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Intraguild predation on *Trichogramma chilonis* Ishii (Hymenoptera: Trichogrammatidae) by the generalist predator *Geocoris ochropterus* Fieber (Hemiptera: Geocoridae)

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Abstract

Intraguild predation (IGP) is common in food web when two natural enemies share the same resources and prey. It may affect the success or failure of a biological control attempt. The role of intraguild predation by *Geocoris ochropterus* Fieber (Heteroptera: Geocoridae) on *Trichogramma chilonis* Ishii (Hymenoptera: Trichogrammatidae) developed on eggs of *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) and *Corcyra cephalonica* (Stainton) (Lepidoptera: Pyralidae) was evaluated under laboratory conditions. In choice experiments, both fifth instar nymph and adult of *G. ochropterus* preferred to predate on unparasitized eggs of *H. armigera* and *C. cephalonica* over parasitized eggs. In no-choice experiments, *G. ochropterus* nymph consumed 58 and 67% of unparasitized *H. armigera* and *C. cephalonica* eggs, compared to 3.33 and 7.38% of parasitized ones. A similar trend was observed in no-choice experiments with adult predator. Additional semi-field and field studies are required to explicate the consequences and intensity of intraguild predation in agro-ecosystem.

Keywords: Intraguild predation, *Geocoris ochropterus*, *Trichogramma chilonis*, Parasitized eggs, Preference

Background

The big-eyed bugs, *Geocoris* spp. (Hemiptera: Geocoridae) are small generalist insect omnivores which prey upon several insect and mite pests (Schuman et al. 2013). In India, *Geocoris ochropterus* Fieber is a very common species found in cotton, lucerne, maize, sunflower, tea, and other fruit and flowering plants. It was observed feeding on *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) eggs (personal observation). In India, *H. armigera* is a polyphagous pest attacking several crops including vegetable, pulses, and cotton. *Trichogramma chilonis* Ishii (Hymenoptera: Trichogrammatidae) is the most popularly used egg parasitoid, which is released primarily against several lepidopteran pests including the notorious and

polyphagous pest, *H. armigera* infesting crops (Gupta and Ballal 2007). When natural enemies share the same niche, resources, and common prey species, they might engage in intraguild predation (IGP), wherein one natural enemy consumes the other (Holt and Polis 1997). IGP may have a negative (Rosenheim 2005) or a positive effect (Gardiner and Landis 2007) on biological control. Thus, it is very much warranted to select species combinations on the basis of their positive interaction so that they can further be used synergistically to enhance the efficacy of biological control agents.

Combined releases of parasitoids and predators were found to be effective in managing pests of several crops. Adnan-Babi and Pintureau (2002) observed that *Trichogramma principium* Sugonyaev and Sorokina and *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae) could be successfully released together for management of cotton bollworms in Syria. Combined releases of *Trichogramma* sp. and *C. carnea* against

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Heliothis spp. (Lepidoptera: Noctuidae) on cotton were made in the USA (Ridgway et al. 1973). *T. chilonis* and *C. carnea* against cotton bollworms and sucking pests in India and *Lysiphlebus testaceipes* (Cresson) (Hymenoptera: Aphidiinae) and *Hippodamia convergens* Guérin-Ménéville (Coleoptera: Coccinellidae) against cotton aphids in cotton (Colfer and Rosenheim 2001) are some of the successful examples.

Combined use of *T. chilonis* and *G. ochropterus* is a strategy being considered for management of lepidopteran insect pests in polyhouses in India. Therefore, IGP is considered as an important factor deciding the success or failure of biological control agents (Rosenheim and Harmon 2006). Velasco-Hernandez et al. (2013) reported that *Geocoris punctipes* (Say) had a significant preference for non-parasitized *Trialeurodes vaporariorum* Westwood (Hemiptera: Aleyrodidae) nymphs in choice tests. However, Naranjo (2007) reported that three generalist predators, *G. punctipes* (Say), *Orius insidiosus* (Say) (Hemiptera: Anthicoridae), and *Hippodamia convergens* Guerin-Meneville preferred parasitized *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) by *Eretmocerus* sp. nr. *emiratus* (Hymenoptera: Aphelinidae) or could not discriminate between parasitized and non-parasitized nymphs.

Studies on the predation by *G. ochropterus* on *H. armigera* eggs are scarce, and there is no information available on IGP by *G. ochropterus* on *H. armigera* eggs parasitized by *T. chilonis*. The purpose of this study was to evaluate the prey preference of adult and mature nymph of *G. ochropterus* for unparasitized and *T. chilonis* parasitized lepidopteran eggs thus to predict the combined field releases of *G. ochropterus* and trichogrammatids.

Materials and methods

Insect cultures and rearing

Initial cultures of *Corcyra cephalonica* (Stainon) (Lepidoptera: Pyralidae) (National Accession number: NBII-MP-PYR-01), *H. armigera* (National Accession number: NBII-MP-NOC-01), and *T. chilonis* (National Accession Number: NBII-MP-TRI-13a) were obtained from the mass production unit at the National Bureau of Agricultural Insect Resources, Bangalore, India. Eggs of *C. cephalonica* and *H. armigera* were glued on cards and exposed separately to *T. chilonis* females in the ratio of 30 eggs per female parasitoid for 24 h in 15 × 1.5 cm test tubes (Gupta and Ballal 2007). *G. ochropterus* was collected from maize field and reared in the laboratory on beans and *C. cephalonica* eggs and *H. armigera* for three generations to acclimatize under laboratory conditions before initiating the experiments. Methodology for *G. ochropterus* rearing was followed as mentioned by Varshney and Ballal (2017). Newly emerged fifth instar nymph and 1- to 2-week-old adult predator females were used in experiments (as adult requires a pre-mating period of 4 to

5 days and can live for more than 8 weeks (personal observation). All the insects under study were maintained, and IGP experiments were conducted at 26 ± 2 °C, 65 ± 2% relative humidity with a photoperiod of 12:12 (L:D).

Assessment of IGP on *Corcyra cephalonica* (Stainon)

No-choice test

In no-choice experiment, 30 6-day-old parasitized (parasitized eggs turn black in color when they are 6 days old which confirms parasitism) and fresh unparasitized *C. cephalonica* were pasted on separate cards. Each card was kept separately in a small-ventilated round plastic box (7.5 cm diameter and 2.5 cm height); the floor of the container was covered with a piece of tissue paper. Newly emerged fifth instar *G. ochropterus* nymph (previously starved for 24 h) was introduced at the rate of one per box. The same set-up was repeated with 8-day-old *G. ochropterus* adult (previously starved for 24 h). During the starvation period, cotton swab soaked in a tap water was provided to the nymph and adult stages of the predator.

The following treatments set up under no-choice were as follows:

- T1—30 unparasitized *C. cephalonica* eggs + 1 *G. ochropterus* mature nymph
- T2—30 parasitized *C. cephalonica* eggs + 1 *G. ochropterus* mature nymph
- T3—30 unparasitized *C. cephalonica* eggs + 1 *G. ochropterus* adult
- T4—30 parasitized *C. cephalonica* eggs + 1 *G. ochropterus* adult

Both nymphs and adults were allowed to forage for 24 h after the introduction of the predator into the arena. After 24 h, eggs were observed under a stereomicroscope (Olympus SZX15) and the number of consumed eggs (i.e., based on empty eggs with ruptured chorion) was recorded to find out the predation level of *G. ochropterus* on parasitized and unparasitized *C. cephalonica* eggs in a no-choice situation. Each treatment was replicated 14 times.

Choice test

In the choice test, 30 6-day-old parasitized eggs and 30 fresh eggs of *C. cephalonica* were pasted on separate cards and kept together in small plastic ventilated round boxes (7.5 cm diameter and 2.5 cm height). One predator each (nymph or adult) of *G. ochropterus* was released into each box holding the parasitized and unparasitized eggs.

The following were the treatments under the choice test:

T1: 30 unparasitized + 30 parasitized *C. cephalonica* eggs + 1 *G. ochropterus* mature nymph

T2: 30 unparasitized + 30 parasitized *C. cephalonica* eggs + 1 *G. ochropterus* adult

Each treatment was replicated 14 times. Observations were recorded after 24 h on the number of eggs damaged by nymphs and adults of predator.

Assessment of IGP on *Helicoverpa armigera* (Hubner)

The same experimental methodology for *H. armigera* eggs were carried out as done in the IGP with *C. cephalonica* eggs.

Additionally, preference index of prey type was evaluated by calculating Manly's index of preference (Manly 1974; Meyling et al. 2004) for each replicate

$$\beta_1 = \frac{\log\left(\frac{e_1}{A_1}\right)}{\log\left(\frac{e_1}{A_1}\right) + \log\left(\frac{e_2}{A_2}\right)}$$

where β_1 is the preference for prey type 1, e_1 is the number of prey remaining after experimentation, and A_1 is the number of prey offered. An index value close to 0.5 indicates that the predator shows no preference for a given prey type, a value close to 1 indicates preference for prey type 1, and a value close to 0 indicates preference for prey type 2 (Meyling et al. 2004). In the present case, unparasitized eggs were chosen as prey type 1. Manly's index applies to experimental situations where killed prey are not replaced (Manly 1974; Sherrat and Harvey 1993; Meyling et al. 2004). Cock (1978) pointed out this index as the only method that takes into account lower prey density throughout the trial development. The value of preference index (β_1) varies from 0 to 1. One-sample t tests were used to compare the experimentally observed Manly's index for unparasitized eggs and a value of 0.5 to test the null hypothesis that the predator selected prey at random.

Data analysis

In no-choice test, one-way ANOVA was used to test for differences in predation rates on the two types of prey by predator. The effect of prey (parasitized and unparasitized) and predator stage (nymph and adult) together with their interaction was also studied using univariate general linear model (two-way ANOVA) with prey and predator stage together with their interaction as fixed factors.

Free-choice bioassay data were analyzed using an independent t test comparing the mean number of parasitized and unparasitized prey consumed by *G. ochropterus*.

Results and discussion

No-choice test

When parasitized and unparasitized eggs of *H. armigera* were provided separately to *G. ochropterus* nymph, it consumed significantly more numbers of unparasitized than parasitized eggs ($F_{1,27} = 64.8$, $P < 0.0001$). The mean number (\pm SE) of eggs was 17.3 ± 2.01 and 1.00 ± 0.28 for unparasitized and parasitized *H. armigera* eggs, respectively. Similar trend with higher preference for unparasitized eggs was observed in case of adult *G. ochropterus* which consumed 26.25 ± 0.99 and 4.28 ± 0.24 unparasitized and parasitized *H. armigera* eggs, respectively ($F_{1,27} = 486.6$, $P < 0.0001$). Two-way ANOVA indicates that predation rate was significantly affected by prey egg type (parasitized and unparasitized) ($F_{1,56} = 292.86$, $P < 0.0001$), predator stage (mature nymph and adult) ($F_{1,56} = 31.6$, $P < 0.0001$), and the interaction between prey egg type and predator stage ($F_{1,56} = 7.46$, $P = 0.009$).

When *G. ochropterus* nymph had access to unparasitized and parasitized *C. cephalonica* eggs, a nymph consumed 20.28 ± 1.43 of the unparasitized eggs and 2.21 ± 0.50 of the parasitized eggs with a significant difference ($F_{1,27} = 286.8$, $P < 0.0001$). However, adult predator consumed 25.4 ± 1.05 unparasitized eggs and 6.14 ± 0.86 parasitized eggs ($F_{1,27} = 199.6$, $P < 0.0001$). When eggs of *C. cephalonica* were offered as prey, the predation rate was significantly affected by prey type (parasitized and unparasitized) ($F_{1,56} = 464.8$, $P < 0.0001$), predator stage (mature nymph and adult) ($F_{1,56} = 27.4$, $P < 0.0001$) but not by the interaction between prey and predator stage ($F_{1,56} = 0.491$, $P = 0.487$) (two-way ANOVA).

Choice test

G. ochropterus nymph consumed significantly more unparasitized *H. armigera* eggs than parasitized eggs when nymph was offered both types of eggs in a choice arena ($t = -22.38$, $df = 19.3$, $P < 0.01$). This result was confirmed by the mean value of the preference index (PI = 0.98 ± 0.005), indicating that *G. ochropterus* nymph had a significant preference for consuming unparasitized eggs (Table 1).

Similarly, *G. ochropterus* adult had a significant preference for unparasitized *H. armigera* eggs in comparison to parasitized eggs in a choice arena ($t = -10.02$, $df = 13.9$, $P < 0.01$). It is clear from the preference index that *G. ochropterus* adult exhibited a significant preference for unparasitized *H. armigera* eggs (PI = 0.95 ± 0.003).

When *C. cephalonica* eggs were used as prey, both nymph and adult of *G. ochropterus* exhibited a significant preference for unparasitized eggs relative to parasitized eggs when both types of eggs were available in a choice arena. *G. ochropterus* nymph consumed higher unparasitized eggs compared to parasitized eggs ($t = -19.8$, $df = 17.37$, $P < 0.01$). This is evident

Table 1 Numbers of *Helicoverpa armigera* and *Corcyra cephalonica* eggs consumed and Manly's index of preference for nymph and adult of *Geocoris ochropterus* given a choice of unparasitized and parasitized eggs by *Trichogramma chilonis*

Lepidopteran egg	Predator stage	No. of unparasitized eggs consumed (mean ± SE)	No. of parasitized eggs consumed (mean ± SE)	Manly's index of preference ^a df = 13, P < 0.001	
				β1 (preference) (mean ± SE)	t
<i>Helicoverpa armigera</i>	<i>G. ochropterus</i> fifth instar	20.7 ± 0.76	1.64 ± 0.38	0.97 ± 0.01	80.1
	<i>G. ochropterus</i> adult	26.57 ± 1.14	3.28 ± 0.22	0.95 ± 0.004	118.3
<i>Corcyra cephalonica</i>	<i>G. ochropterus</i> fifth instar	21.29 ± 0.93	1.35 ± 0.39	0.96 ± 0.01	53.6
	<i>G. ochropterus</i> adult	23.7 ± 1	2.07 ± 0.54	0.94 ± 0.01	47.2

^aOne-sample t tests by comparing Manly's index for non-parasitized eggs and a value of 0.5 to test the null hypothesis that the predator selected prey at random

with a preference index (PI = 0.96 ± 0.009) which indicated that *G. ochropterus* nymph had a significant preference for unparasitized *C. cephalonica* eggs (Table 1).

A similar trend was observed in the case of *G. ochropterus* adult, which also showed a significant preference for unparasitized *C. cephalonica* eggs (PI = 0.94 ± 0.009).

Total consumption of parasitized and unparasitized eggs of both *C. cephalonica* and *H. armigera* by *G. ochropterus* nymph and adult in choice and no-choice tests has been depicted in Fig. 1. It is also clear that although nymph and adult of *G. ochropterus* consumed significantly more parasitized eggs of *C. cephalonica* in the no-choice test compared to the choice one ($t = 3.65$, $df = 38.2$, $P = 0.001$) but in case of *H. armigera*, there is no significant difference in consumption of parasitized *H. armigera* eggs ($t = 0.39$, $df = 49.7$, $P > 0.05$) in both tests.

In the present study, daily observations of nymphal and adult treatments revealed that although *G. ochropterus* fed on few parasitized eggs, it could not consume more parasitized eggs. Non-preference for parasitized eggs has been reported in the case of several predators. Oliveira et al. (2004) reported that predatory

pentatomid, *Podisus maculiventris* (Say) (Hemiptera: Pentatomidae), showed a greater preference for unparasitized eggs of *Ephestia kuehniella* Zeller (Pyralidae: Lepidoptera) when compared to eggs parasitized by *T. brassicae* Bezdenko. *H. zea* (Boddie) eggs parasitized by *T. pretiosum* Riley were not accepted by *Chrysoperla externa* (Hagen) (Ciociola-Junior et al. 1999). Anthocorid predators *Xylocoris flavipes* (Reuter) (Hemiptera: Anthocoridae) and *O. insidiosus* had a greater preference for unparasitized prey eggs in comparison to those parasitized by *T. pretiosum* (Ruberson and Kring 1991). Gupta and Ballal (2007) reported significantly higher preference for unparasitized eggs of *H. armigera* and *C. cephalonica* by *O. tantillus* (Motschulsky) and *Blaptostethus pallescens* Poppius (Hemiptera: Anthocoridae). *Coccinella septempunctata* Linnaeus and *Harmonia axyridis* Pallas (Coleoptera: Coccinellidae) preferred non-parasitized *Aphis glycines* Matsu-mura (Hemiptera: Aphididae) over mummified aphids (Xue et al. 2012). Similar result has been documented by Snyder et al. (2004) who reported that *H. axyridis* can complement aphid biocontrol by the parasitoid *Aphelinus asychis* Walker (Hymenoptera: Aphelinidae), rather than disrupting control through intraguild predation.

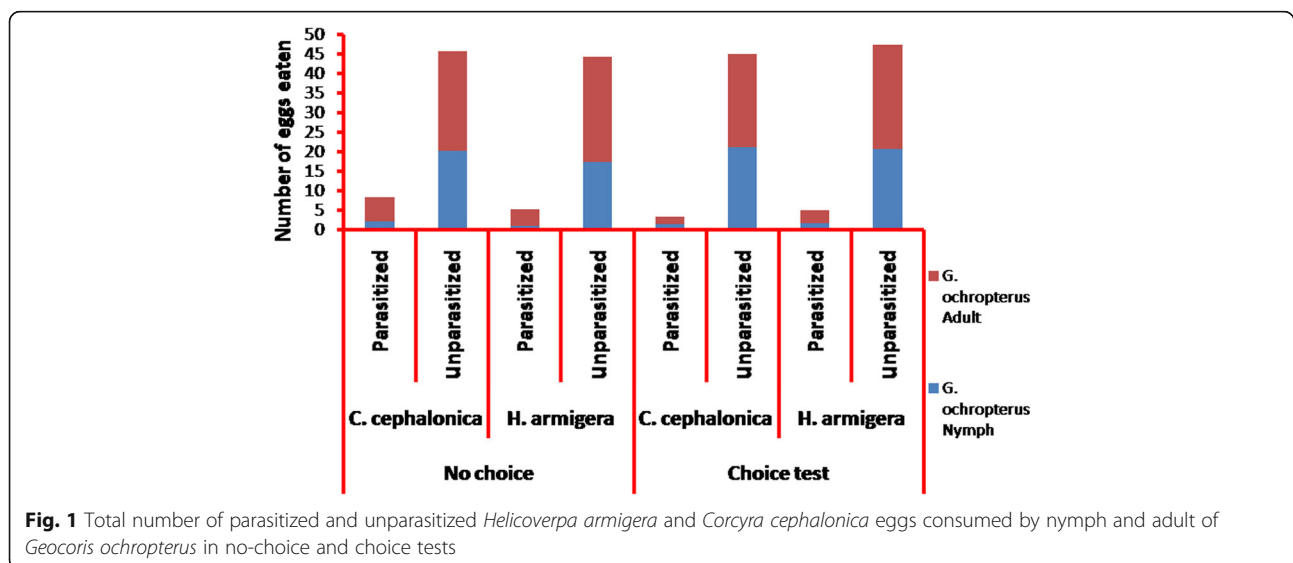


Fig. 1 Total number of parasitized and unparasitized *Helicoverpa armigera* and *Corcyra cephalonica* eggs consumed by nymph and adult of *Geocoris ochropterus* in no-choice and choice tests

Four-day-old parasitized eggs contain third instar of *Trichogramma* parasitoid which deposit dark melanin granules on the inner surface of egg chorion causing the eggs to turn black and hard. The hardness of the chorion of the parasitized eggs on day 6 may also be due to the formation of pupal stage at this time. This could be a reason for lower preference of parasitized eggs by this predator. There are some other factors, which may influence IG-predator preferences, such as hardening the cuticle (Chailleux et al. 2013), physiological/chemical changes (Gelman et al. 2002) in parasitized eggs, and prey species (Roger et al. 2000). Further studies are required to understand the potential reasons for non-acceptance of parasitized eggs by the geocorid predator. There are reports describing the negative effect of IGP on biological control program (Raymond et al. 2000; Snyder and Ives 2001), while there are other reports where positive effect of IGP was observed leading to successful control of pest population (Colfer and Rosenheim 2001; Xue et al. 2012).

Before making combined releases of a predator and a parasitoid, besides studying possible IGP by the general predator on the parasitoid, it would be useful to study the possibility of the parasitoid parasitizing the eggs and other stages of the predator. Further studies focused on the effect of age of the parasitized eggs on the feeding preference of *G. ochropterus* are warranted. Additional semi-field and field studies are required to explicate the consequences and intensity of IGP in agro-ecosystem as in field conditions, IGP is influenced by many factors such as habitat complexity, multispecies interaction, and escape possibilities (Velasco-Hernandez et al. 2013). In complex ecosystem, the effects of IGP are expected to be weaker than in simple laboratory contexts (Janssen et al. 2007) because there are many existing preys on which a general predator can feed.

Conclusions

In conclusion, present studies indicate that combined releases of *G. ochropterus* and *T. chilonis* may be feasible but glass house and field studies are warranted to confirm the usefulness of such combined release of natural enemies to improve the biological control programs targeting lepidopteran pests.

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Authors' contributions

RV participated in the design of the study, conducted experiments, preparation of manuscript and performed the statistical study. CRB

contributed in design of study and preparation of manuscript. Both authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

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