



Research Article

Stage-specific functional response of predaceous ladybird beetle, *Harmonia eucharis* (Mulsant) (Coleoptera: Coccinellidae) to green apple aphid, *Aphis pomi* De Geer (Hemiptera: Aphididae)

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ABSTRACT: Functional response of different larval instars, adult males and females of the predaceous coccinellid, *Harmonia eucharis* (Mulsant), was evaluated under laboratory conditions to varying density of green apple aphid, *Aphis pomi* De Geer. The life stages of *H. eucharis* exhibited a curvilinear Type II functional response. The fourth instar larva of *H. eucharis* consumed more aphids (34.06 aphids / day each) due to its larger size and greater voracity as compared to first instar larva (14.73 aphids / day each), second instar larva (25.73 aphids / day each), third instar larvae (29.06 aphids / day each), adult female (28.06 aphids / day each) and adult male (22.06 aphids / day each). The search rate and handling time estimated for different stages of *H. eucharis* showed that the fourth instar had higher search rate, whereas the handling time showed the opposite trend as search rate. The results suggested that fourth instar larva of *H. eucharis* is the efficient predator for the biological control of *A. pomi*. Further field-based studies are needed to confirm this hypothesis.

KEY WORDS: *Aphis pomi*, coccinellids, functional response, handling time, *Harmonia eucharis*, search rate

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INTRODUCTION

Ladybird beetles have been receiving attention as biological control agent due to their ability to feed on a large number of aphids (Obrycki, 1998; Khan *et al.*, 2009). For most species of coccinellids, both adults and larvae are potential predators of a wide range of prey, including aphids (Hagen, 1962; Sarmiento *et al.*, 2007) and phytophagous mites, which cause serious damage to horticultural crops including fruits and vegetables all over the world (Moreira *et al.*, 2004; Khan *et al.*, 2007).

Predators react to the density of prey in several ways, which were first described and defined by Solomon (1949) and then analyzed by Holling (1959). The responses of a predator to changes in prey density can be divided into two responses: a) functional response or change in the number of prey consumed in response to changing prey density and b) numerical response or the change in predator density resulting from a change in prey density (Solomon, 1949). This is further supported by plotting the number of prey killed against the number of prey available and analyzing a continuum of patterns, which ecologists have

delimited into four types (Holling, 1959 and 1966). The functional response curves may represent an increasing linear rise to plateau for crustacean predators (Type I), a curvilinear rise to a plateau for predaceous insects (Type II), an s-shaped curve rising to a plateau for vertebrate predators (Type III) and a dome-shaped functional response (Type IV) caused by disturbance of the insect predator by prey activity at high prey density (Luck, 1985). Sabelis (1992) reported another type of functional responses Type V. Predaceous ladybird beetles show a Type II functional response, as reported for *Coccinella septempunctata* (Shukla *et al.* 1990), *Eriopis connexa* (Sarmiento *et al.*, 2007), *Harmonia axyridis* (Roy and Wagnberg, 2008), *Calvia punctata*, *Hippodamia variegata* (Khan and Mir, 2008) and *Adalia tetraspilota* (Khan *et al.*, 2009).

Two parameters are widely used to describe the functional response of a predator feeding on a single species of prey; these are the predator's "attack rate" or "searching rate" (a) and its handling time (T_h) (Hassell *et al.*, 1976). When the predator passes through a series of size classes, different values of a and T_h will characterize each predator

instars-prey combination. The coefficient of searching efficiency estimates the steepness of an increase in predation with the satiation threshold (Hassell, 1978). Despite the undoubted importance of such predator stage effects on the dynamics of predator-prey interaction (Khan, 2009), only few studies have actually measured a and T_h values for a range of predator instars feeding on prey. Thus, the objectives of this study were to determine the functional response of different class sizes of *H. eucharis* feeding on various densities of green apple aphid, *Aphis pomi*.

MATERIALS AND METHODS

Culture maintenance and experimental design

Cultures of both, predatory coccinellid (*H. eucharis*) and aphids (*A. pomi*), were established in a controlled temperature room. The aphids and the predators were collected from University apple orchard of Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar Campus, Srinagar, Jammu and Kashmir, India, during 2007 in June and maintained at $25 \pm 2^\circ\text{C}$ temperature, $60 \pm 10\%$ relative humidity and a photoperiod of 14 hour light: 10 hour dark.

Ten pairs of coccinellids were released for mating and oviposition into plastic container (height 20 cm and diameter 15 cm) containing moist filter paper and covered with muslin cloth and provided daily with sufficient prey for egg laying and survival. Newly hatched larvae were collected from the jars and reared individually. The different stage sizes of *H. eucharis* were taken from the culture for experiments. The larvae and adults were starved for 24 hrs in vials individually before the experiments. This was to minimize differences in individual hunger levels (Nakamura, 1977). Thereafter, they were introduced individually into the experimental jars separately together with 2, 4, 8, 16, 32, 64, 128, 256 aphids on excised apple leaves stuck to agar medium. The test predators were randomly assigned to the aphid density treatments and one treatment (control) was also designed for natural mortality of aphids. At each aphid density, 3 replicates were used for different instars larvae and adults and replicated 10 times density wise. After 24 hrs, the numbers of aphids consumed by the different class size predators were recorded by counting the remaining aphids present in each jar.

Data analysis

The numbers of aphids preyed by different stages of coccinellids at different densities were analyzed separately using a non-linear least square programme (R Development Core Team 2008). Usually, it is difficult to discriminate between Type II and III functional responses as mentioned by many workers (Mills, 1982; Trexler, 1988). Hence, prior to fitting the data to a particular Holling's Disc equation (1959), *i.e.*, type II functional response, Royama (1971) and Rogers (1972) equations on the "random predator equation

(2)" was taken into consideration. In order to avoid the errors incurred by applying the linear regression method to estimate a and T_h as suggested by Rogers (1972), non-linear function (nls) provided by the R-software (R Development Core Team 2008) was used.

RESULTS AND DISCUSSION

The functional responses usually provide insights into the suitability of a predator as a biocontrol agent. The type of functional response, that is the shape of relationship of the number of prey eaten versus prey available, influences to the dynamics of the predator-prey population and may contribute to the stability of predator-prey systems (Hassell, 1978; Taylor, 1980). As seen from Fig. 1, the functional responses of different larval instars and adult male and female of *H. eucharis* to various densities of *A. pomi* were typically of Type II with a steep initial rise in consumption rates as the prey density increased (Table 1). The consumption rate of fourth instar larvae was increased up to 34.06 aphid / day each (Fig. 1d), which was higher than that of third instar (29.06 aphids), adult female (28.06 aphids) second instar (25.73 aphids), adult male (22.06 aphids) and first instar (14.73 aphids) (Figs. 1a – 1e). Similar functional responses were reported by Omkar and Pervez (2004) and Khan (2009) in *Propylea dissecta* and *Adalia tetraspilota* to increasing density of *Aphis gossypii* and *Bravicornyne brassicae*. This type of response was also reported for other coccinellid species such as *Coccinella septempunctata*, *Cheilomenes sexmaculata* and *Harmonia axyridis* (Sinha *et al.*, 1982; Shukla *et al.*, 1990; Parvez and Omkar, 2005; Khan and Mir, 2008).

The consumption of *A. pomi* by the larvae of *H. axyridis* increased significantly with age and the last instar larvae consumed maximum number of *A. pomi* under the various increasing densities. Similarly, the adult female of *H. eucharis* consumed more aphids than adult male, but less than the third and fourth instar larvae. Cardoso and Lazzari (2003) reported similar consumption of *Cinara* spp. by fourth instar larvae of *Cycloneda sanguinea* (L.) and *Hippodamia convergens*. The consumption rates of different instar larvae were varied due to their size and voracity. Large size coccinellids consumed more aphids than smaller ones (Isikber, 2004; Khan and Mir, 2008). The female of two-spotted lady beetle, *Adalia bipunctata* ate more of pea aphid *Acyrtosiphon pisum* than males to meet growth and reproductive requirements (Hemphill *et al.*, 1996; Roche, 1998).

The fourth instar larvae of *H. eucharis* responded more vigorously to lower densities of *A. pomi* than other instars larvae and adults. Cardoso and Lazzari (2003) reported that the functional response of fourth instar larvae of *H. convergens* and *C. sanguinea* showed an earlier and steeper increase than that of other instar larvae and adults when the densities of *Cinara* nymphs increased and the

Table 1. Stage-specific functional response of predaceous ladybird beetle, *H. eucharis* to green apple aphid, *A. pomi*

Stages of <i>H. eucharis</i>	Parameter	Estimate	SD	<i>t</i> value	r ² at p<0.001	Residual SD
I instar larva	<i>a</i>	2.74106	0.35705	8.363	0.552	0.6167
	<i>T_h</i>	1.57132	0.06207	29.817		
II instar larva	<i>a</i>	2.65137	0.29539	8.976	0.6238	1.129
	<i>T_h</i>	0.89932	0.03587	25.072		
III instar larva	<i>a</i>	3.09049	0.36310	8.512	0.6235	1.384
	<i>T_h</i>	0.77363	0.03251	23.796		
IV instar larva	<i>a</i>	2.76241	0.37895	7.290	0.6481	1.785
	<i>T_h</i>	0.68211	0.03625	18.820		
Adult male	<i>a</i>	2.64471	0.38066	6.948	0.6047	1.216
	<i>T_h</i>	1.09703	0.05316	20.635		
Adult female	<i>a</i>	3.06928	0.38820	7.906	0.6198	1.430
	<i>T_h</i>	0.80856	0.03615	22.370		

former species of approached a higher level of predation than the latter.

The asymptotes in the Type II curve display the point of maximum consumption rate. A non-linear model was further used to find out the correctness of the shapes and in such studies ecologists normally face difficulties in curve fitting when the data set of Type II response shows inclination towards Type III response. Such a response could designate that the predator showed better performance due to switching or learning. While the non-linear model easily illuminates the fragile differences in the Type II and III responses, it fails to categorize them from Type I (Holling, 1959). The investigational data, especially of fourth instar larvae of *H. eucharis* preying on *A. pomi* at lower density, seem to sustain a Type I functional response, the data were further strongly fitted to equation 2. The response of different stages of the predator at lower and higher densities might lead to wrong predictions. Therefore, efforts are wanted to make a similar logistic model to differentiate Type I from II and III (Parvez and Omkar, 2005; Khan and Mir, 2008). Unfortunately, the non-linear model for functional response of predaceous ladybird beetles is least reported. The functional response parameters obtained by reciprocal transformation (Livdahl and Stiven, 1983) gave the best fit to the data and can be used to simulate prey consumption value at any prey density. Thus, efforts needed to generate voluminous experimental data at different aphid densities in the laboratory conditions.

The search rates (*a*) and handling time (*T_h*) are presented in Table 1. The fourth instar larvae had the highest search rate that was not significantly higher than adult female whilst the handling time of the fourth instar larvae was significantly lower than other classes of *H. eucharis*.

Apparently, the attack rate is related to speed, searching rate and distance, which a predator responds in the presence of (Holling, 1959; Omkar and Parvez, 2004; Mushtaq and Khan, 2010a). The attack rate and handling time are the parameters that replicate the significance of these responses. These parameters differed drastically and the stages of *H. eucharis* possess different capacities to pursue the prey at increasing *A. pomi* densities. It also shows that different stages of *H. eucharis* manifesting similar quantitative response curves may not necessarily have the same quantitative impact on *A. pomi*.

It can be concluded that *H. eucharis* exhibited Type II functional response, which differed quantitatively among the different stages feeding on *A. pomi*. Low handling time and high search rate were exhibited by fourth instar larvae than other classes of *H. eucharis* and hence the fourth instar have the efficiency for the management of *A. pomi* infestation. However, further field studies are required in order to assess this predator's efficiency under natural conditions.

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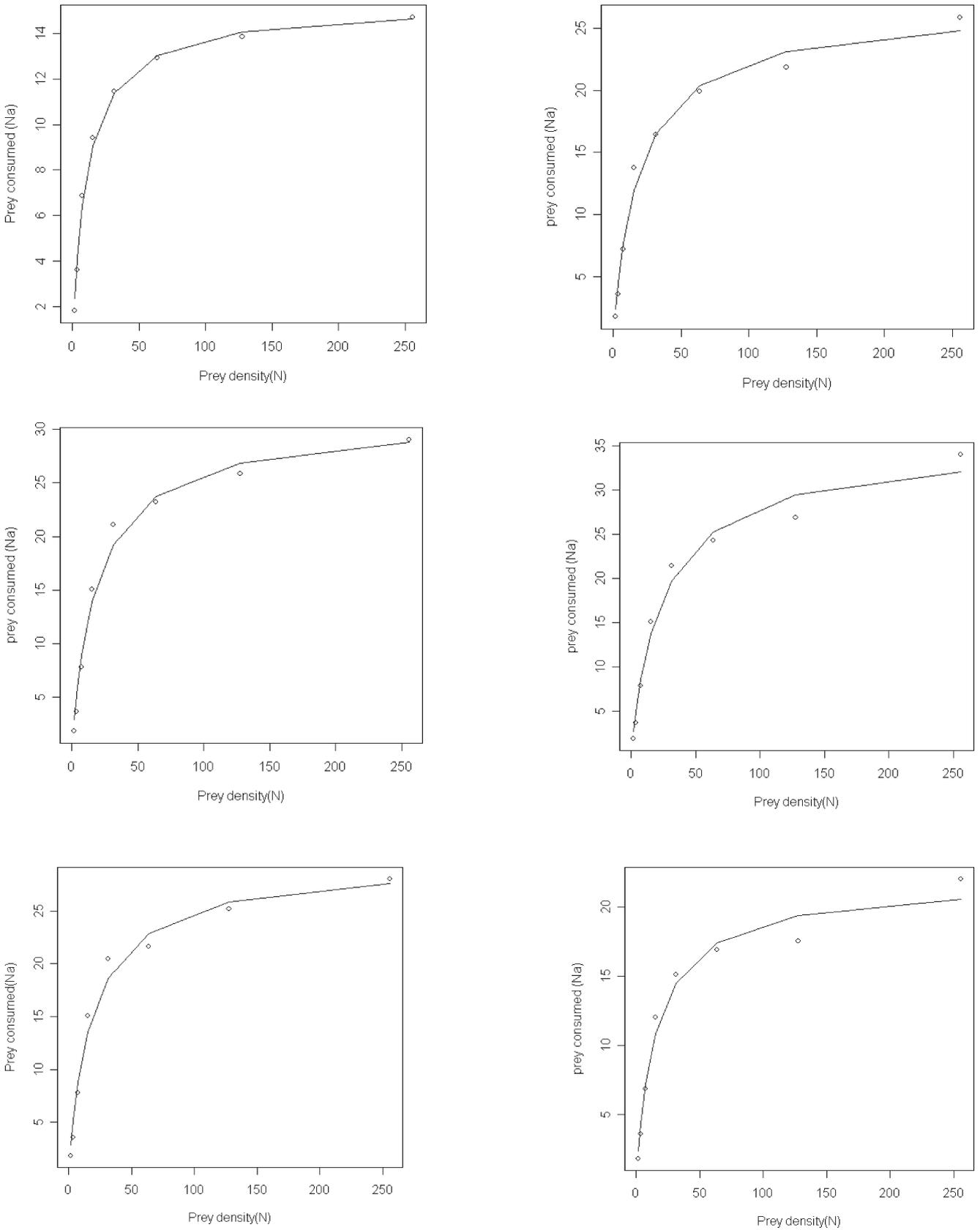


Fig. 1. Type II curvilinear functional response curves of *H. eucharis* (a to d) I to IV instar larvae and (e and f) adult female and male to *A. pomi*

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