

Area dependent searching efficiency of *Scymnus syriacus* (Col.: Coccinellidae) feeding on *Aphis craccivora* (Hem.: Aphididae)

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Abstract

Searching efficiency is a key parameter of functional response which is in turn the major components in the selection of predators and parasitoids for biological control. Searching efficiency of *Scymnus syriacus* Mulsant feeding on *Aphis craccivora* Koch was determined at five different experimental arenas (i.e. 195, 247, 304, 385 and 650 cm²) on broad bean (*Vicia fabae* L.). To do this, functional response of the predator to different densities (i.e., 10, 20, 30, 40 and 60) of the third instar nymphs of *A. craccivora* was studied. At each experiment, one 48-h-old female was introduced to the aphid density in a container (as an experimental arena) and replicated five times. The experiments were carried out at 25° ± 1C, 65 ± 5% RH and a photoperiod of 16L: 8D h. Using the logistic regression, a type III functional response was determined for *S. syriacus* in the entire five experimental arenas. Searching efficiency was found to be area dependent as it decreased as the area of experimental arena increased. The maximum expected predation rates (T/T_h) were 48.56, 42.44, 40.77, 38.09 and 34.88 in the five experimental arenas, respectively. The area searched as a function of prey density indicated that as prey density increased, the area searched by the predator decreased. It is concluded that the size of searching area and prey density, both influence foraging behavior of *S. syriacus*.

Key words: functional response, *Scymnus syriacus*, searching efficiency, *Aphis craccivora*, experimental arena, area searched

چکیده

قدرت جستجو، یکی از پارامترهای کلیدی واکنش تابعی است که از اجزای مهم در انتخاب شکارگرها و پارازیتوئیدها در کنترل بیولوژیک است. قدرت جستجوی کفشدوزک *Scymnus syriacus* Mulsant با تغذیه از شته‌ی افاقیا، *Aphis craccivora* Koch در پنج سطح (صحنه) متفاوت آزمایشگاهی (۱۹۵، ۲۴۷، ۳۰۴، ۳۸۵ و ۶۵۰ سانتی‌متر مربع) روی گیاه لوبیا، *Vicia fabae* L. تعیین شد. برای تعیین این پارامتر، واکنش تابعی شکارگر در تراکم‌های مختلف (۱۰، ۲۰، ۳۰، ۴۰ و ۶۰) از پوره‌ی سن سوم شته‌ی افاقیا مطالعه شد. در هر آزمایش یک عدد کفشدوزک با عمر ۴۸ ساعت در تراکم طعمه در یک ظرف (به عنوان یک سطح آزمایشی) و در ۵ تکرار رهاسازی شد. آزمایش‌ها در دمای ۱ ± ۲۵ درجه‌ی سلسیوس، رطوبت نسبی ۵ ± ۶۵ درصد و روشنایی به تاریکی ۸:۱۶ ساعت انجام شد. با استفاده از رگرسیون لجستیک، واکنش تابعی نوع سوم برای کفشدوزک *S. syriacus* در کل سطوح آزمایشی تعیین شد. نتایج نشان داد که قدرت جستجو وابسته به سطح عرصه‌ی آزمایشگاهی است، به طوری که با افزایش اندازه‌ی سطح صحنه‌ی آزمایش، مقدار آن کاهش پیدا کرد. حداکثر نرخ حمله‌ی مورد انتظار (T/T_h) در پنج سطح آزمایشی به ترتیب ۴۸/۵۶، ۴۲/۴۴، ۴۰/۷۷، ۳۸/۰۹ و ۳۴/۸۸ طعمه تخمین زده شد. سطح جستجو شده به عنوان تابعی از تراکم طعمه، نشان داد که وقتی تراکم طعمه افزایش پیدا کرد، سطح جستجو شده توسط شکارگر کاهش یافت. نتیجه این که سطح جستجو (صحنه‌ی آزمایش) و تراکم طعمه، هر دو، رفتار کاوشگری *S. syriacus* را تحت تأثیر قرار می‌دهند.

واژگان کلیدی: واکنش تابعی، *Scymnus syriacus*، قدرت جستجو، *Aphis craccivora*، صحنه‌ی آزمایش، سطح جستجو شده

Introduction

The black bean aphid, *Aphis craccivora* Koch, infests grain legumes and groundnuts throughout the world, more particularly in the tropics (Blackman & Eastop, 2000). Insect predators are frequently reckoned as effective regulators of insect pest populations (Cardoso & Lazzari, 2003; Padamalatha *et al.*, 2003) which has led their increasing use in insect pest management programs (Weidenmann & Smith, 1997; Riudavets & Castane, 1998).

Species of the genus *Scymnus* Kugelann have been studied in many countries (Uygun & Atlihan, 2000; Wanntorp, 2004; Pluke *et al.*, 2005; Woin *et al.*, 2006). Some species were introduced from their native lands into the USA, as *Scymnus frontalis* (F.) was imported from Turkey as a potential biological control agent of the Russian wheat aphid, *Diuraphis noxia* (Mordvilko) (Gibson *et al.*, 1993), and *Scymnus ningshanensis* Yu & Yao was introduced from China for biological control of the hemlock woolly adelgid, *Adelges tsugae* Annand (Buntin *et al.*, 2003, 2004).

The interacting components between natural enemies and preys should clearly be understood to enhance or augment the effect of natural enemies in a prey population (Rabb, 1974). These include functional response occurring at individual level of both predator and prey and numerical response occurring at population level of both predator and prey (Holling, 1959). The term functional response was first introduced by Solomon (1949) to describe basic components of the relationship between a natural enemy and its host. Solomon (1949) defined the functional response as the relationship between the number of prey attacked per predator and prey density.

The functional response is an important characteristic of predator-prey systems and a key component of predator-prey models (Jeschke *et al.*, 2002). It is also one of the key components in the selection of biological control agents (Lester & Harmsen, 2002) and therefore important for the understanding of how to improve the effectiveness of biological control agents. Different factors may influence searching efficiency and the type of functional response both abiotic such as temperature (Mohaghegh *et al.*, 2001; Skirvin & Fenlon, 2003; Zamani *et al.*, 2006; Kouhijani Gorji *et al.*, 2009) and relative humidity (Svendsen *et al.*, 1999), and biotic such as prey or host species (Donnelly & Phillips, 2001; Fathipour *et al.*, 2002; Fathipour *et al.*, 2003; Hoddle, 2003; Allahyari *et al.*, 2004; Faria *et al.*, 2004), availability of alternative food (Wei & Walde, 1997), predator sex (Parajulee *et al.*, 1994), age and feeding history of the predator (Eveleigh & Chant, 1981; Castagnoli & Simoni, 1999) and host plant (Sabelis *et al.*, 1999; Fathipour *et al.*, 2001; Madadi *et al.*, 2007). As examples, an

influence of plant traits on the shape or parameters of functional responses has been demonstrated for the 14-spotted lady beetle to Russian wheat aphids on wheat grass and rice grass (Messina & Hanks 1998); for the seven spotted lady beetle to mustard aphids on kale, radish and wild turnip (Kumar *et al.*, 1999); for predatory phytoseiid mites against spider mites on ornamental plants (Skirvin & Fenlon 2001).

The objective of this study was to examine the effect of experimental arena size on the searching efficiency and the type of functional response of *S. syriacus* under laboratory conditions.

Materials and methods

Insect rearing

Larvae and adults of *S. syriacus* were collected from Black locust, (*Robinia pseudoacassia* L.) and *Malva sylvestris* L. trees at the faculty of Agriculture in the University of Guilan (North of Iran) and reared on potted broad bean, *Vicia fabae*, infested with *A. craccivora* at $25 \pm 1^\circ\text{C}$, $70 \pm 5\%$ R.H. and a photoperiod of 16: 8 (L: D) h. The *A. craccivora* third instar nymphs were collected from its host plant, *R. pseudoacassia*, in order to have access to a steady supply of prey for the experiments.

Functional response experiments

Different densities (10, 20, 30, 40 and 60) of the third instar nymphs of *A. craccivora* were placed on three apical leaves of broad bean separately in different transparent containers as experimental arena. The areas of five different size containers (experimental arena) were 195 (15 × 13 cm), 247 (19 × 13cm), 304 (19cm × 16cm), 385 (22 cm × 17.5cm) and 650 (25 × 26 cm) cm², respectively. Each container was covered with a micromesh on the lid for ventilation. One 48-h.-old female adult of *S. syriacus* was released into each container. Each female was starved for 24h prior to be exposed to the prey. Each prey density at every experimental arena (container) was replicated five times. The predators were removed after 24h, and the number of aphids eaten in each container was determined. The entire five different functional response experiments were carried out at the conditions mentioned earlier.

Data analysis

Two principle steps underlie the statistical analysis of the functional response: (1) model selection, and (2) hypothesis testing (Juliano, 1993). In the first step, a logistic regression

analysis of the proportion of prey eaten as a function of initial density was performed. For predator functional responses, logistic regression is particularly useful in distinguishing between type II and type III responses, which are not easily determined by nonlinear regressions that use the number of prey eaten as the dependent variable. The sign of the slope on linear part of the curve estimated by the logistic regression (negative or positive) can be used to distinguish the shape of the functional response curve (type II or type III, respectively) (Trexler *et al.*, 1988; Juliano, 1993; Messina & Hanks, 1998). The data were fitted to the logistic regression which describes the relationship between N_a/N_0 and N_0 (Juliano, 1993):

$$N_a/N_0 = \exp(P_0 + P_1N_0 + P_2N_0^2 + P_3N_0^3) / (1 + \exp(P_0 + P_1N_0 + P_2N_0^2 + P_3N_0^3)) \quad (1)$$

Where N_a/N_0 is the probability a prey is eaten by a predator and P_0 , P_1 , P_2 and P_3 are the intercept, linear, quadratic and cubic coefficients, respectively. Using the CATMOD procedure of SAS version 9.1., if $P_1 < 0$, the proportion of prey eaten declines monotonically with the initial number of prey offered, thus describing a type II functional response. If $P_1 > 0$, the proportion of prey eaten is positively density-dependent, thus describing a type III functional response (Juliano, 1993).

In the second step, because the experiment is usually conducted without prey replacement, the prey density declines as the experiment proceeds. Roger's random predator equation (Rogers 1972; Royama, 1971; Juliano, 1993) is generally used to overcome the prey replacement problem in Hollings model as follows:

$$N_a = N_0 [1 - \exp(a(T_h N_a - T))] \quad (2)$$

Where N_a is the number of prey eaten, N_0 is the number of prey offered, T is the total time available for the predator, a is the searching efficiency, and T_h is the handling time.

Type III functional response can be derived using Hassell's model (Hassell, 1978) where the attack rate (a) is a hyperbolic function of the prey density as follows:

$$a = (d + bN_0) / (1 + cN_0) \quad (3)$$

By substituting the value of a to the Roger's equation, we get the type III model as:

$$N_a = N_0 \{1 - \exp[(d + bN_0)(T_h N_a - T) / (1 + cN_0)]\} \quad (4)$$

Where N_a = number of prey eaten; N_0 = initial prey density (number of prey offered); T = total time; T_h = handling time; b , c and d are parameter constants. For our data, parameters c

and d were not significantly different from 0 (i.e., 95% of confidence intervals (CI) included 0); therefore a reduced type III models was used to fit the experimental data:

$$N_a = N_0 \{1 - \exp [bN_0 (T_h N_a - T)]\} \quad (5)$$

Searching efficiency was estimated using equation (6):

$$(a = bN_0) \quad (6)$$

Finally, the proportion of the plant searched by the predator was estimated using equation (7) from O'Neil (1997):

$$SA^{-1} = N_a \cdot N^{-1} \quad (7)$$

Where N_a is the number of prey attacked, N^{-1} ($1/N_0$) is the number of prey, S is the estimated of plant area searched, and A^{-1} ($1/A$) is the estimate of plant size (e.g., leaf area, plant height, leaf number). This relationship assumes that the proportion of prey attacked was equal to the proportion of area searched. Re-arranging equation (7) allows estimation of searching area searched by the predator using equation (8):

$$S = (N_a \cdot N^{-1}) A \quad (8)$$

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

Results

Functional response curves of *S. syriacus* on different experimental arenas are shown in fig. 1. Logistic regression analyses of the proportion of prey eaten (table 1) indicated a type III functional response at all experimental arenas. Searching efficiency was indirectly density dependent ($R^2 = 0.8182$), it decreased as experimental area size increased (fig. 2). Searching efficiency (a) was the highest at smallest experimental area and lowest at largest one. Comparison of searching efficiency (a) of *S. syriacus* in different sizes of experimental arenas showed that there was significant differences between searching efficiency at all areas tested ($F = 101.81$; $df = 8, 16$; $P < 0.001$). The maximum expected predation rate (T/T_h) of the third instar nymphs of *A. craccivora* by *S. syriacus* decreased with the increase of experimental areas (table 2).

Table 1. Results of logistic regression analysis of the proportion of *A. craccivora* third instars nymphs eaten by *S. syriacus* females against initial prey densities offered in different experimental arenas.

Areas	Area size (cm ²)	Parameter	Estimate	SE	X ²	P
A	195	Constant	1.4888	1.2571	1.4	0.2363
		Linear	0.00863	0.1348	0.00	0.9490
		Quadratic	0.000017	0.0042	0.00	0.9968
		Cubic	0.000572	0.00003	0.02	0.882
		Constant	1.3097	0.1408	1.32	0.2509
B	247	Linear	0.00266	0.1211	0.00	0.9825
		Quadratic	0.00375	0.00375	0.00	0.9444
		Cubic	0.0000218	0.000034	0.00	0.9949
		Constant	-0.9998	1.0192	0.96	0.3266
		Linear	0.2005	0.1122	3.19	0.0739
C	304	Quadratic	-0.00550	0.00353	2.42	0.1196
		Cubic	0.000042	0.000039	1.69	0.1942
		Constant	-0.6639	0.9984	0.44	0.5060
		Linear	0.1377	0.1091	1.59	0.2071
		Quadratic	-0.00335	0.00343	0.95	0.3285
D	385	Cubic	0.000022	0.000032	0.47	0.4936
		Constant	-0.9198	0.9656	0.91	0.3408
		Linear	0.1191	0.1046	1.30	0.2548
		Quadratic	-0.00263	0.00328	0.64	0.4236
		Cubic	0.000015	0.00003	0.26	0.6090

O'Neil (1997) equation was used to estimate the area (cm²) searched as a function prey density. It was indicated that an increase in prey density resulted in decrease in the area searched by the predator (fig. 3). Average areas searched by *Scymnus syriacus* at different densities of *Aphis craccivora* were estimated as 156.65, 181.05, 209.96, 254.22 and 383.5 cm² at five different experimental arenas, respectively.

Table 2. Data analysis of the functional response of *S. syriacus* female to different densities of the third instars nymphs of *A. craccivora* in different experimental arenas.

Area	Type	b	T _h (h)	r ²	T/T _h
A	III	0.00576± 0.00046	0.494	0.99	48.56
B	III	0.00475± 0.0045	0.565	0.99	42.44
C	III	0.00463± 0.00033	0.588	0.99	40.77
D	III	0.00446± 0.000032	0.630	0.99	38.09
E	III	0.00365± 0.0003	0.687	0.99	34.88

Discussion

The searching efficiency of *S. syriacus* at different area sizes was found to be area dependent; it decreased as the area of experimental arena increased. Other research workers

have also found that many factors such as host density (Hassell, 1982), host size and age class (Luck *et al.*, 1982; Murdoch *et al.*, 1987), natural enemy reproductive state and age (Vet, 1983; Waage, 1990), the presence of other natural enemies (Hassell & Varley, 1969), temperature (Isikber, 2005; Kouhjani Gorji *et al.*, 2009), plant size and architecture (O'Neil, 1988; Grevstad & Kleptka, 1992) can influence the searching efficiency of natural enemies. Some others have found that the success of parasitoids and predators encountering hosts/prey decreases with an increase in plant size (Ables *et al.*, 1980; Thorpe, 1985), plant complexity (Ramsy, 1977) and plant surface area and volume (Kanour & Burbutis, 1984). These findings are most likely to be important in the management of pest populations like aphids in larger environments such as field.

Scale of experimental arena is an important issue in the study of prey consumption by predators in relation to prey density or its distribution, as differences in spatial scales may influence predator responses to variation in these factors (Gascon & Travis, 1992; Ives *et al.*, 1993). Hodek *et al.* (1984) state that small experimental area which is optimal for easy search for prey do not reflect the real searching efficiency of the predator. However, there are few studies on the effects of large scale experimental arena on prey consumption rate of adult lady beetles. Yasuda & Ishikawa (1999) in a study on the effect of prey density and its spatial distribution on foraging behavior of the adult lady beetle, *Harmonia axyridis* (Pallas) found that the predator had limited ability to search out prey over large spatial scales. Hukusima & Ohwaki (1972) also reported that predation rate of *H. axyridis* on aphids was much higher in small cages.

Female *Coccinella septempunctata* L. consumed over 100 aphids per day in a Petri dish, while field observation revealed that adult predators consumed much lower number of prey at the field condition (Kawuchi, 1990).

Functional response of *Oenopia conglobata* (L.) to different densities of *Hyalopterus pruni* (Geoffroy) in Petri dishes of 6, 8 and 12 cm in diameters showed that size of experimental arena did not affect prey consumption by all larval and adult stages of *O. conglobata*. Since an increase in the size of experimental arena led in lower number of prey consumed (Yasar & Ozger, 2005), therefore, the results obtained here were not in agreement with those of Yasar & Ozger (2005).

It was found that an increase in prey density would result in decrease in the area searched by *S. syriacus*. This was similar to those obtained for *Cryptolaemus montrouzieri* (Mulsant) searching for a hemipteran prey, *Planococcus citri* (Risso) (Garcia & O'Neil, 2000)

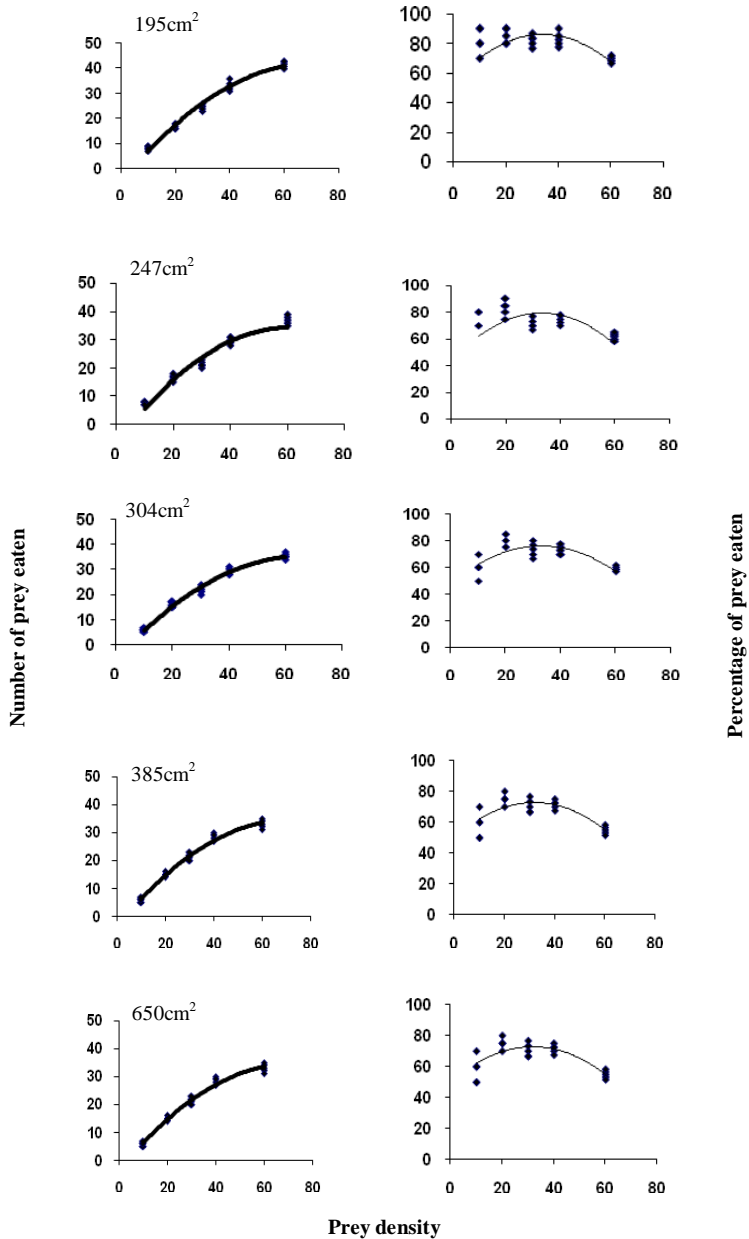


Figure 1. Functional response curves (left) of *S. syriacus* female at different densities of third instar nymphs of *A. craccivora* and percentage of predation (right) in different experimental areas.

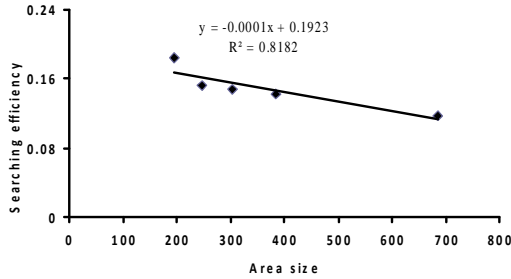


Figure 2. Relationship between searching efficiency of *S. syriacus* and different area sizes (cm²).

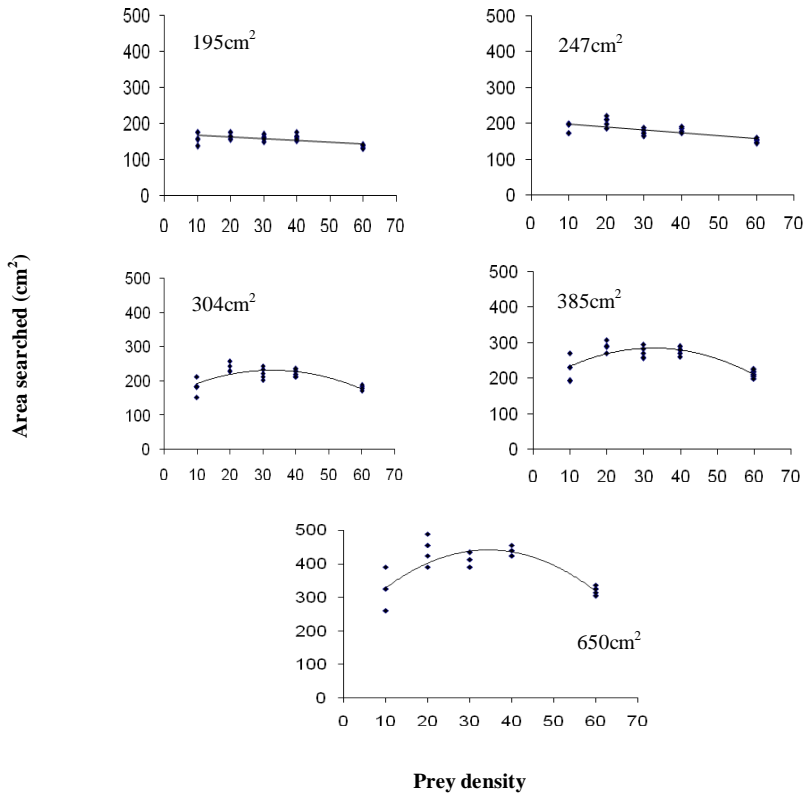


Figure 3. Estimated area searched by *S. syriacus* for *A. craccivora* at different experimental arenas. Area searched was estimated using O’Neil’s (1997) equation.

and *Podisus maculiventris* (Say) searching for a coleopteran prey, *Leptinotarsa decemlineata* (Say) in potatoes (O'Neil, 1997).

It is concluded that size of searching area and prey density both influence foraging behavior of *S. syriacus*, as searching efficiency is inversely area dependent and prey density would decrease the searching area. This should be taken into consideration when releasing the predator in the field.

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