

FUNCTIONAL AND NUMERICAL RESPONSES OF *SCYMNUS SYRIACUS* MARSEUL (COLEOPTERA: COCCINELLIDAE) TO THE BLACK BEAN APHID, *APHIS FABAE* SCOPOLI (HEMIPTERA: APHIDIDAE) UNDER LABORATORY CONDITIONS

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Abstract: Functional and numerical responses are basic to any investigation of predator-prey relationships and key components in the selection of predators for biological control. In this study, functional and numerical responses of the female and male ladybeetles, *Scymnus syriacus* Marseul to different densities of third instar nymphs of *Aphis fabae* (i.e. 5, 10, 20, 30, 40, 60 and 80) as prey, were studied in a growth chamber (25°C, 65±5% RH and a photoperiod of 16L : 8D h) on the broad bean, *Vicia fabae* Linn. Using the logistic regression, a type II functional response for both female and male ladybeetles was determined. Using Nonlinear least-square regression, the searching efficiency (a') and handling times (T_h) of the female and male adults were estimated as 0.123±0.006 h, 0.434±0.012 h and 0.115±0.008 h, 0.514±0.016, respectively. The Rogers model was used to estimate the maximum theoretical predations (T/T_h) for female and male, which were 55.18 and 46.64, respectively. These results indicated a higher efficiency in female ladybeetles. The reproductive numerical response, in terms of eggs laid, increased curvilinearly with increasing prey density. The reproductive response trend was similar to the shape of the type II functional response. This similarity means both responses are interlinked and function simultaneously. The efficiency of the ingested food conversion (ECI) of the females decreased with prey density, as females laid 25±0.65 eggs when exposed to the highest prey density (80) and 3±0.44 eggs at lowest prey density (5).

Key words: *Scymnus syriacus*, *Aphis fabae*, functional response, numerical response, the efficiency of conversion

INTRODUCTION

Aphis fabae Scopoli (Hemiptera: Aphididae) is a polyphagous cosmopolitan pest (Blackman and Eastop 2000) and one of the best-known pests of agricultural ecosystems, causing damage to horticultural plants (Minks and Harrewijn 1989).

The ladybeetle, *Scymnus syriacus* Marseul is a widespread and dominant aphidophagous predator species of the genus *Scymnus* in Iran. This species is especially prevalent in the northern part (Guilan) of the country (Emami 1996). There is now an increased awareness of the negative side effects of chemical insecticides on the environment. For this reason, biological control using natural enemies to suppress pests is currently considered an important component in integrated, ecologically sound crop management systems (Hodek and Honek 1996). Ecologists have focused extensively on functional and numerical responses as a means of assessing the impact of a natural enemy on a prey population. The functional response relates to the change in the predation rate with changing prey density. Numerical response of the predator can be expressed in terms of a progressive change in the number of its progeny in relation to increas-

ing prey density (Solomon 1949). Three factors contribute to changes in the functional and numerical responses of predators. First, predators may reduce their migration rate with increasing prey densities (Zemek and Nachman 1998). Secondly, Murdoch (1971) has suggested a developmental response, in which predators can grow faster at higher prey densities. Finally, predators may interfere with each others foraging and reduce the functional response of each individual predator in a population (Abrams and Ginzburg 2000). The combined influence of these factors on a predator's response to prey density has been referred to as the total response (Price 1997).

When the number of prey killed is plotted against the number of prey available, a continuum of patterns may emerge from which ecologists delimit three types of functional responses (Holling 1966; Trexler *et al.* 1988). Other types of functional responses have been reported: type IV (Luck 1985) and type V (Sabelis 1992). The functional response curves may represent an increasing linear relationship (Type I), a decelerating curve (Type II), or a sigmoidal relationship (Type III) (Pervez and Omkar 2005). A type II functional response with a decelerating predation rate has the potential to destabilize prey-predator

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population dynamics due to an inverse density-dependent mortality of the prey (Hassell 1978). In contrast, the type III functional response, which incorporates density-dependent prey mortality, may stabilize the dynamics (Murdoch and Oaten 1975). An investigation on the functional response of the ladybeetle, *Scymnus subvillosus* Goeze at different densities of the mealy plum aphid *Hyalopterus pruni*, Geoffroy showed that response of each larval stage, and adults matched Holling's type II functional response (Athan and Guldal 2009). The functional responses of female and male, third and fourth instars larvae of *Scymnus syriacus* Marseul to different densities of *Aphis spiraeicola* Patch were found to be a type II functional response (Emami 1996).

The numerical response of adult Coccinellids to aphid density is particularly important in determining the effectiveness of these natural enemies. The reason for this is that adult Coccinellids can respond to the lower range of aphid densities (Mills 1982) and are not vulnerable to intraguild predation (Agarwala and Dixon 1991). The interacting components between natural enemies and prey should clearly be understood to enhance or augment the effect of natural enemies in a prey population (Rabb 1974). The interacting components include not only the functional response occurring at the individual level of both predator and prey, but also the numerical response occurring at the population level of both predator and prey (Holling 1959). The reproductive response is directly related to the rate at which the predator can catch and consume suitable prey which will in part be determined by the functional response (Beddington *et al.* 1976). Numerical response may be more important in more stable habitats, such as perennial crops (Wiedenmann and Smith 1997).

Wright and Laing (1980) found that *Hippodamia tredecimpunctata tibialis* Say showed a greater numerical response than *Coleomegilla maculate lengi* Timberlake at high density of *Rhopalosiphum maidis* (Fitch), due to its greater fecundity. The numerical response of the two lady beetles by oviposition was a linear type. A similar result was obtained by Uygun and Atlihan (2000) for *Scymnus levailanti* at lower density of its prey, *Aphis gossypii*.

The objectives of this study were to evaluate functional responses of female and male, numerical responses of the female *Scymnus syriacus* ladybeetle to different densities of *A. fabae* as prey, and also the efficiency of the females' conversion of ingested food (ECI).

MATERIALS AND METHODS

Predator and Prey cultures

Larvae and adults of *Scymnus syriacus* Marseul were collected from the aphid (*Aphis fabae*) colony of an infested broad bean field at the College of Agriculture in the University of Guilan (North of Iran) and reared on potted broad bean, *Vicia fabae* L. infested with *A. fabae* Koch.

The third instar nymphs of *Aphis fabae* were collected from their host plant, *Vicia fabae* L in order to have access to a steady supply of prey for the experiments. All aphids and predators stocks were kept in a growth chamber at

25±1°C, 70±5% relative humidity (RH), and at a photoperiod of 16:8 (L:D) h.

Functional response

To study the functional response of *S. syriacus*, the adults of this predator (2-day-olds) of both sexes were separately presented to different densities of third instar nymphs of *A. fabae* (5, 10, 20, 30, 40, 60 and 80) in a transparent plastic container (15x13 cm). Aphids were settled down on three apical leaves of the broad bean plant, *V. fabae* L. Individual adult males and females of *S. syriacus* were starved for 24 h. prior to experiments. Each experiment was replicated five times. After 24 hour, predators were removed from the containers and the number of aphids eaten by each male and female ladybeetle was recorded.

Numerical response

Five (48-h-old) female ladybeetles were starved for 24 h prior to experimentation. Thereafter, they were exposed to different densities of third instar nymphs of *A. fabae* (*i.e.* 5, 10, 20, 30, 40, 60 and 80) settled down on three apical leaves of the broad bean plant, *V. fabae* L for 24 h. After 24 h, the females were removed from the experiment containers (as mentioned earlier) and the number of eggs laid, was recorded. Five replicates of each prey density were used. In this experiment, the efficiency of conversion of ingested food (ECI) into egg biomass at different prey densities was also calculated using the equation (1) of Omkar and Pervez (2004).

$$ECI = \frac{\text{Number of eggs laid}}{\text{Number of prey consumed}} \times 100 \quad (1)$$

Data analysis

The type of the functional response was determined by logistic regression analysis [SAS/STAT, CATMOD procedure (SAS version 9.1)] of the proportion of killed prey (N_e) in relation to initial prey density (N_0) (Trexler and Travis 1993). The data were fitted to the logistic regression which describes the relationship between N_e/N_0 and N_0 (Juliano 2001):

$$\frac{N_e}{N_0} = \exp \left(\frac{P_0 + P_1 N_0 + P_2 N_0^2 + P_3 N_0^3}{1 + \exp (P_0 + P_1 N_0 + P_2 N_0^2 + P_3 N_0^3)} \right) \quad (2)$$

where:

P_0, P_1, P_2 and P_3 – the parameters to be estimated

If the linear parameter P_1 is negative, a type II functional response is evident, whereas a positive linear parameter indicates density-dependent predation and thus a type III functional response (Juliano 2001). Once the type of functional response was determined, both the disc equation (Holling 1959) (4) and the random attack equation (Royama 1971; Rogers 1972) (5) were used to estimate handling time (T_h) and searching efficiency or attack rate (a'). For the type II response, the equations are as follows:

$$N_a = \frac{a' T N_0}{1 + a' T_h N_0} \quad (4)$$

$$N_a = N_0 [1 - \exp(a' (T_h N_0 - T))] \quad (5)$$

where:

N_a – the number of prey eaten,

N_0 – the number of prey offered,

T – the total time available for the predator,

a' – the searching efficiency, and T_h is the handling time.

Statistical analysis of the functional response was performed using the SAS software (SAS Institute 2001). A nonlinear regression was used (the least square technique with DUD initialization) to estimate predator handling time and searching efficiency.

RESULTS

Parameter estimates for logistic regressions of proportion of prey killed (N_a/N_0) against number of prey offered (N_0), for the female adults of *S. syriacus* for 24 h, are presented in table 1. The logistic regression for both the females and males of *S. syriacus* had a significant linear parameter $P_1 < 0$. The proportion of prey consumed by both sexes declined with increasing prey density (Fig. 1). This suggested that both females and males of *S. syriacus* showed a type II functional response.

The coefficient of attack rates (a') and handling times (T_h) (estimated by Holling disc equation and Rogers random attack equation) of both sexes are presented in table 2,

Table 1. Maximum likelihood estimates from logistic regression of proportion of prey eaten as a function of initial prey densities by female and male of *S. syriacus* (n = 5)

Sex	Parameters	Estimate	SE	χ^2	P
Female	Constant	3.7815	0.8354	20.49	0.0001
	Linear	-0.1203	0.0596	4.07	0.0437
	Quadratic	0.00165	0.00130	1.62	0.2028
Male	Constant	2.7491	0.6413	18.37	0.0001
	Linear	-0.0820	0.0482	2.89	0.0527
	Quadratic	0.00107	0.00109	0.96	0.3261

χ^2 – called Chi squared; P – the probability level

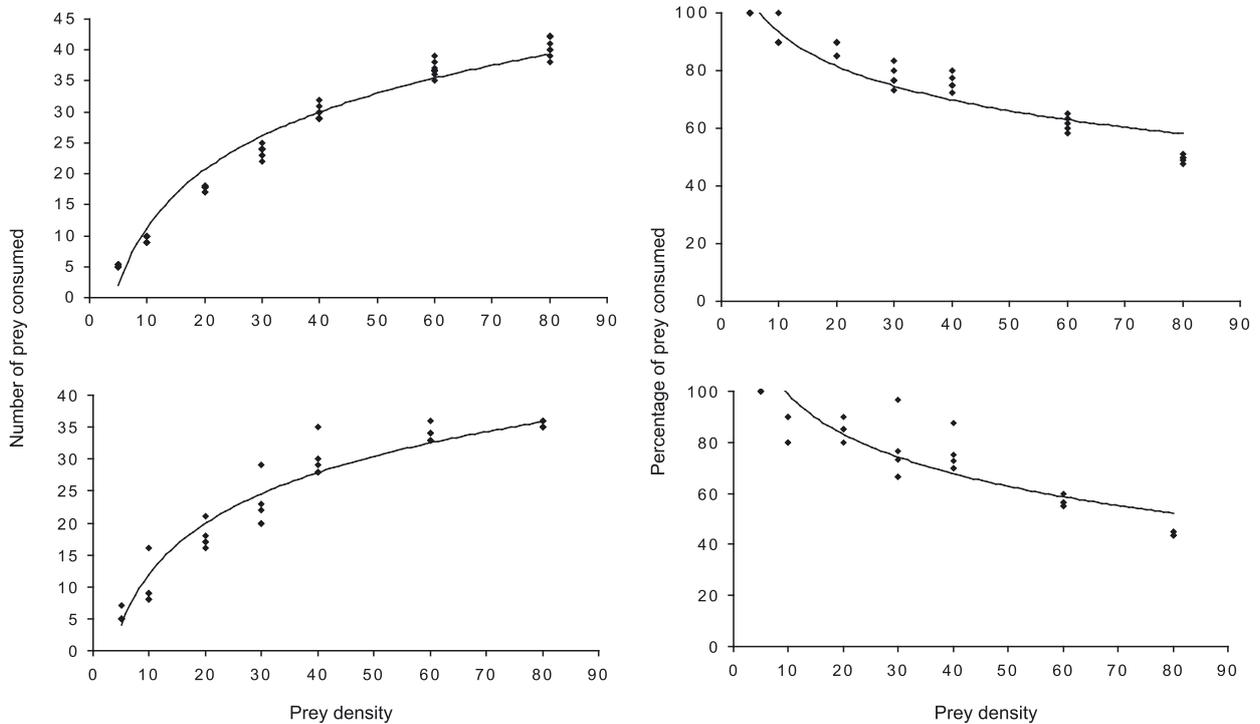


Fig. 1. Functional responses (left) and percentage of predation (right) of the *S. syriacus* female (above) and male (below) to the different prey densities of *A. fabae*. Symbols and lines represent the observed and predicted numbers (random predator equation), respectively

Table 2. Coefficient of attack rate (a) and handling time (T_h) [estimated by Holling disk equation and Rogers random attack equation] of female and male of *Scymnus syriacus* fed on *Aphis fabae*

Model		Parameters	Estimate	SE	95% CI		T/T_h
					Lower	Upper	
Holling	Female	a	0.0478	0.00152	0.044	0.0509	78.32
		T_h	0.3064	0.0125	0.2810	0.3319	
	Male	a	0.0479	0.00219	0.0435	0.0524	62.5
		T_h	0.3848	0.0188	0.3465	0.4231	
Rogers	Female	a	0.1231	0.00673	0.1095	0.1368	55.29
		T_h	0.4349	0.0120	0.4105	0.4593	
	Male	a	0.1155	0.00825	0.0987	0.1323	46.69
		T_h	0.5145	0.0169	0.4801	0.5489	

showing that females of *S. syriacus* had a shorter handling time and higher searching efficiency than the males. The estimated maximum rates of predation (T/T_h) using disc equation and the random attack equation for females and males were 78.32, 55.18 and 62.37, 46.64.

The values of the coefficient of determination (R^2) and standard errors of the estimated parameters indicated that both equations (disc and random predator equations) adequately described the functional response of *S. syriacus* ($R^2 = 0.99$). But Rogers random attack equation yielded a lower residual sum of squares (34.51 and 52.93

for female and male, respectively) indicating a better fit, than did the Holling disc equation (50.66 and 80.05).

The oviposition by adult females of *S. syriacus* (Fig. 2) increased curvilinearly with prey density ($F = 139.58$, $df = 4, 6$, $p < 0.0001$) and reached a plateau at higher densities, while the ECI of the female ladybeetles decreased with prey density (Fig. 3). The females laid 25 ± 0.65 eggs when exposed to the highest prey density (80) and 3 ± 0.44 eggs at the lowest prey density (5).

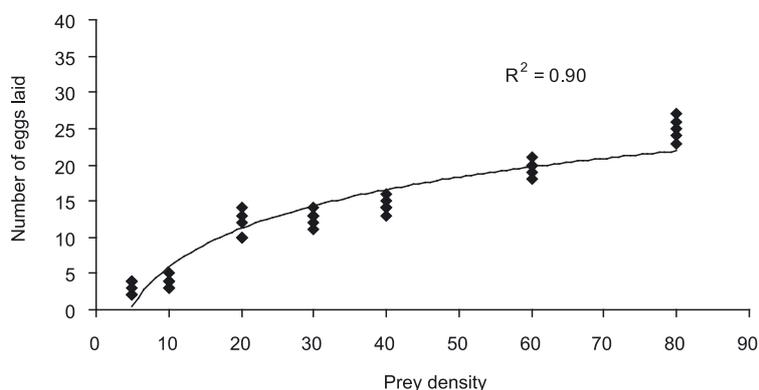


Fig. 2. Number of eggs laid by a female of *S. syriacus* at different densities of *A. fabae*

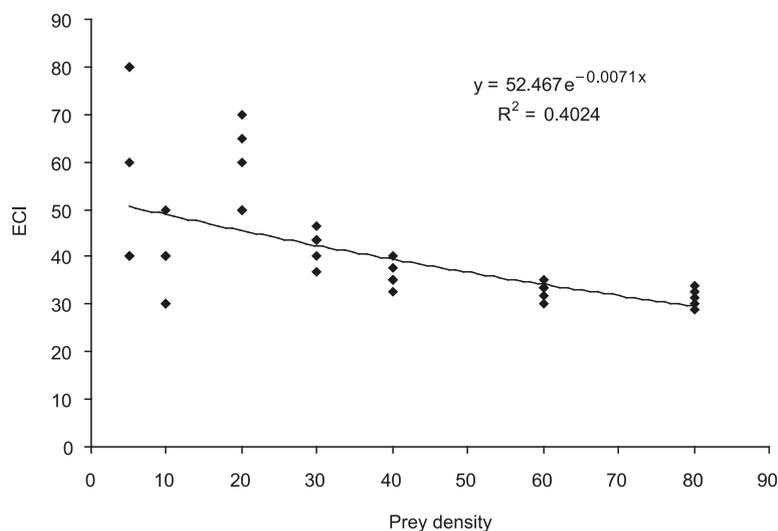


Fig. 3. Relationship between ECI (the efficiency of conversion of ingested food) of *S. syriacus* at different densities of *A. fabae*

DISCUSSION

The functional response of a natural enemy offers a good conceptual framework for understanding the action of agents in inundative releases (Waage and Greathead 1988). Many studies have been devoted to the foraging behaviour of insect predators (e.g. Dixon 1959; Nakamura 1982; Ettiffouri and Ferran 1993), but foraging differences between the sexes have received little attention. Thus, we tested differences in the foraging responses of *S. syriacus* sexes, to different densities of *A. fabae* as prey.

The present study showed that the functional and numerical responses of *S. syriacus* described a curvilinearly rise to a plateau (Holling type II response). The negative values for the linear parameters ($P_1 < 0$) obtained in this study confirmed the type II responses for both sexes of ladybeetle. Similarly, Moura *et al.* (2006) showed a type II functional response of *Coccinella undecimpunctata* to *A. fabae* densities. Hemptinne *et al.* (1996) found that the response can be markedly different between sexes, as males of two-spot ladybeetle, *Adalia bipunctata* (Linn) consumed fewer aphids and showed no functional response, unlike their female counterparts.

Type II functional responses are evidenced by an initial decrease in the proportion of prey eaten with increasing prey offered (Trexler *et al.* 1988; Juliano 1993). Although three types of functional responses described by Holling (1959) may occur in coccinellids (Hodek and Honek 1996), the fact is that type II is the most common in these insects, as reported for several ladybeetles preying on distinct aphid species, such as *Cheilelomenes vicina* Mulsant (Ofuya 1986), *Scymnus hoffmanni* (Ding-Xin 1986), *Coccinella septempunctata* (Kumar *et al.* 1999), *Scymnus levaillanti* Mulsant (Uygum and Athhan 2000), *Scymnus creperus* Mulsant (Wells *et al.* 2001), *Harmonia axyridis* (Lee and Kang 2004), *P. dissecta* (Omkar and Pervez 2004; Pervez and Omkar 2005), *Cheilelomenes sexmaculata* Fabricius, *C. transversalis* (Pervez and Omkar 2005) and *Hippodamia variegata* (Goeze) (Farhadi *et al.* 2010).

The handling time (T_h) is a good indicator of the predation rate (Athán and Guldal 2009). The T_h value for females was lower than for males in this study. Therefore, the maximum theoretical predation rate (T/T_h) of females was greater than for males. The values of searching efficiency estimated by both Holling and Rogers models for females were also greater than for males. The greater number of prey consumed by females may be due to the larger size of females, and also the additional energy requirement to produce eggs (Hodek and Honek 1996; Omkar and James 2004). According to Nordlund and Morrison (1990), the handling time affects the type of functional response, suggesting that the shorter the handling time, the faster the curve reaches the asymptote. Furthermore, handling time can influence other components, such as attack rate and searching efficiency (Beddington 1975).

The shape of the reproductive response was similar to that of functional response showing that both responses are interlinked and function simultaneously (Omkar and Pervez 2004). Similarly, a curvilinear relationship was observed between *Aphis gossypii* density and number of eggs laid by *P. dissecta* (Omkar and Pervez 2004). The prey

density-dependent fecundity was also sigmoidal in *Cheilelomenes lunata* Fabricius (Ofuya and Akingbohunge 1988) and curvilinear in *Menochilus sexmaculata* (Agarwala and Bardhanroy 1997) and even in *Lysiphlebus fabarum* Marshall parasitizing the black bean aphid, *A. fabae* (Mahmoudi *et al.* 2010). Comparison of the mean number of eggs laid by the predator at different densities of prey, showed that there were significant differences among number of eggs at various prey densities. This difference was more evident at higher prey densities.

The trend of ECI in this study indicated that the conversion rate of prey biomass was higher at lower densities, as it decreased at higher prey densities. In other words, if we consider the structure of the model, the No. of eggs laid at different prey density has a decelerating rate like type II functional response or as the curve of numerical response. So, number of eggs laid at low prey density multiplied by 100 is relatively higher than those at higher prey density. Therefore, we can see a decelerating trend as prey density increases. Similarly, Omkar and Pervez (2004) reported that the ECI of *P. dissecta* decreased with increasing prey density. The decreased ECI at higher prey densities may suggest that well-fed females laid greater number of eggs, investing much in maintenance and metabolic costs (Omkar and Pervez 2004).

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