Research Article

Functional and aggregational response of *Chrysoperla* sp. (*carnea*-group) (Neuroptera: Chrysopidae) on *Brevicoryne brassicae* (Linnaeus) (Hemiptera: Aphididae)

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ABSTRACT: This study evaluated the functional and aggregational responses of 2nd and 3rd instar larvae of *Chrysoperla* sp. (*carnea*-group) on medium sized aphids of *Brevicoryne brassicae* (L.). The functional response was investigated at prey densities of 2, 4, 8, 16, 32, 64 and 128 aphids per larvae and the studies revealed that behaviour of both the larval instars matched Holling's Type II functional response. The response curve exhibited a curvilinear rise to the plateau. The 3rd instar larvae displayed a higher rate of predation than the 2nd instar. The maximum attack rate (*a*) with lowest handling time (*Th*) was determined by r^2 value which was found to be highest for 3rd instar larvae ($r^2 = 0.7308$) followed by 2nd instar larvae ($r^2 = 0.733$). Numerical response (aggregational response) was investigated at varied density of prey, *viz.*, 8, 16, 32, 64 and 128 aphids and varied density of predators, *viz.*, 1, 2, 3, 4 and 5. The maximum aggregation response was observed at highest host density of aphids (128) with the maximum number of predators (5). The rate of attack (a) was highest for 3rd instar larvae (2.32) at lowest predator density (1) and showed a downward trend with increase in predator densities due to intra-specific competition under conditions of food limitation.

KEY WORDS: Aggregational response, *Brevicoryne brassicae, Chrysoperla* sp. (*carnea*-group)*, functional response, handling time, numerical response, search rate

INTRODUCTION

Cabbage aphid, *Brevicoryne brassicae* (L.) (Hemiptera: Aphididae) is a specialized pest and a world wide problem on cruciferous crops with a substantial negative impact on many plant species including cabbage, cauliflower, knol khol, kale, turnip, radish and other cruciferous crops. It causes direct damage by sucking plant sap, which induces plant deformation and indirect damage by heavy production of honeydew (Athhan *et al.,* 2004). There are studies indicating that natural enemies may be effective against aphids in integrated pest management and biological control programmes (Tassan *et al.,* 1979). The common green lacewing, C*hrysoperla* sp. (*carnea*-group) (Neuroptera: Chrysopidae) is one of the important bio-control agents that have tolerance to a wide range of ecological factors and is commonly used as a predator of different pest organisms (Ridgway and Jones, 1969). Green lacewing larvae possess excellent searching qualities, high dispersal ability, wide geographical distribution and host range, broad habits, resistance to certain pesticides and voracious larval feeding capacity, particularly against

aphid pests. Further, from commercial point of view, *Chrysoperla* sp. (*carnea*-group) larvae are ideal bio-control agents because they can be effective against a wide variety of pests in so many different cropping patterns (Saminathan *et al.*, 2003). Biological control theory for predator–prey interactions has been based upon a model of communities composed of discrete trophic levels; plants, herbivores and predators in which biological control agents are top consumers (Rosenheim *et al.*, 1999). One of the fundamental aspects of predator–prey interactions is the relationship between prey density and predator consumption, to which Solomon (1949) and Holling (1959; 1961) attributed the terms functional and numerical responses. The functional response of a predator is a key factor in regulating the population dynamics of predator-prey systems and describes the rate at which a predator kills its prey at different prey densities (Parvez and Omkar, 2005; Khan and Mir, 2008), whereas the numerical response (aggregational response) is the attraction of predators to prey density which increases the stability of predator–prey systems (Holling, 1961; Hassell, 1978). The important components of these responses are searching

rate (*a*) and handling time (*Th*), time spent in dominating, eating and digesting the prey (Hassell *et al.,* 1976).The study of functional and numerical responses is important in understanding the underlining mechanism in predator-prey interactions, in elucidating the practical role of co-evolutionary relationships and in contributing towards biological control (Houck and Strauss, 1989). The objective of the study was to determine the potential of *Chrysoperla* sp. (*carnea*-group) preying on *B. brassicae* through the study of functional and aggregational response.

MATERIALS AND METHODS

The experiment was carried out during 2007 in the laboratory of Division of Entomology, S. K. University of Agriculture Science and Technology of Kashmir, Shalimar, Srinagar, India. The functional response, cannibalism and aggregational response were assessed in controlled laboratory conditions of 25-30°C temperature with a 14:10 (light: dark) photoperiod and 60-70% relative humidity.

Insect arena

Chrysoperla sp. (*carnea*-group) eggs were obtained from the fields as well as from the culture maintained in the laboratory and *B. brassicae* were collected from cabbage fields at the research farm of SKUAST-K Shalimar and were maintained in cages (18 x 18 x 18 cm). The required stages of chrysopid (2nd and 3rd instars larvae) and aphids were taken from the culture and transferred to clear plastic jars (15cm diameter and 20cm height) with the help of a fine soft brush. A small twig of knol khol containing the required density of *B. brassicae* fitted into a conical flask containing water was placed inside each jar. The open end of the jar was then covered with a muslin cloth tightly with the help of a rubber band. One treatment (control) was also designed for natural mortality of aphids.

Functional and aggregational response

The functional response was evaluated at prey densities of 2, 4, 8, 16, 32, 64 and 128 aphids per predator per jar on *B. brassicae,* whereas numerical response (aggregational response) was evaluated at varied prey densities of aphids (8, 16, 32, 64 and 128) with varying densities of predators, (1, 2, 3, 4, and 5 per jar). Another set of experiments was also designed for the study of cannibalism at the above mentioned densities of prey with varying densities of predators. Each experiment was replicated five times and number of aphids (Mean ± S.E) consumed by 2nd and 3rd instar chrysopid larvae and cannibalism was also recorded after 24 hours. The aphids left unpreyed were removed and known number

of fresh aphids was provided daily in the experiment. The data for both the responses were collected and computed after taking observations strictly according to the procedures followed by various workers such as Athhan *et al.* (2004), Liu and Chen (2001) and Khan and Zaki (2008).

Statistical analysis

The functional and aggregational responses of *Chrysoperla* sp. against *B. brassicae* at different densities was measured or described by fitting Holling's disk equation to the data (Holling, 1959). The difference in two response curves is possibly related to the substrate on which experiments were performed. Holling's disk equation for Type II functional response was written on confidence limits (95%) and asymptotic standard errors are used as indicators of differences in searching rates for the 2nd and 3rd instars of *Chrysoperla* sp. against *B. brassicae.*

$$N_a = \frac{a(N/V)T_t}{1 + aT_h(N/V)} \quad \text{................................ (1)}$$

where, N_a = the number of prey consumed/predator, a = the rate of successful search, V = volume of plastic jar, N = the density of prey, T_t = the handling time of each prey and T_h = the total time prey and predator are exposed to each other.

The successful search rate of *Chrysoperla* sp. (*carnea*-group) over the experiment period was computed as:

$$a = 1/P \ In \ [N_1/(N_1-N_2)] \quad \text{.......…………...(2)}$$

where, a = Search rate, P = number of predators used, N_1 = density of prey, N_2 = number of prey consumed. Each of the above mentioned analysis was conducted by using non-linear function nls provided by the R-software (R Development Core Team, 2008).

Cannibalism: The data obtained from the experiments were subjected to statistical analysis after suitable transformation as suggested by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Functional response

The II and III instar larvae of *Chrysoperla* sp. (*carnea*-group) exhibited curvilinear curve Type II functional response on increase of *B. brassicae* density and the 3rd instar larvae consumed more prey than 2nd instar larvae at all densities (Figs. 1, 2 and Table 1). The consumption per day of 2nd larvae varied from 1.60 ± 0.20 to 23 ± 0.37, while in case of 3rd instar larvae the consumption per day

Table 1. Coefficient of attack rate (*a*) and handling time (*Th*) of *Chrysoperla* sp. (*carnea*-group) derived from Type II functional response using *B. brassicae* as prey

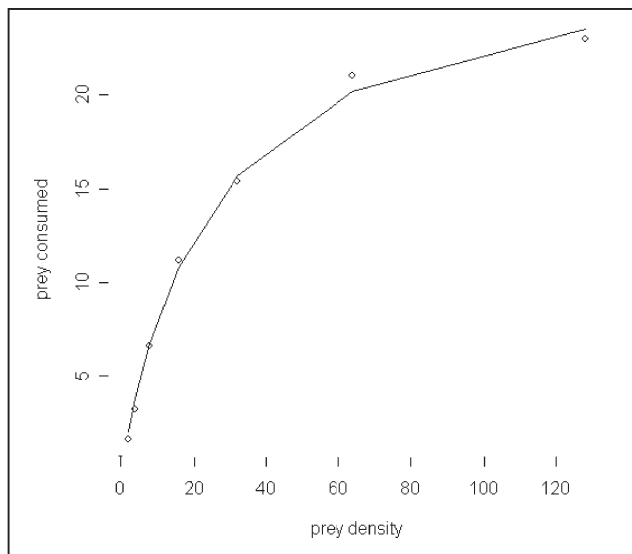| Aphid species used	*C. carnea* (group) (instars)	Parameters	Estimate ± S.E	t-value	P-value	r^2 at <0.001
B. brassicae	2nd instar	*a*	2.15 ± 0.14	15.57	P<0.001	0.7330
		Th	0.84 ± 0.03	30.13	P<0.001	
	3rd instar	*a*	2.40 ± 0.28	8.59	P<0.001	0.7308
		Th	0.74 ± 0.04	16.47	P<0.001	

Fig. 1. Functional response of *Chrysoperla* sp. (*carnea*-group) 2nd instar larva at different prey densities of *B. brassicae*
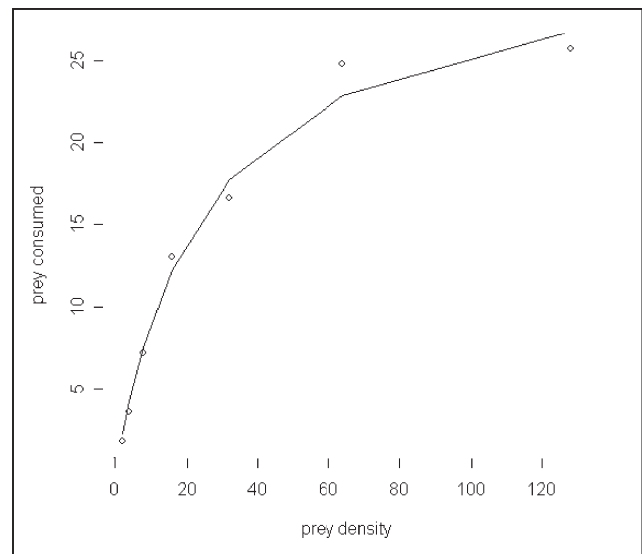

Fig. 2. Functional response of *Chrysoperla* sp. (*carnea* group) 3rd instar larva at different prey densities of *B. brassicae*

varied from 1.8 ± 0.00 to 25.8 ± 0.58 on *B. brassicae*. The quantity of prey consumed by depends on the larval age as well as density of the prey as supported by Scopes (1969) and Athhan *et al* (2004). An acceleration in consumption until density 110 was verified, after which consumption tended to decrease. This suggested an adjustment to type II functional response. Although less common in insects, the Type II model was verified by Kabissa *et al*. (1996) in *C. externa* preying on *Helicoverpa armigera*. The relative rate of prey consumption by *Chrysoperla* larvae was higher at lower prey densities (Fig. 3), indicating that it could be more effective at lower prey densities. A similar finding was shown by Mushtaq and Khan (2010). It exhibits a significant decline in consumption rate at higher prey densities, which might be due to attainment of satiation (Mills, 1982) or interference-stimulation, which can lead the predator to reject the prey (Reis *et al*., 2003).
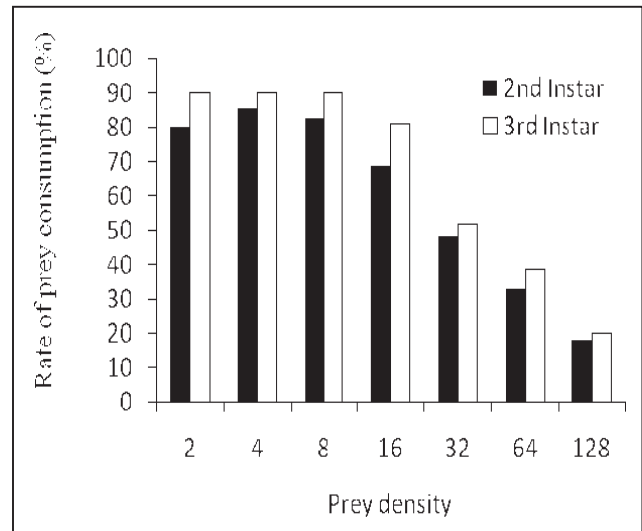

Fig. 3. Rate of prey consumption of *Chrysoperla* sp. (*carnea*-group) on different densities of *B. brassicae*

The result revealed that a Type II asymptotic curve described the data well. The asymptote in the curve showed the point of highest consumption rate. A non-linear model was further used to settle the accuracy of the shapes, as in such studies ecologists usually face difficulties in curve fitting when the data set of Type II response shows preference towards Type III response. It can lead to drawing deceptive inferences, which further might lead to wrong predictions about the destiny of prey-predator relations. The values for the non-linear parameter $(P \leq 0.001)$ obtained in this study verify the Type II response for the two larval instars of *Chrysoperla* used. The non-linear model thus can be suggested as a tool for further analyzing functional response curves.

The parameters estimated in evaluating the components of functional response are attack rate and handling time. The search rate tended to decrease when density increased (Fig. 4 and 5). According to Holling (1961), time spent in handling reduces search rate at higher densities, which can be attributed to proportional higher consumption at lower densities besides limit imposed by satiation at higher densities. Evaluating the handling time, a tendency to increase was noticed as prey density increased both for 2nd and 3rd instar larvae preying on *B. brassicae*. However, the mean coefficient of attack rate was higher for 3rd instar larvae with low handling time compared to 2nd instar larvae (Table 2 and Fig. 6). The coefficient of attack rate and handling time were the parameters used to find out the extent of these responses. Their values differed significantly $(P \leq 0.001)$ between the stages of predatory species when exposed to prey species, which indicates that they have different abilities to respond to increasing prey densities. This also indicates that predators exhibiting analogous functional
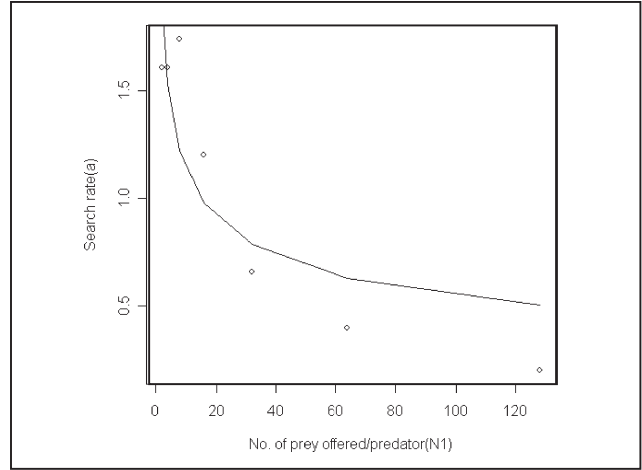

Fig. 4. Search rate of *Chrysoperla* sp. 2nd instar larva at different prey densities of *B. brassicae*
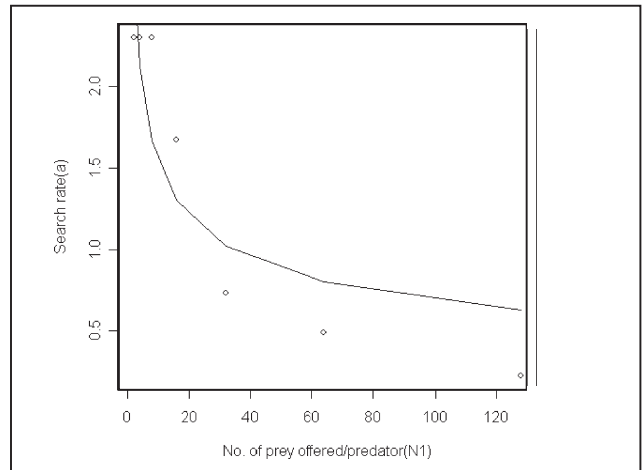

Fig. 5. Search rate of *Chrysoperla* sp. 3rd instar larva at different prey densities of *B. brassicae*.

Table 2. Coefficient of attack rate (a) of *Chrysoperla* sp. (*carnea*-group) derived from aggregational response using *B. brassicae* as prey

C. carnea (group) (instar)	Predator density	Attack rate (a) (estimate a±S.E)	r^2 at $\leq$ t value	P value	0.001
II instar	1	1.86 ± 0.25	7.41	P<0.001	0.86
	2	1.36 ± 0.16	8.21	P<0.001	0.85
	3	0.74 ± 0.07	10.47	P<0.001	0.76
	4	0.55 ± 0.12	4.58	P<0.001	0.04
	5	0.23 ± 0.01	9.29	P<0.001	0.06
III instar	1	2.32 ± 0.39	5.96	P<0.001	0.81
	2	1.81 ± 0.178	10.19	P<0.001	0.91
	3	0.89 ± 0.85	10.41	P<0.001	0.75
	4	0.73 ± 0.18	3.88	P<0.001	0.11
	5	0.19 ± 0.05	3.60	P<0.001	0.61

response curves cannot be deemed to respond similarly. The differences in parametric values might be due to the variation in size, voracity, satiation time, hunger levels, digestive ability, walking speed, etc. (Parvez and Omkar, 2005; Khan, 2009).

Aggregational response

Aggregation or attraction of predators to prey density is called "aggregational response". Aggregational response increases the stability of spatially-distributed predator-prey system (Holling, 1961). The results of this study indicated that aggregation or attraction of predators increased with increase in prey density, i.e., they showed strong degree of arrestment in patches of higher host density of *B. brassicae*. The maximum prey consumption of 82.2 ± 0.63 ($P \le 0.001$) for 2nd instar and 112.4 ± 0.24 ($P \le 0.001$) for 3rd instar was recorded at higher prey density of 128 with predator density of 5 with negligible intra-specific competition (Fig. 7 and 8). Prey and predator densities play an important role for the survival of predator. Results indicated that only two predators survived at the density of 8 aphids in case of 2nd instar larvae and in case of 3rd instar larvae only one survived. But a prey density increased upto 128 aphids was sufficient for the survival of all five predators (Fig. 7 and 8). Maximum aggregation of predators (2nd and 3rd instar) found at higher prey densities was due to sufficient availability of food that reduced the chances of cannibalism which in turn encouraged their survival and stability in a given area.

The larval cannibalism exhibited by *Chrysoperla* sp. at varying predator density was reduced with increasing prey densities. When prey density was 128 aphids, the cannibalism was not exhibited and the cannibalism was higher for 3rd instar (Table 3 and 4). The results reported here suggested that larvae of predators cannibalize in the presence of aphids but the intensity of cannibalism is greater when aphids are scarce. This implies that the occurrence of cannibalism is possibly linked to the chances of encountering of aphids. At higher density, less cannibalism is linked to a higher encounter of aphid (Agarwala, 1991). In case of *Chrysoperla*, the cannibalistic study is scanty for the comparison of data and no such studies have been conducted so far regarding aggregational response. However, Holling (1959) advocated that aggregational response was shown to be very important for several predator-prey systems and predators selected for biological control should have a strong aggregational response, otherwise they would not be able to suppress pest population. The estimated search rate (*a*) showed a downward fall as predator density increased, *i.e.*, 1.86 ± 0.25 to 0.23 ± 0.01 for 2nd instar and 2.32 ± 0.39 to

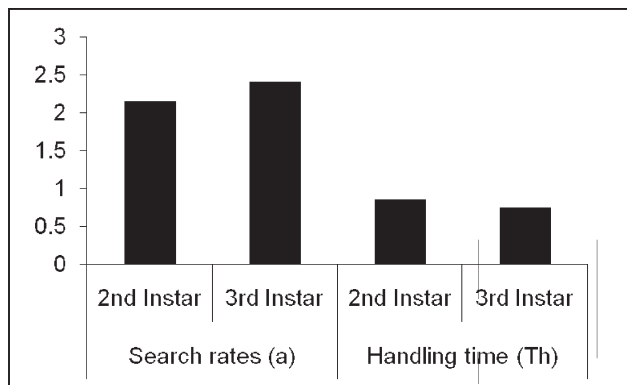**Fig. 6. Coefficient of attack rate (a) and handling time (Th) of *Chrysoperla* sp. derived from Type II functional response using *B. brassicae* as prey**
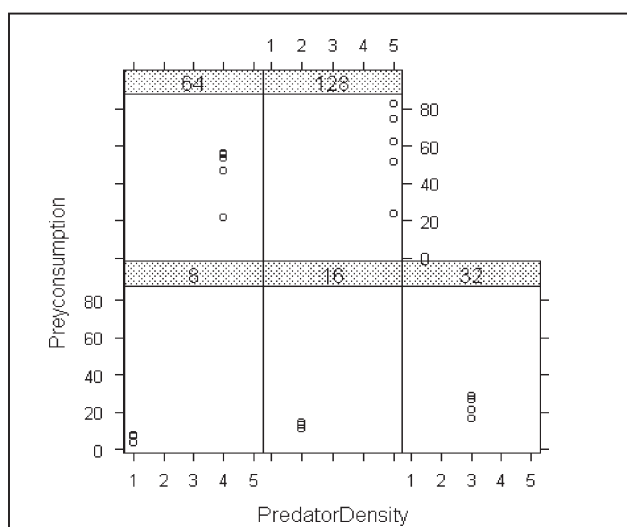

Fig. 7. Aggregational response of *Chrysoperla* sp. 2nd instar larvae against *B. brassicae*. Dots showed the number of larvae survived and their height showed prey consumption at different density

Fig. 8. Aggregational response of *Chrysoperla* sp. 3rd instar larvae against *B. brassicae*. Dots showed the number of larvae survived and their height showed prey consumption at different density
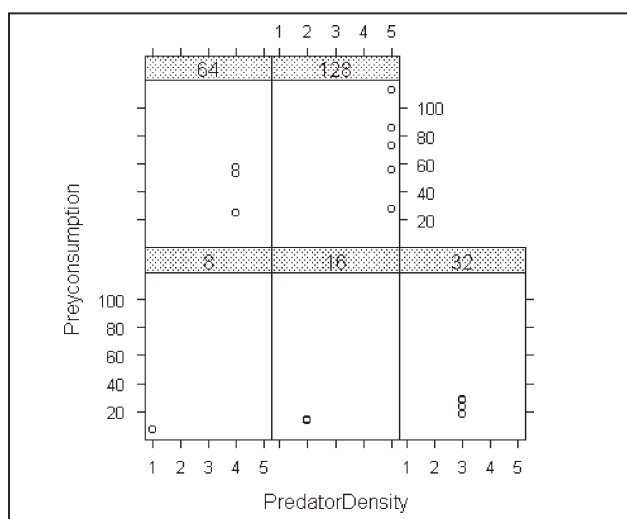
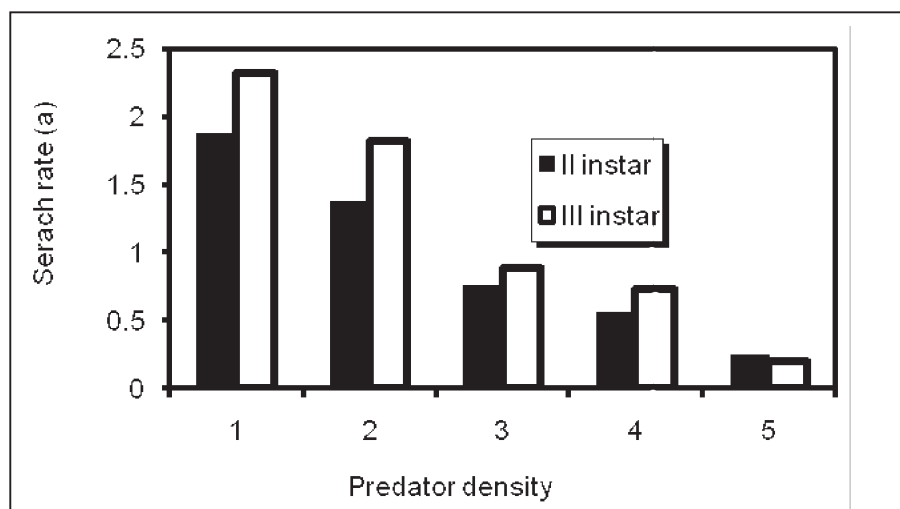**Table 3. Cannibalism in 2ⁿᵈ instar larvae of *Chrysoperla* sp. at different densities of *B. brassicae***

Prey Density	Mean number of predators cannibalized with varying predator densities			
	2	3	4	5
8	0.8 ± 0.20 (1.18 ± 0.10)	1.4 ± 0.24 (1.36 ± 0.08)	2.6 ± 0.24 (1.8 ± 0.06	3.8 ± 0.20 (2.07 ± 0.05)
16	0.6 ± 0.24 (1.02 ± 0.125)	0.8 ± 0.20 (1.11 ± 0.10)	2.2 ± 0.20 (1.63 ± 0.06)	3.4 ± 0.24 (1.97 ± 0.06)
32	0.00 ± 0.00 (0.71 ± 0.00)	0.4 ± 0.24 (0.91 ± 0.12)	0.8 ± 0.20 (1.12 ± 0.10)	2.0 ± 0.37 (1.57 ± 0.10)
64	0.00±0.00 (0.71 ± 0.00)	0.00 ± 0.00 (0.71 ± 0.00)	0.00 ± 0.00 (0.71 ± 0.00)	0.4 ± 0.24 (0.91 ± 0.12)
128	0.00 ± 0.00 (0.71 ± 0.00)	0.00 ± 0.00 (0.71 ± 0.00)	0.00 ± 0.00 (0.71 ± 0.00)	0.00 ± 0.00 (0.71 ± 0.00)

*Mean ± S.E of 5 replications; *figures in ( ) represent square root transformation

Table 4. Cannibalism in 3ʳᵈ instar larvae of *Chrysoperla* sp. at different densities of *B. brassicae*

Prey Density	Mean number of predators cannibalized with varying predator densities			
	2	3	4	5
8	1.0 ± 0.00 (1.22 ± 0.00)	2.0 ± 0.00 (1.58 ± 0.00)	3.8 ± 0.20 (2.070 ± 0.05)	4.0 ± 0.00 (2.12 ± 0.00)
16	0.8 ± 0.44 (1.02 ± 0.17)	1.4 ± 0.24 (1.36 ± 0.08)	2.6 ± 0.24 (1.75 ± 0.07)	3.6 ± 0.24 (2.02 ± 0.06)
32	0.2 ± 0.2 (0.81 ± 0.10)	1.0 ± 0.00 (1.22 ± 0.00)	2.0 ± 0.00 (1.58 ± 0.00)	2.8 ± 0.20 (1.81 ± 0.06)
64	0.00 ± 0.00 (0.71 ± 0.00)	0.00 ± 0.00 (0.71 ± 0.00)	1.0 ± 0.00 (1.22 ± 0.00)	1.4 ± 0.24 (1.36 ± 0.08)
128	0.00 ± 0.00 (0.71 ± 0.00)	0.00 ± 0.00 (0.71 ± 0.00)	0.00 ± 0.00 (0.71 ± 0.00)	0.00 ± 0.00 (0.71 ± 0.00)

*Mean ± S.E of 5 replications; *figures in ( ) represent square root transformation

Fig. 9. Coefficient of attack rate (a) of *Chrysoperla* sp. derived from aggregational response to *B. brassicae*

0.19 ± 0.05 for 3rd instar (Fig. 9). As density of predators increases under conditions of food limitation, individual predators waste an increasing proportion of their searching time in encounters with other con-specifics. The results are in conformity with Khan and Zaki (2008) who reported that search rate *(a)*, of *Chrysoperla* sp. (*carnea*-group) on Euonymus aphid, *Aphis fabae solanella* Theobald decreased from 0.27 to 0.13 with increased predator density. In general, search rate recorded for 2nd instar larvae was higher as compared to 3rd instar, which may be due to higher aphid consumption (Athhan *et al.*, 2004). Similarly, Khan and Zaki (2008) reported that this variation in searching rates might be due to hunger levels, digestive power and searching speeds.

Although obtained in the laboratory conditions, the results of this work allow us to conclude that maximum aggregation, high search rates and consumption ability of 3rd instar larvae at patches of higher aphid infestation could reflect its efficacy as an important biocontrol agent for the management of *B. brassicae* in cruciferous vegetable crops.

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