screen-house conditions. The rates of release were fixed as 4, 5, and 6 s instar grubs plant^{-1} and a total of 3 releases were made at 7 days interval, with first release at appearance of the aphid, *Myzus persicae* (Sulzer) and whitefly, *Bemisia tabaci* (Gennadius). The pooled data for the years 2018 and 2019 revealed that, the release rates 4, 5, and 6 grubs plant^{-1} were not statistically different in reducing the population of these pests. The factorial analysis based on the release rate and time of these releases suggested that single release of *C. zastrowi sillemi* at 4 grubs plant^{-1} was effective against sucking pests in tomato grown under screen-house conditions.

Keywords: Tomato, *Myzus persicae*, *Bemisia tabaci*, *Chrysoperla zastrowi sillemi*, Protected structures

Background

India ranks second in the area and production of tomato, *Lycopersicon esculentum* Mill. Tomato production in the tropics is extremely subjected to abiotic stresses like temperature, airflow, and humidity (Ajwang et al. 2002) and to biotic stresses caused by insects like whitefly, aphids, and thrips, and plant viruses transmitted by these insects (Premachandra et al. 2005). The use of synthetic insecticides is widely adopted for the management of these pests, as they are reported to have a rapid action against them. However, their indiscriminate use has several potential harmful effects, disturbing the ecological balance and creating problems like pest resurgences, resistance to pesticides and deleterious effects on non-target organisms (Prakash et al. 2008). The overuse of pesticides has led to pesticide laden agricultural produce (Donkor et al. 2016), particularly the vegetables which are consumed fresh or partially processed (Mwanja et al. 2017).

To fetch higher market price, growing off-season vegetables under screen-house conditions is becoming popular in recent years. Though, the screening of such net-houses has a propensity to exclude larger pests like leaf miners and caterpillars, smaller insects such as *Mysus persicae* (Sulzer), *Aphis gossypii* Glover, *Bemisia tabaci* (Gennadius), *Trialeurodes vaporariorum* (Westwood), *Thrips tabaci* Lindeman, and *Tetranychus urticae* Koch may escape through these screens. The micro-environment of the screen-houses provides congenial conditions for the multiplication of these pests. This

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causes net-house cultivators to use chemical pesticides in an inappropriate manner. Plant protection of the agri-intensive crops, especially vegetables, through biological control, may provide an alternate ecologically benign way to residue free food production under restricted conditions like net-house cultivation. Augmentative as well as inoculative releases of various biocontrol agents have been successfully established for insect control in a number of field crops (Sharma et al. 2018). In fact, these releases can be much more effective inside greenhouse conditions since it ensures restricted dispersal. Lacewings as one of the most economically important biocontrol agents manage various insect pests, especially sucking pests under different agro-ecosystems. Its wide host range as well as geographical distribution, insecticide resistance, voracious larval feeding ability and amenability to rearing makes it a good bioagent for pest management (Pappas et al. 2011). *Chrysoperla zastrowi sillemi* Esben-Peterson (Neuroptera: Chrysopidae) is an important natural predator because of its ability to control a multitude of soft bodied insects like coccids, mealybugs, aphids, thrips, psyllids, whiteflies and eggs, and larvae of many lepidopteran pests and mites infesting on various crops. Adult lacewings feed upon nectar, pollen, and sugary plant secretions (Hemalatha et al. 2014). Under Indian context, it is the most economically important chrysopids, which was earlier referred as *Chrysoperla carnea* Stephens. Hence, a revision in the nomenclature of *C. carnea* was done and erected *C. zastrowi sillemi* to include both the population from India as well as Middle East (Henry et al. 2010).

Most studies regarding the evaluation of predatory efficiency of *C. zastrowi sillemi* has been conducted either in laboratory conditions or in field conditions (Satpathy et al. 2012; Aggarwal and Neetan 2014; Manjunatha et al. 2018). Though some works in greenhouse environment have been conducted (El-Arnaouty et al. 2000; Ahmadzadeh and Hatami 2006), yet very few have been reported for the sucking pests infesting tomato under screen-house conditions. Among various pests, *M. persicae* and *B. tabaci* have been reported to cause damage to net-house grown tomatoes in Indian Punjab (Kaur et al. 2010).

Therefore, the objective of this study was to validate and promote the biocontrol technology comprising inundative releases of *C. zastrowi sillemi* for the management of sucking pests viz. *M. persicae* and *Bemisia tabaci* in tomato grown under protected structures.

Materials and methods

Raising of plant material

An indeterminate variety of tomato "*Punjab Sartaj*" developed by Department of Olericulture, Punjab Agricultural University, Ludhiana, India, was chosen, which could be successfully grown under net-house conditions. The crop was raised in two screen-houses: one at Entomological Research Farm and the other at New Horticultural Orchard, Punjab Agricultural University, Ludhiana. The experiments were conducted in double-door gated screen-house structures made of galvanized iron pipes covered with ultraviolet-stabilized 40 mesh size net. The mesh size thus selected was to provide physical barrier for the insect pests to a large extent, but to assure adequate ventilation of the structures. The screen-house was 31.5 × 10 m with an arc-shaped top. The height of the net-house was 3 m at the center and 2 m at the side walls. In both the years (2018 and 2019), the crop was transplanted in the last week of January. Seedlings were transplanted on 15 cm high beds (3 m ×30 cm), keeping a row-to-row and plant-to-plant spacing of 1.20 m × 30 cm, respectively. Plants were trained upright with the help of bamboos and nylon ropes. The crop was raised following all the recommended University Package of Practices for the net-house cultivation, excluding the management of insect pests.

Rearing of *C. zastrowi sillemi*

C. zastrowi sillemi grubs, the bioagent was mass reared in the laboratory. About 200 pairs of adults' cultures were maintained at biocontrol unit at Department of Entomology, Punjab Agricultural University, Ludhiana. These adults were then kept in oviposition cages measuring (75 cm × 30 cm). The sides of the cage were fitted by nylon wire mesh and the sliding top was fitted with black muslin cloth for harvesting the eggs. The adults were fed daily with swabs containing equal quantity of honey + protein supplement + water + yeast extract dissolved in small quantity of water. The yeast extract was added since it is rich in vitamins (especially B complex) and minerals. The prepared diet was provided daily to the adults kept in a glass vessel. One day old eggs were easily dislodged from the top cover by using a sponge. The eggs collected were used for field release or mass multiplication in the future.

For larval rearing, three day old 120 chrysopid eggs were mixed with 0.75 ml of sterilized *Corcyra cephalonica* Stainton eggs. On hatching, the larvae start feeding on the *Corcyra* eggs. On the 3rd day, individual grubs were then transferred to small glass vials. Separation of the grubs was done to prevent cannibalism prevalent in the 2nd instar grubs. The eggs were refilled in the glass vial every 3 days, and it continued till the grubs became pupae. The cocoons were collected 24 h after their formation and were placed in oviposition cage for emergence and the whole cycle of rearing was repeated.

Treatment protocol

Second instar chrysopid grubs were released at the rate of 4, 5, and 6 grubs plant^{-1}. A total of 3 releases were made at 7 days interval, with first release at appearance of the pest. The pre-count data of aphids and whiteflies plant^{-1} were recorded before the release and the population of the sucking pests was recorded 7 days after each release. The population was recorded from 10 randomly selected plants from each replication. The number of aphids and whiteflies were calculated on per plant basis.

Statistical analysis

The mean population of aphids and whiteflies were subjected to two-way analysis of variance (ANOVA) in randomized block design. Data on population were subjected to square root transformations prior to analysis and are presented as mean ± standard error (SE).Different treatment means were separated at P = 0.05 (Gomez and Gomez 1984).

Results and discussion

Efficacy of *C. zastrowi sillemi* against *M. persicae*

The population of *M. persicae* recorded during evaluation of predatory potential of *C. zastrowi sillemi* grubs conducted in the year 2018 is shown in Table 1. Observations recorded 7days after the first release (DAFR) of grubs revealed that all the 3 release treatments were significantly better than untreated control in reducing the aphid population (P < 0.0001). At 7 days after the 2nd release (DASR), and 7 days after 3rd release (DATR) also, the plants released with *Chrysoperla* grubs (4, 5, and 6 grubs plant^{-1}) were recorded with significantly lower aphid population than the untreated control (P < 0.0001). After all the 3 releases, a mean population of 0.52 aphids plant^{-1}was recorded in plants released with 4 grubs, whereas the number of aphids recorded per plant was 0.47 and 0.38, where the number of grubs per plant released was 5 and 6, respectively. The 3 release treatments were not statistically different, however they were significantly better (P <0.0001) than untreated control wherein, mean aphid population of 32.45 aphids plant^{-1} was recorded.

Data shown in Table 1 reveals significantly lower population of aphids in all the *Chrysoperla* release treatments than the control during 2019. At 7 DAFR, 7 DASR, and 7 DATR, a significantly lower population of the aphid was recorded in plants released with chrysopid grubs (4, 5, and 6 grubs plant^{-1}) as compared to untreated control (P < 0.0001). Mean aphid population (0.66, 0.57, and 0.49 aphids plant^{-1}), after the 3 releases in different release rates (4, 5, and 6 grubs plant^{-1}, respectively), were not statistically different. Highest mean aphid population (31.67 aphids plant^{-1}) was recorded in untreated control, which was significantly higher (P < 0.0001) than aphid population recorded on released plants.

Efficiency of *C. zastrowi sillemi* against *B. tabaci*

The data on predatory potential of *C. zastrowi sillemi* evaluated against *B. tabaci* in tomato plants during 2018 revealed significantly lower population of whiteflies on *Chrysoperla* released plants than untreated control (Table 2). Plants treated with chrysopid grubs (4, 5, and 6 grubs plant^{-1}) recorded with a significantly lower population of whiteflies at 7 DAFR, 7 DASR and 7 DATR than in the control (P < 0.0001). After all the 3 releases, a mean population of 0.33 whiteflies plant^{-1}was recorded in plants released with 4 grubs plant^{-1}, whereas population of 0.27 and 0.31 whiteflies was recorded on plants released with 5 and 6 grubs plant^{-1}, respectively. These release treatments were statistically superior (P < 0.0001) to untreated control (12.54 whiteflies plant^{-1}) in reducing the whitefly population.

In 2019 also, a significantly lower population of whiteflies was recorded on the released plants than the control. *Chrysoperla* releases (4, 5, and 6 grubs plant^{-1}) made at 7 DAFR, 7 DASR and 7 DATR resulted in a significantly lower population of whiteflies (P < 0.0001) on tomato plants than that of untreated control. The mean population of whiteflies (0.28, 0.29, and 0.33 plant^{-1}) after the 3 releases was not statistically different with the

Table 1 Predatory efficiency of *C. zastrowi sillemi* against *M. persicae* under protected cultivation conditions

Number of grubs/plant	Mean[#] number of aphids per plant									
	2018				Mean	2019				Mean
	Pre-count	7 DAFR*	7 DASR**	7DATR***		Pre-count	7 DAFR*	7 DASR**	7DATR***	
4	23.87[a]	1.27 ± 0.07[a]	0.23 ± 0.03[a]	0.07 ± 0.03[a]	0.52 ± 0.19[a]	33.73[a]	1.47 ± 0.09[a]	0.43 ± 0.18[a]	0.07 ± 0.07[a]	0.66 ± 0.22[a]
5	24.60[a]	1.20 ± 0.12[a]	0.13 ± 0.03[a]	0.07 ± 0.03[a]	0.47 ± 0.19[a]	34.83[a]	1.20 ± 0.15[a]	0.47 ± 0.03[a]	0.03 ± 0.03[a]	0.57 ± 0.18[a]
6	25.10[a]	1.00 ± 0.12[a]	0.10 ± 0.02[a]	0.03 ± 0.03[a]	0.38 ± 0.16[a]	34.67[a]	1.00 ± 0.17[a]	0.37 ± 0.03[a]	0.10 ± 0.02[a]	0.49 ± 0.14[a]
Untreated control	29.77[a]	31.22 ± 0.20[b]	32.73 ± 0.27[b]	33.40 ± 0.60[b]	32.45 ± 0.38[b]	36.03[a]	30.97 ± 0.38[b]	31.43 ± 0.03[b]	32.60 ± 0.06[b]	31.67 ± 0.27[b]
P value	0.163	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.815	< 0.0001	< 0.0001	< 0.0001	< 0.0001

[#]Mean of three replications

Means ± standard error followed by the same letter within a column are not significantly different (P < 0.05)

*7 days after first release

**7 days after second release

***7 days after third release

Table 2 Predatory efficiency of *C. zastrowi sillemi* against *B. tabaci* under protected cultivation conditions

Number of grubs/plant	Mean[#] number of whiteflies per plant									
	2018				Mean	2019				Mean
	Pre-count	7 DAFR*	7 DASR**	7DATR***		Pre-count	7 DAFR*	7 DASR**	7DATR***	
4	13.60[a]	0.63 ± 0.03[a]	0.23 ± 0.03[a]	0.13 ± 0.03[a]	0.33 ± 0.08[a]	10.33[a]	0.57 ± 0.20[a]	0.20 ± 0.10[a]	0.07 ± 0.03[a]	0.28 ± 0.10[a]
5	14.13[a]	0.50 ± 0.12[a]	0.23 ± 0.03[a]	0.07 ± 0.03[a]	0.27 ± 0.07[a]	10.53[a]	0.63 ± 0.09[a]	0.20 ± 0.06[a]	0.03 ± 0.03[a]	0.29 ± 0.09[a]
6	12.47[a]	0.47 ± 0.03[a]	0.33 ± 0.07[a]	0.13 ± 0.03[a]	0.31 ± 0.05[a]	10.03[a]	0.50 ± 0.15[a]	0.37 ± 0.27[a]	0.13 ± 0.03[a]	0.33 ± 0.11[a]
Untreated control	13.80[a]	11.80 ± 0.31[b]	12.77 ± 0.09[b]	13.07 ± 0.24[b]	12.54 ± 0.22[b]	10.10[a]	10.10 ± 1.33[b]	10.57 ± 1.50[b]	10.60 ± 0.35[b]	10.42 ± 0.59[b]
P value	0.767	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.980	< 0.0001	< 0.0001	< 0.0001	< 0.0001

[#]Mean of three replications
Means ± standard error followed by the same letter within a column are not significantly different ($P < 0.05$)
*7 days after first release
**7 days after second release
***7 days after third release

releases of grubs at 4, 5, and 6 plant^{-1}, respectively. A statistically significant ($P < 0.0001$) higher population of 10.64 whiteflies plant^{-1} was recorded on the plants maintained as untreated control.

The pooled data (2018 and 2019) for the evaluation of *C. zastrowi sillemi* against *M. persicae* in tomato under screen-house conditions, shown in Table 3 revealed significantly lower population on the released plant than the control. The plants with different releases (4, 5, and 6 grubs plant^{-1}) were recorded with a significantly lower population of *B. tabaci* at 7 DAFR, 7 DASR, and 7 DATR ($P < 0.0001$). The mean population of aphids after the 3 releases showed that the releases of grubs at 4, 5, and 6 plant^{-1} were not statistically different. After 3 releases, a mean population of 0.59, 0.52, and 0.43 aphids plant^{-1}was recorded on plants released with 4, 5, and 6 *Chrysoperla* grubs plant^{-1}, respectively. All the 3 releases were significantly better ($P < 0.0001$) than untreated control (32.06 aphids plant^{-1}).

Similarly, pooled data for 2 years (2018 and 2019) for whiteflies revealed significantly lower population on the released plant than the control (Table 3). At 7 DAFR, 7 DASR and 7 DATR, the plants on which *Chrysoperla* grubs were released (4, 5, and 6 grubs plant^{-1}), were recorded with significantly lower whitefly population ($P < 0.0001$) than untreated control. Different grub numbers per plant (4, 5, and 6) were not statistically different with each other (0.31, 0.28, and 0.32 whiteflies plant^{-1}, respectively) in reducing the population of whitefly on screen-house grown tomatoes, but were statistically better ($P < 0.0001$) than untreated control (11.84 whiteflies plant^{-1}).

In order to protect crops from pests, adverse climatic conditions and to reduce dependency on frequent pesticide use, net/poly cultivation practices are widely adopted in many parts of the world. But these structures have limitations, particularly with small insect pests, which can easily escape through the physical screens provided. These pests multiply rapidly under ambient temperature and relative humidity conditions, thereby resulting in significant crop losses. Under net-/polynet-house conditions, the high predatory potency of chrysopids against sucking pests have earlier been reported against sweet potato whitefly, *Bemisia tabaci* (Gennadius) (Breene et al. 1992), green peach aphid, *Myzus persicae* (Sulzer) (El-Arnaouty et al. 2000) and greenhouse whitefly, *Trialeurodes vaporariorum* West (Ahmadzadeh and Hatami 2006). In greenhouse tomatoes, efficacy of two green lace wings species,

Table 3 Predatory efficiency of *C. zastrowi sillemi* against *M. persicae* and *B. tabaci* under protected cultivation conditions (2018–2019 pooled)

Number of grubs/plant	Mean[#] number of aphids per plant				Mean	Mean[#] number of whiteflies per plant				Mean
	Pre-count	7 DAFR*	7 DASR**	7DATR***		Pre-count	7 DAFR*	7 DASR**	7DATR***	
4	28.80[a]	1.36 ± 0.07[a]	0.33 ± 0.09[a]	0.07 ± 0.03[a]	0.59 ± 0.14[a]	11.97[a]	0.60 ± 0.09[a]	0.22 ± 0.05[a]	0.10 ± 0.03[a]	0.31 ± 0.06[a]
5	29.72[a]	1.20 ± 0.09[a]	0.30 ± 0.08[a]	0.05 ± 0.02[a]	0.52 ± 0.13[a]	12.33[a]	0.57 ± 0.07[a]	0.22 ± 0.03[a]	0.05 ± 0.02[a]	0.28 ± 0.06[a]
6	29.88[a]	1.00 ± 0.09[a]	0.23 ± 0.06[a]	0.07 ± 0.02[a]	0.43 ± 0.10[a]	11.25[a]	0.48 ± 0.07[a]	0.35 ± 0.13[a]	0.13 ± 0.02[a]	0.32 ± 0.06[a]
Untreated control	32.90[a]	31.09 ± 0.20[b]	32.08 ± 0.31[b]	33.00 ± 0.32[b]	32.06 ± 0.24[b]	11.95[a]	10.95 ± 0.72[b]	11.67 ± 0.8[b]	11.83 ± 0.58[b]	11.84 ± 0.40[b]
P value	0.181	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.895	< 0.0001	< 0.0001	< 0.0001	< 0.0001

[#]Mean of three replications
Means ± standard error followed by the same letter within a column are not significantly different ($P < 0.05$)
*7 days after first release
**7 days after second release
***7 days after third release

C. carnea and *Chrysoperla rufilabris* (Burmeister) was evaluated against tomato psyllids (Al-Jabr 2000). Both the species were capable of completing their lifecycle on tomato psyllid. *C. carnea* grub consumed approximately twice as many psyllids as did *C. rufilabris*, but the development of the latter was faster. The present study also underlines the potential of *C. zastrowi sillemi* in reducing the population of sucking pests in screen-house grown tomatoes. The second instar grubs at various release rates, i.e., 4, 5, and 6 grubs plant^{-1} significantly reduced the population of aphids and whiteflies on the tomato plants than the control. These release treatments were shown to be equally effective in pest control, even at the lowest release rate tested, i.e., 4 grubs plant^{-1}.

One of the major concerns on success of biocontrol agents against crop pests is their performance in the field. These agents are to be used innundatively, i.e., their repeated applications are required. However, there is always an optimal rate at which these bioagents have to be released. The increased release rate may increase the cost of implementing biological control and may not improve the pest control proportionately (Collier and van Steenwyk 2004). There are several studies, wherein increase in release rate of the natural enemies did not affect the pest density significantly (Jung et al. 2004; Alomar et al. 2006). So, under certain pest situations, if farmers have the liberty to decrease the number of releases, it will enhance the adoption of this technology at farm level. The present findings indicate that a single release of *Chrysoperla* grubs was sufficient for suppressing the population of both *M. persicae* and *B. tabaci* on tomato plants grown under screen-house conditions.

Further, the timing of biological intervention sometimes has relatively more impact on pest control than the release rate. The release timing affects the host: natural enemy synchrony and decide the successful establishment of a biocontrol agent in the field (Liu and Stansly 2005). We are of the opinion that these grubs were able to the decimate aphid and whitefly population to a negligible level, with the pre-condition that a not very high initial population of these pests was present on tomato plants. The present study is supported by the earlier work of Daane and Yokota (1997) who reported that biological control of vine leafhoppers, *Erythroneura variabilis* (Beamer) and *E. elegantula* (Osborn) by *Chrysoperla* spp. was more affected by the method and timing of application as compared to release rates. Similarly, predatory mite *Phytoseiulus persimilis* Athias-Henriot managed the two-spotted spider mite, *Tetranychus urticae* (Koch) effectively, when the predator was released early in the season irrespective of the release rate (Campbell and Lilley 1999). The technology has clear advantages over synthetic chemicals in terms of negligible environmental contamination and adverse impact on non-target organisms. However, concerted research on rational use of these biological entities is required to further explore their functionality and resilience.

Conclusion

The results conclude that a single release of 2nd instar *C. zastrowi sillemi* grubs at 4 plant^{-1} may prove effective in reducing the increasing population of *M. persicae* and *B. tabaci* on screen-house grown tomatoes. Though, a lot depends on the initial incidence of the pests. The results are valuable in generating information on potential management of sucking pests of screen-house grown tomatoes.

Abbreviations

DAFR: Days after first release; DASR: Days after second release; DATR: Days after third release

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Authors' contributions

IJN carried out the study, analyzed the data, and drafted the manuscript. SS designed the project and was responsible for final interpretation of data. RK maintained the insect culture and edited the manuscript. All authors read and approve the final manuscript.

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