Functional response and reproductive attributes of the aphidophagous ladybird beetle, *Harmonia dimidiata* (Fabricius) in oak trees of sericultural importance

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ABSTRACT

Harmonia dimidiata (Fabricius) (Coleoptera: Coccinellidae) is the dominant predator of the aphid species *Cervaphis quercus* Takahashi. This aphid is a serious pest of oak trees in several parts of north-east India. Young leaves of oak trees are used in sericulture by rural people and by industry in several parts of north-east India. The effect of different aphid densities on food consumption and fecundity of *H. dimidiata* was studied in the laboratory. Female beetles were maintained from the time of eclosion till death at a fixed density of 25, 50, 75,100 or 125 aphids. Both the functional response and the reproductive numerical response showed the upper asymptote at 100 adult aphids/female. At this density, females matured earlier and produced more eggs over a longer reproductive period. At lower prey densities, females matured late and they either did not produce eggs or produced fewer eggs. At the higher prey densities, females did not produce more eggs than the asymptote. Results suggested that *H. dimidiata* are an effective predator of *C. quercus* aphids on oak trees and could be exploited as a biological control agent in the rising phase of aphid population growth.

Introduction

Ladybird beetles (Coleoptera: Coccinellidae) are beneficial tools in the biological control of phytophagous pests, such as aphids, diaspids, coccids, adelgids, aleyrodids, pentatomids, thrips and acarids (Hodek and Honek, 1996; Dixon, 2000). Among the prey groups, aphids are regarded as the most severe insect group due to their unique host plant association, high reproductive potential, polymorphism and long range dispersal activities (Dixon, 1998).

The aphid, *Cervaphis quercus* Takahashi (Hemiptera: Aphididae: Greenideinae), is a monophagous consumer of oak trees *Quercus serrata* Thunberg (Family Fagaceae). These oak trees grow abundantly in the foothills of Manipur state, north-east India and are also cultivated for the sericulture of the silkworm *Antheraea proylei* Jolly (Lepidoptera: Bombycidae). High populations of *C. quercus* have been reported during April–September when oak trees produce young leaves and apical shoots. During this period, temperatures, rainfall, and relative humidity are high (21 °C to 24 °C, average 12.6 mm/rainy day and 73% to 77%, respectively) (Shantibala et al., 1995; Sharmila et al., 2007). Heavy colonization of oaks by aphids results in the curling and yellowing of leaves and may lead to stunted growth of plants (Raychaudhuri, 1980). The reduction of aphid attacks on oak trees is important to the people engaged in sericulture. Use of potential natural enemies can provide natural control of aphid populations.

Among the natural enemies of *C. quercus*, the ladybird beetle species *Harmonia dimidiata* (Fabricius) is the dominant predator in the field (Singh, 1992). Field studies on the numerical response of *H. dimidiata* suggest that adults become active when aphid density per plant is low and that their aggregation and reproduction are closely synchronized with natural populations of *C. quercus* on oak trees (Sharmila et al., 2007). However, there is no information regarding its functional and reproductive numerical responses to changes in prey density. This information is important to ascertain its usefulness as a biological control agent (Agarwala and Bardhanroy, 1999; Omkar and Pervez, 2002; Agarwala et al., 2007).

Aphid populations are ephemeral and are found primarily on host plants when their apical shoots are growing (Dixon, 1998). Growing aphid populations may undergo rapid changes in density due to several factors, such as natural enemies, deterioration in host quality and climatic changes (Galecka, 1966; Mohammed and van Emden, 1989; Helden et al., 1994; Agarwala and Datta, 1999). As a result development of larvae and reproduction of adult females of predators present in aphid colonies are likely to be affected (Agarwala et al., 2001).

The objective of this study was to investigate the effects of *C. quercus* aphid density on the functional response and reproductive attributes of *H. dimiditata* females.

Materials and methods

Males and egg laying females of *H. dimidiata* attacking aphid populations on oak trees were collected from Regional Tasar Research

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Table 1
Mean ($\pm$ sem) values of aphids consumed, eggs produced, progeny loss, pre-oviposition period, oviposition period and adult longevity of *H. dimidiata* females in adult life at increasing prey density ($n = 10$ replicates for each prey density).

Prey density	Aphids eaten (no.)	Eggs produced (total no. of eggs)	Progeny loss (arcsine root transformed)	Pre-oviposition period (days)	Oviposition period (days)	Adult longevity (days)
25	$247.53 \pm 9.45a$	0.00	0.00	0.00	0.00	$25.50 \pm 0.12a$
50	$587.22 \pm 7.39b$	$637.80 \pm 12.47a$	$2.71 \pm 0.10a$	$14.2 \pm 2.13a$	$22.80 \pm 0.97a$	$43.18 \pm 0.09b$
75	$1728.64 \pm 32.40c$	$755.80 \pm 19.017b$	$1.64 \pm 0.08a$	$11.20 \pm 0.49b$	$29.20 \pm 1.85b$	$50.94 \pm 4.67c$
100	$2244.17 \pm 54.80d$	$969.20 \pm 18.47c$	$0.41 \pm 0.02a$	$9.40 \pm 0.87c$	$36.40 \pm 1.66c$	$60.90 \pm 8.06d$
125	$1934.4 \pm 23.78d$	$846.34 \pm 5.09c$	$1.02 \pm 0.06a$	$10.10 \pm 1.02c$	$31.20 \pm 1.31c$	$54.60 \pm 7.34d$

Mean values followed by different letters in a column denote significant differences by Tukey's multiple range test at $P < 0.01$.

Station, Manipur, in north-east India (24°44′N, 93°58′E). Beetles were kept in ventilated plastic boxes ($6 \times 17.5 \times 11.6$ cm) and offered an excess supply of live *C. quercus* prey until females began to lay eggs. Each egg cluster was transferred to a 9 cm petri dish (area 150 cm² approx.), which was lined with moistened filter paper. Upon hatching, individual larvae were reared in 5 cm petri dishes on an excess supply of *C. quercus*. Sufficient numbers of larvae were reared at each prey density so as to get 10 adult females that were weighed within 12 h of eclosion and kept individually in 9 cm petri dishes. Unmated males of similar ages were collected from the stock culture and were confined with 2-day-old females in a 1:1 ratio for 4 h to facilitate mating. This was repeated every 48 h at the time of food change in order to maintain the reproductive vigor of females and continued till their death. Individual gravid *H. dimidiata* females (pre-oviposition period: mean $\pm$ SE $= 9.40 \pm 0.87$, $n = 14$) were kept in 9 cm petri dishes in an incubator at a temperature of 22 ± 1 °C and a photoperiod of 16:8 (L:D) h. They were provided with a prey density of 25, 50, 75, 100 or 125 live adult aphids per female per day. The remaining aphids were removed and replaced by fresh aphids every 24 h. The mean number of aphids eaten (functional response) and the number of eggs produced (reproductive numerical response) by female beetles at different prey densities were noted at 24 h intervals for the duration of their life. This was repeated 10 times at each prey density. Percent progeny loss (number of unviable eggs $\times$ 100 / total number of eggs produced), pre-oviposition period, oviposition period and adult longevity were also determined.

Statistical analysis

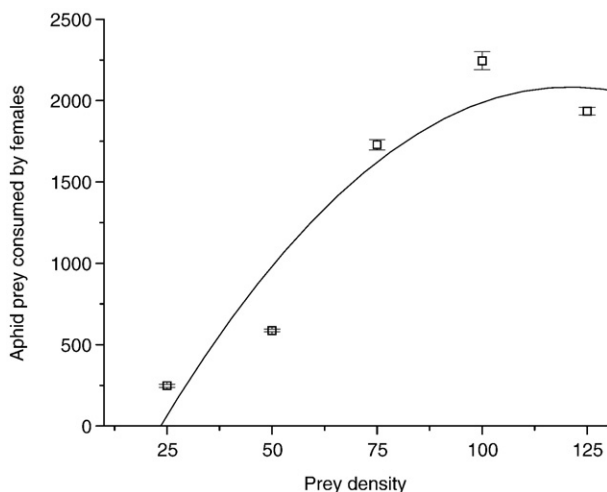For the purpose of clarity, regression lines of the functional response and the reproductive numerical response were drawn based on mean values of aphids consumed and eggs produced, respectively. The raw data of these experiments were subjected to 1-factor ANOVA for interaction between the prey density and the effects, viz. prey consumed, eggs produced, progeny loss, pre-oviposition period, oviposition period, and adult longevity (Table 1). All proportional or percent data were arcsine root transformed before statistical analysis. When necessary, comparison between treatments was made by Tukey's multiple comparison tests. A significance level of 0.05 was used to reject the null hypothesis. Data analysis was done with the help of statistical programme 'Origin 7'.

Results

Functional response and reproductive numerical response

The mean number of aphids eaten and eggs produced by a *H. dimidiata* female per day increased gradually from low prey density to higher prey density, until an upper asymptote was recorded at 100 aphids/female/150 cm² (ANOVA: aphids eaten: F ratio $= 9.67$; $df = 4$, 45, $P < 0.05$; eggs produced: F ratio $= 33.17$, $df = 4$, 45, $P < 0.05$, Table 1). The number of aphids consumed and eggs produced by females were recorded to be the minimum at 50 aphids/female/cm². At 125 aphids/female, prey consumption and egg production were not significantly different from 100 aphids/female/150 cm². Female beetles did not produce eggs at the density of 25 aphids. Regression analysis suggested that a curvilinear response is a better fit to the feeding data ($Y = -0.11 + 53.12X - 0.22X^2$, $r^2 = 0.91$, $P < 0.01$; Fig. 1) and to the egg production data ($Y = -68.36 + 32.54X - 0.163X^2$, $r^2 = 0.97$, $P < 0.01$; Fig. 2) than a linear response with a flat maximum (feeding: $Y = 0.16 + 0.09X$, $r^2 = 0.83$, $P < 0.05$; egg production: $Y = 8.09 + 1.09X$, $r^2 = 0.71$, $P < 0.05$). Changes in egg production by *H. dimidiata* females closely resembled the changes in the quantity of aphids eaten at different prey densities (Figs. 1 and 2).
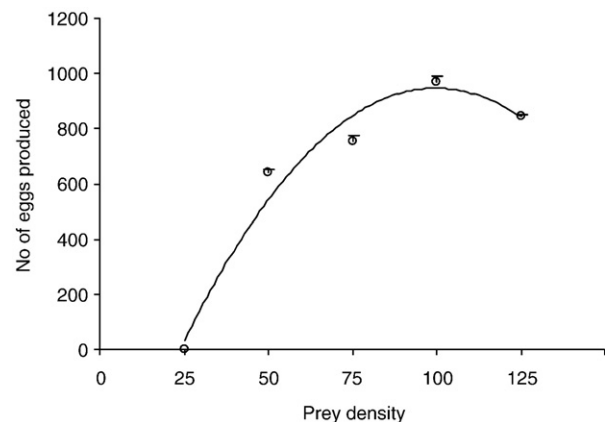

Fig. 1. Functional response of number of aphids consumed by *H. dimidiata* females (mean $\pm$ SE) during its adult life at different prey densities.

Fig. 2. Reproductive numerical response of number of eggs produced by *H. dimidiata* females (mean $\pm$ SE) during its oviposition period at different prey densities.
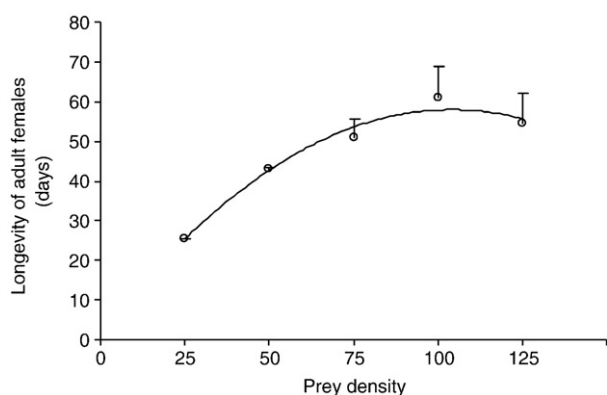
Fig. 3. Adult life span of *H. dimidiata* females (mean ± SE) in response to different prey densities.

Pre-oviposition period and oviposition period

Females kept at lower prey densities had a longer pre-oviposition period and a shorter oviposition period than the females that were kept at higher prey densities (Table 1). Time taken to mature eggs and to begin laying them was lowest at 100 aphids/female/150 cm^2 although this was not significantly different from the pre-oviposition period of females kept at 125 aphids/female/150 cm^2. Females kept at a prey density of 25 aphids/female/150 cm^2 did not produce eggs, and these females had the shortest life span (25.50 days) (Table 1).

Adult longevity

Females maintained at lower prey densities had a shorter life span than females kept at higher prey densities (ANOVA: *F* ratio = 3.62; *df* = 4, 45, *P* < 0.05; Table 1). Regression analysis suggested a non-linear response of adult longevity to prey density with an upper asymptote recorded at 100 aphids/female/150 cm^2 ($Y = 1.37 + 27.20X - 3.27X^2$, $r^2 = 0.98$, $P < 0.05$). At higher prey density, adult longevity was not statistically different from the asymptote (Fig. 3).

Progeny loss

Progeny loss is the proportion of the eggs produced by females that did not hatch. Females kept at a prey density of 100 aphids showed less progeny loss than the females that were kept at lower or higher prey densities (Table 1). However, the observed differences in progeny loss were not statistically significant.

Discussion

A number of studies have demonstrated the effects of prey density on the feeding, survival and reproduction of aphidophagous predators (Evans and Youssff, 1992; Ives et al., 1993; Yasuda and Ishikawa, 1999; Agarwala et al., 2001). Most coccinellid predators, as well as other predators of aphids, are reported to show Holling's (1965) functional response type II (Hodek and Honek, 1996; Agarwala et al., 2001). Such a response is typical of predators foraging in unstable prey populations and this response means rapid utilization of food by predators even at lower densities. In the present study, *H. dimidiata* females displayed a similar response.

The reproductive numerical response of *H. dimidiata* females to prey density was similar to the functional response. Such a correspondence in the shapes of the functional and numerical responses is suggestive of the dependence of the predator's rate of increase on their successful searching for and consumption of prey.

Results of this study revealed a significant influence of prey density on the reproductive attributes of *H. dimidiata* in terms of egg production, reproductive period and number of eggs hatched. Results further suggested that the age to maturity was profoundly affected by the quantity of food eaten by females during pre-oviposition period. Females reared at 100 aphids/female/150 cm^2 attained maturity significantly faster than the females kept at lower prey densities. The above findings are similar to those of Rhamalingham (1985), Agarwala and Bardhanroy (1997), and Agarwala et al. (2001) wherein decreased consumption due to less suitable aphids or poor supply of preferred aphid prey resulted in longer pre-reproductive periods. Longer reproductive periods of females accompanied by higher fecundity and higher success rate of eggs hatching was recorded at 100 aphids/female/150 cm^2 which might be ascribed to optimum consumption and utilization of aphid food that provided adequate energy for maturation of eggs over a longer period. Lower prey density might have affected the egg development and consequently higher progeny loss as certain amount of food is necessary for proper maturation of the ovarioles (Honek, 1980). Ferran et al. (1984) recorded a linear relationship between the weight of food consumed and number of eggs deposited.

Feeding and oviposition patterns of individual predators reflect the adaptiveness of their populations to foraging conditions in fields. Host-plant restricted aphid colonies are often irregularly distributed in space and time (Honek, 1991; Agarwala and Bhattacharya, 1995; Dixon, 1998). As a result, at any instant, the number of aphids available in a patch as food for predators may vary. In such environments, predators able to adjust to variable food resources will have greater impact on prey population.

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