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Functional response of *Serangium montazerii* (Col.: Coccinellidae) to different densities of *Dialeurodes citri* (Hem.: Aleyrodidae): an open-patch approach

S. M. Fotukkiaii and A. Sahragard*
Department of Plant Protection, Faculty of Agricultural Sciences, University of Guilan, Rasht, Iran.
*Corresponding author, E-mail: sahragard@guilan.ac.ir

Abstract

The functional response of a predator is the base of prey-predator dynamics. Functional response of *Serangium montazerii* Fürsch at different egg densities (50, 100, 150, 200 and 250) of *Dialeurodes citri* (Ashmead) was studied in an open-patch experiment, in a growth chamber (25 ± 1°C, 65 ± 5% RH and a photoperiod of 16: 8 L: D h) on 'Thompson' navel orange (*Citrus sinensis* cv. Thompson) apical leaves. A type II functional response was obtained using logistic regression. The searching efficiency (a') and handling times (T_h) of the female adults using nonlinear least-square regression were estimated as 0.0421 ± 0.00945 h^{-1} and 0.0896 ± 0.0362 h, respectively. Mean times required for the female predator to settle in a patch were 121.4, 140, 116, 83 and 78 minutes at above-mentioned prey densities, respectively. It was inversely density dependent (R^2 = 0.740). The proportion of female predators remaining in open patches at the end of the experiment was directly dependent on prey density (R^2 = 0.9). It was concluded that the type of functional response obtained here was in agreement with studies on this predator in closed patches.

Key words: *Serangium montazerii*, different densities, functional response, open patch

چکیده

واکنش تابعی کفشدوزک *Serangium montazerii* (Col.: Coccinellidae) نسبت به تراکم‌های مختلف سفیدبالک مرکبات، *Dialeurodes citri* (Hem.: Aleyrodidae): روش open-patch

سیده معصومه فتوک‌کیایی و احد صحراگرد

واکنش تابعی شکارگر، به‌عنوان اساس و پایه‌ی دینامیسم شکار- شکارگر در نظر گرفته می‌شود. واکنش تابعی کفشدوزک *Serangium montazerii* Fürsch در تراکم‌های مختلف (۵۰، ۱۰۰، ۱۵۰، ۲۰۰ و ۲۵۰) تخم سفیدبالک مرکبات، *Dialeurodes citri* (Ashmead)، در یک آزمایش open-patch مطالعه شد. این آزمایش در یک اتاقک رشد (دمای ۲۵ ± ۱°C، رطوبت ٪۶۵ ± ۵ و دوره‌ی نوری ۱۶: ۸ ساعت تاریکی: روشنایی) با برگ‌های انتهایی سرشاخه‌ی پرتقال تامسون ناول، *Citrus sinensis* cv. Thompson، انجام شد. با استفاده از رگرسیون لجستیک، واکنش تابعی نوع دوم به‌دست آمد. پارامترهای قدرت جستجو (a') و زمان دست‌یابی حشره‌ی ماده به طعمه (T_h) با استفاده از مدل رگرسیون غیر خطی با روش حداقل مجموع مربعات، به‌ترتیب ۰/۰۴۲۱ ± ۰/۰۰۹۴۵ h^{-1} و ۰/۰۸۹۶ ± ۰/۰۳۶۲ h برآورد شد. میانگین زمان مورد نیاز برای شکارگر ماده جهت استقرار در یک patch در تراکم‌های مختلف شکار، به‌ترتیب ۱۲۱/۴، ۱۴۰، ۱۱۶، ۸۳ و ۷۸ دقیقه محاسبه شد. میانگین زمان استقرار وابسته به عکس تراکم بود (R^2 = ۰/۷۴۰). در پایان آزمایش، نسبت شکارگرهای ماده‌ی باقی‌مانده در هر patch به‌طور مستقیم به تراکم شکار وابسته بود (R^2 = ۰/۹). نتیجه‌ی این آزمایش نشان داد که نوع واکنش تابعی این شکارگر در توافق با نوع آن در closed patch است.

واژگان کلیدی: *Serangium montazerii*، تراکم‌های مختلف، واکنش تابعی، open patch

Introduction

The citrus whitefly, *Dialeurodes citri* (Ashmead) is a polyphagous insect that infests evergreen and deciduous plants (Mound & Halsey, 1978). In the Mediterranean region, it is one of the three economically important whiteflies on citrus (Uygun *et al*., 1990; Rapisarda *et al*., 1996). Immature stages settle under the leaves and suck plant sap. They excrete a large amount of honeydew that stimulates the sooty mould fungus growth (Žaniĉ, 2001). Coccinellids are one of the important groups of predatory insects that have immense biocontrol potential (Omkar & Pervez, 2003). *Serangium montazerii* Fürsch was recorded as a predator of *D. citri* in Iran (Fürsch, 1995) and Turkey (Yigit *et al.*, 2003). This lady beetle seems to have a potential to be a biocontrol agent of the cotton whitefly, *Bemisia tabaci* (Genn.), which could be used in biological control programmes (Al-Zyoud, 2008).

The functional response relates to the changes in predation rate with changing prey density (Solomon, 1949). It gives a quantitative description of the behaviour of a predator when it encounters different densities of its prey (Holling, 1959). The functional response curves may represent an increasing linear relationship (type I), a decelerating curve (type II), or a sigmoidal relationship (type III) (Holling, 1959).

Several other types of functional responses have been reported, such as type IV (Luck, 1985) and type V (Sabelis, 1992). A type II functional response with a decelerating predation rate has the potential to destabilize prey-predator 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 & Oaten, 1975). So, predators that impose positively density dependent prey mortality (type III) are supposed to potentially manage the prey population and could be considered as efficient biocontrol agents (Hassell, 1978; Berryman, 1999; Bernstein, 2000). Nevertheless, certain predators exhibiting type II response have been successfully established and managed prey populations (Hughes *et al*., 1992). Meanwhile, Fernández-Arhex & Corley (2003) by reviewing the literature on the functional response of parasitoids used in biocontrol, found that there was no clear relationship between curve shape and success in control. They concluded that other attributes of the parasitoid or predator behaviour should be taken into account to understand and predict their successes as control agents.

The only study on the functional responses of *Serangium* spp. has been done on *B. tabaci* in China. The functional response of *Serangium* sp. on all immature stages of *B. tabaci* was found to be type II (Anonymous, 2007).

Van Alphen & Jervis (1996) stated that natural enemies may leave the experimental patch for a short period, but they return and continue searching for prey (or hosts). Sakaki & Sahragard (2011) tested this hypothesis and found that the kind of patch (open or closed) did not affect the type of functional response for female *Scymnus syriacus* Marseul to different densities of *Aphis gosypii* Glover. Therefore, they obtained a type II functional response in an open-patch experiment for female *S. syriacus*. The current study was aimed at testing the above hypothesis once again for the female *S. montazerii* to different *D. citri* egg densities where the predator was allowed to leave the experimental arena.

Materials and methods

The *Citrus sinensis* cv. Thomson navel leaves including *D. citri* eggs and *S. montazeri* females were collected from a citrus orchard in Ramsar (Mazandaran province, Northern Iran). All whitefly and predator stocks were kept at 25 ± 1°C, 65 ± 5% RH and a photoperiod of 16: 8 (L: D) h.

To study the functional response of *S. montazerii*, the adult females of this predator were separately presented to different densities of *D. citri* eggs (50, 100, 150, 200 and 250) in a transparent plastic container (12 × 9 × 5 cm). The eggs required for each prey density level were left on the apical leaves of the host plant and the rest were removed using a needle under a stereomicroscope. Individual adult females of *S. montazerii* were starved for 24 h. Each experiment was replicated five times. The mean time required for the settlement of each predator in a patch, was measured by observing and recording the behaviour of the predator after it was released into each container. Then, the cover of the container was removed to allow the predator to leave each experimental arena (container). After 24 h, the number of whitefly eggs eaten by female predators was recorded. At the end of each experiment, the number of female predators remaining in each patch was also recorded.

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 eggs (N_e) in relation to initial prey density (N_0) (Trexler & Travis, 1993). In the logistic regression, a cubic model was used (Juliano, 2001):

$$N_e / N_0 = \exp(P_0 + P_1N_0 + P_2N_0^2 + P_3N_0^3) / [1 + \exp(P_0 + P_1N_0 + P_2N_0^2 + P_3N_0^3)]$$

where P_0, P_1, P_2 and P_3 are 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 a type III functional response (Juliano, 2001). Once the type of functional response was determined, the random attack rate equation (Royama, 1971, Rogers, 1972) was used to estimate handling time (T_h) and searching efficiency or attack rate (a') as follows: $N_a = N_0$ [1 - exp (a' ($T_h N_a$ - T))], where N_a is the number of prey eaten, N_0 is the number of prey offered, and T is the total time available for the predator.

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 from the logistic model of the proportion of eggs of *D. citri* consumed by *S. montazerii* over a 24-h period versus prey density are shown in table 1. The logistic regression for female *S. montazerii* had a significant linear parameter $P_1 < 0$ and the proportion of prey consumed by the female declined with increasing prey egg density (fig. 1). This suggested that that female *S. montazerii* showed a type II functional response. The handling time (T_h) and coefficient of attack rate (a') estimated by Rogers' random attack equation are presented in table 2. The value of coefficient of determination (R^2) of the estimated parameters indicated that random predator equation (Rogers, 1972) adequately described the functional response of *S. montazerii* (R^2 = 0.972).

Table 1. Maximum likelihood estimate from logistic regression of proportion of prey eaten as a function of initial prey densities by female *Serangium montazerii*.

Parameter	Estimate	SE	X^2	*P*
Constant	1.0938	0.2324	22.14	< 0.0001
Linear	- 0.0107	0.00300	12.68	0.0004
Quadratic	0.000022	$8.899E^{-6}$	6.35	0.0117

The proportion of predators remaining in each patch after 24 h was density dependent (R^2 = 0.9) (fig. 2). Mean time required for the female predator to settle in a patch was proportional to the density of prey in each experimental arena (fig. 3).

Table 2. Coefficient of attack rate (a') and handling time (T_h) estimated by Rogers' random attack equation for female *Serangium montazerii* fed on *Dialeurodes citri* eggs.

Para.	Estim.	SE	95% CI		R^2
			Lower	Upper	
a'	0.0421	0.00945	0.0225	0.0616	0.972
T_h	0.0896	0.0362	0.0147	0.1645	

Para. = Parameter; Estim. = Estimate.

Discussion

The type II functional response obtained in this study gave a satisfactory fit to the data of *S. montazerii* preying on the eggs of *D. citri*, which is the most frequently observed type for a wide variety of predators, including insect parasitoids (Begon *et al*., 1996; Fernández-Arhex & Corley, 2003; Aukema & Raffa, 2004). Some of these examples are: *Aphidecta obliterate* (L.) and *Adalia bipunctata* (L.) (Timms *et al*., 2008), *Coccinella undecimpunctata* (L.) (Moura *et al*., 2006), *Cheilelomenes vicina* Mulsant (Ofuya, 1986), *Scymnus hoffmanni* Weise (Ding-Xin, 1986), *Coccinella septempunctata* (L.) (Kumar *et al*., 1999), *Scymnus levaillanti* Mulsant (Uygun & Atlihan, 2000), *S. creperus* Mulsant (Wells *et al*., 2001), *Harmonia axyridis* (Pallas) (Lee & Kang, 2004) and *Serangium* sp. (Anonymous, 2007) in closed-patch experiments. This type of functional response has also been reported for *S. syriacus* preying on *A. gossypii* in an open-patch experiment (Sakaki & Sahragard, 2011). 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).

The handling time affects the type of functional response; shorter the handling time, the faster the curve reaches the asymptote (Nordlund & Morisson 1990). Furthermore, handling time can influence other components such as attack rate and searching efficiency (Beddington *et al*., 1976).

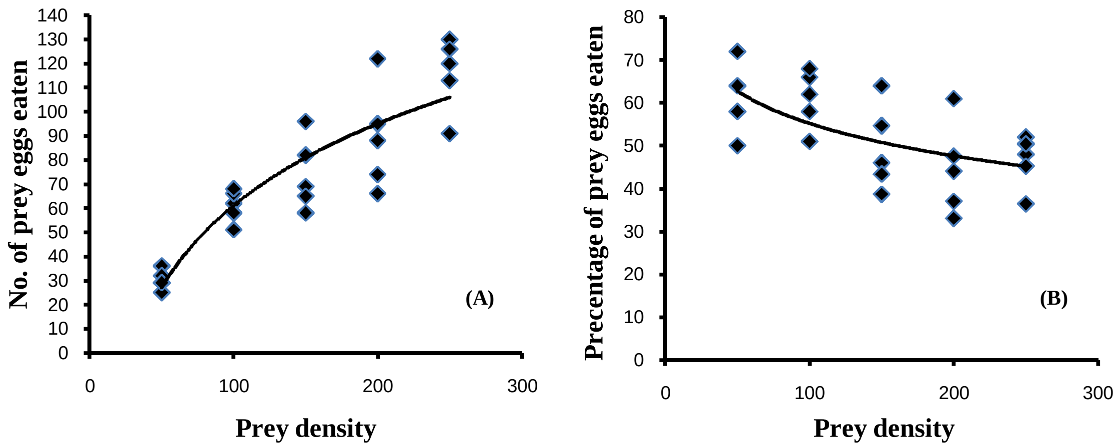

Fig. 1. Functional response (A) and percentage of predation (B) of the *Serangium montazerii* female at different densities of *Dialeurodes citri* eggs.

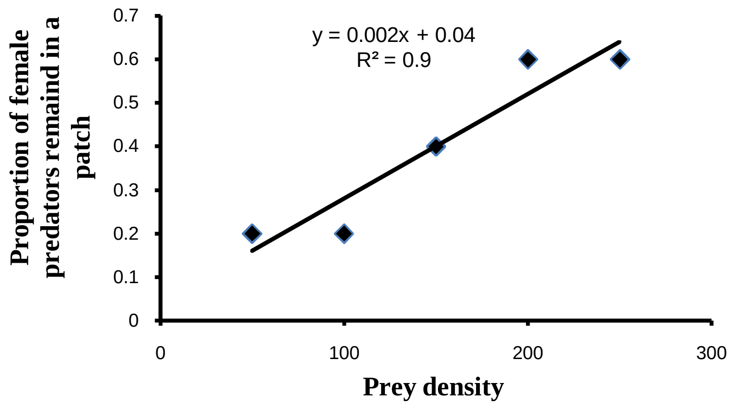

Fig. 2. Proportion of female *Serangium montazerii* remained in open patches after 24 h.

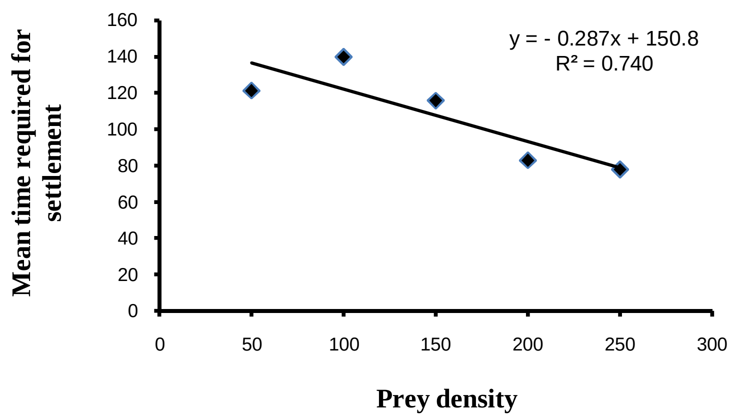

Fig. 3. Mean times (in minutes) required for the female *Serangium montazerii* to settle in a patch.

Our results showed that the mean time required for the female to settle in a prey patch decreased with the increase of prey density. The proportion of predators remaining in each patch after 24 h was density dependent in an open-patch arena. These results were in agreement with the findings of Sakaki & Sahragard (2011) on *S. syriacus*, preying on the third instars of *A. gossypii*. It has also been shown that if a parasitoid (predator) forages for a fixed time in each patch, it will stay longer on those with more prey because it will encounter more prey per search time and will therefore spend longer in handling prey (Hertlein & Thorarinsson, 1987).

This finding showed once again that the availability of the prey was the main factor which influenced predator's behaviour, as it was shown in the study of Sakaki & Sahragard (2011). Although the female *S. montazerii* was allowed to leave the patch, the number of predators remaining in each arena was directly dependent on prey egg densities. It was also concluded that the type of functional response obtained here was in agreement with studies on this predator in closed patches (Fotukkiaii & Sahragard, 2012).

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