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Host-dependent functional response of *Typhlodromus bagdasarjani* (Acari: Phytoseiidae) feeding on *Tetranychus urticae* (Acari: Tetranychidae)

Afsoon Azadi-Qoort¹, Amin Sedaratian-Jahromi^{1*} and Azadeh Farazmand²

1. Department of Plant Protection, Faculty of Agriculture, Yasouj University, Yasouj, Iran; E-mails: a.azadi297@gmail.com, Sedaratian@yu.ac.ir

2. Department of Agricultural Zoology, Iranian Research Institute of Plant Protection, Agricultural Research Education and Extension Organization (AREEO), Tehran, Iran; E-mail: afarazmand@iripp.ir

* Corresponding author

ABSTRACT

Typhlodromus (Anthoseius) bagdasarjani Wainstein & Arutunjan is an indigenous species naturally inhabiting mulberry and fig trees in urban regions. The current study was conducted to evaluate possible effects of four host plants including cucumber, tomato, eggplant, and watermelon on the functional response of *T. bagdasarjani* feeding on different densities (2, 4, 8, 16, 32, 64, and 128) of immature stages (larva + protonymph) of *Tetranychus urticae* Koch. The experiments were conducted under laboratory conditions at 25 ± 1 °C, $60 \pm 5\%$ RH, and a photoperiod of 16:8 (L:D) h. The logistic regression revealed type II functional response on the tomato, eggplant, and watermelon and a type III one on the cucumber. The handling time (T_h) and searching efficiency (a) were estimated using the Rogers equation. The highest and lowest values of T_h in the type II functional response were recorded on the watermelon (0.927 ± 0.061 h) and eggplant (0.632 ± 0.085 h), respectively. Accordingly, the highest and lowest values of searching efficiency in this type of functional response were obtained on the watermelon (0.055 ± 0.009 h⁻¹) and eggplant (0.028 ± 0.005 h⁻¹), respectively. The maximum predation rate (T/T_h) was recorded on the eggplant (37.963 prey/day). On the cucumber, the value estimated for the handling time was 1.341 ± 0.079 h. The maximum predation rate on this host plant was estimated to be 17.90 prey/day. In conclusion, our findings revealed effects of different host plants on the functional response of *T. bagdasarjani* showing that this species may be more effective in suppressing the population of *T. urticae* on the cucumber.

KEY WORDS: Cucumber, eggplant, foraging behaviors, predatory mites, spider mites, tomato, watermelon.

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INTRODUCTION

The two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae), is considered as the most important mite pest on various host plants including bean, soybean, cucumber, eggplant, melon, tomato, strawberry, pumpkin, and rose under both greenhouse and field conditions (Zhang 2003; Maleknia *et al.* 2016). Adaptability to greenhouse conditions, high reproductive potential and considerable feeding activity enable this species to develop resistant populations to the chemical pesticides (Dermauw *et al.* 2003). However, intensive use of chemical compounds can cause serious ecological problems to non-target organisms and natural enemies (Yu 2008; Merlin *et al.* 2022).

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Accordingly, safe alternatives such as biocontrol agents and resistant hosts have been considered to keep the destructive populations of *T. urticae* below the economic threshold (Heuvelink 2005; Rahmani Piyani *et al.* 2021).

Predatory mites from the family Phytoseiidae are important biocontrol agents of phytophagous mites and small insects (McMurtry *et al.* 2013). *Typhlodromus (Anthoseius) bagdasarjani* Wainstein & Arutunjan is an indigenous species in Iran that naturally inhabits mulberry and fig trees in urban regions (Demite *et al.* 2014; Jafarian *et al.* 2022; Afkhami *et al.* 2024). Species of this genus were categorized as type III generalist predators and can feed and reproduce on a wide range of prey (McMurtry *et al.* 2013). Biology, behavioral aspects, interaction with other natural enemies, and mass-rearing of this species on different diets have already been studied (Ganjisaffar *et al.* 2011a, b; Farazmand *et al.* 2012; Khanamani *et al.* 2015).

Host plants can influence pests and their natural enemies through physical and chemical characteristics (Messina and Hanks 1998; Khanamani *et al.* 2014). They may indirectly affect the natural enemies by altering prey or host suitability (Cedola *et al.* 2001). One of the interactions between prey/host and its natural enemy is the functional response, providing insights about the attacking and searching capacity of biocontrol agents (Holling 1959; Altwegg *et al.* 2006; Islam and DeLong 2022). The type of functional response and its parameters can be influenced by biotic and abiotic factors (Nguyen *et al.* 2024), including host plants with different forms and densities of trichomes, which can alter the foraging behavior of natural enemies (Messina and Hanks 1998; Madadi *et al.* 2007; Farhadi *et al.* 2010; Sobhani *et al.* 2013; Park *et al.* 2021).

Among factors that affect the functional response of *T. bagdasarjani* only type and prey stages have been studied (Farazmand *et al.* 2012; Moghadasi *et al.* 2014). This study aims to investigate the effect of four host plants on the functional response of this predatory mite.

MATERIALS AND METHODS

Biological materials

The seeds of cucumber (cultivar “Negin”), tomato (cultivar “Isabella”), eggplant (cultivar “Bell”), and watermelon (cultivar “Crimson”) were selected for the present study in consideration to their acceptance by Iranian farmers. The seeds were obtained from the Plant Protection Organization, Yasouj, Iran, and sown in plastic pots (16 cm diameter and 20 cm height) filled with approximately 250 g fertilized field soil (2:1 mix of field soil and manure sheep). Two seeds were planted in each pot at a depth of 3–4 cm. The pots were kept under greenhouse conditions (27 ± 5 °C, $65 \pm 15\%$ R.H., and natural light period). During the experiments, all plants were irrigated at the same time (two-day intervals). No chemical fertilizers or pesticides were used. These plants were utilized for the maintenance of mite colonies (prey and predator) and experimentations.

The initial samples of spider mites were collected from infested bean fields in Kohgiluyeh and Boyer Ahmad Province ($30^{\circ} 46' N$, $51^{\circ} 30' E$, 2060 m a.s.l.). Four different colonies (*i.e.* one colony on each host plant) were separately kept in ventilated cages ($200 \times 70 \times 100$ cm) covered with fine mesh net. In each cage, 6–8 infested plants were placed. The damaged hosts were replaced with new clean ones weekly. All colonies were supplemented with the new mite samples to minimize any inbreeding effects. Mites were reared under greenhouse conditions (25 ± 5 °C, $65 \pm 15\%$ R.H., and natural photoperiod) for four generations before experiments. The immature stages of *T. urticae* (*i.e.* larva and protonymph) reared on each host plant were harvested daily and used as predator food.

The initial population of *T. bagdasarjani* was obtained from the laboratory colony in the Department of Agricultural Entomology, Faculty of Agriculture, Tarbiat Modares University. The mites were randomly divided into four different groups and placed on the leaf discs (8 cm diameter) of each host plant. Immature stages of *T. urticae* (daily) were used together with pollen corn (twice a week) as food for the predators. To avoid predator mix, mite colonies were separately maintained in four different growth chambers (25 ± 1 °C, $65 \pm 5\%$ R.H., and a photoperiod of 16L: 8D h).

The leaf disc method was used in the assay. The arena was built from two different sets of Petri dishes; 6 and 8 cm in diameter and both 1.5 cm height. At the beginning of reproductive stage, the leaves of each host plant were cut into rings with a diameter of 5.5 cm. A bed of water-saturated cotton was placed in a smaller dish and the leaf ring was transferred on it. A cotton strip was wrapped around the leaf edges to prevent predators from escaping. The small dishes were placed in the larger ones and sufficient water was added to the larger dishes during the daily check to maintain the freshness of leaves. The lid of the larger discs had a ventilation hole in its center (1.5 cm diameter), which was covered with a fine-mesh net to facilitate the escape of additional moisture.

Experimental procedure

To accomplish the experiments, the same-age female predators (< 24h) were used. For determining the functional response of *T. bagdasarjani* on each host plant, different densities (2, 4, 8, 16, 32, 64, and 128) of immature stages of prey (larva and protonymph) were exposed to females for a constant period (24 h). The experimental area was leaf disc as previously explained. A female predator was introduced into each arena, which was supplied with different densities of prey. After 24 hours, the female predator was removed and the number of prey consumed was carefully counted using a stereomicroscope. On different host plants, each prey density was replicated for 12 times.

Data analysis

A one-way ANOVA was utilized to compare the predation rate of *T. bagdasarjani* at different prey densities (PROC GLM, SAS 2002), followed by the SNK test for mean grouping ($P < 0.05$).

The general statistical method was to analyze the functional response data based on the two-step method (Juliano 2001) through the SAS software (2002). To determine the type of functional response, logistic regression of the ratio of consumed prey to the primary prey density (N_a/N_0) was used (Trexler and Travis 1993). For this purpose, the data were processed into the following polynomial function:

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

After determining the type of functional response, using nonlinear regression with the NLIN procedure in the program presented by Juliano (1993) and the DUD technique, the attack rate (a) and handling time (T_h) coefficients in type II functional response were calculated using equation 2 (Royama 1971; Rogers 1972).

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

where N_a is the number of prey killed, N_t is the initial number of prey, T is the total time available for the predator, a is the attack rate and T_h is the handling time.

For the type III response, the attack rate is assumed to increase with host density according to the equation $a = (d + bN_0)/(1 + cN_0)$ (Hassell *et al.* 1977). In cases where both d and c are not significantly different from 0, this leads to $a' = bN_0$ which can be inserted into equation (2). This yields the equation 3 (Hassell 1978):

$$N_a = N_0 [1 - \exp(-bTN_0 | 1 + bNT_h N_0^2)] \quad (3)$$

Then, for each host density, the attack coefficient (a) can be determined as $a = bN_0$. In type III functional response, the attack rate is a function of prey density (N_0) and was calculated as $a' = bN_t$. An iterative nonlinear least-squares regression was used to fit the random predator equation to the

data to estimate the parameters describing the type II response. Likewise, a non-linear least squares regression procedure was used to fit equation (3) to the data producing a type III response.

RESULTS

ANOVA showed that prey density significantly affected the predation rate of *T. bagdasarjani* (Table 1). There was a statistical difference between the average number of prey (larva and protonymph) consumed by *T. bagdasarjani* at different densities on the tested host plants (Table 1). On all host plants, the number of prey consumed increased significantly with prey density, from a minimum at prey density of two to a maximum at prey density of 128.

Table 1. The number (mean \pm SE) of prey consumed by predatory mite *Typhlodromus bagdasarjani* at different densities of *Tetranychus urticae* on different host plants.

Prey densities	Different host plants			
	Cucumber	Eggplant	Tomato	Watermelon
2	1.33 \pm 0.23 ^e	1.67 \pm 0.13 ^e	1.75 \pm 0.13 ^d	1.92 \pm 0.83 ^e
4	3.20 \pm 0.22 ^{de}	2.67 \pm 0.41 ^e	3.33 \pm 0.19 ^d	3.33 \pm 0.28 ^e
8	5.13 \pm 0.43 ^{de}	2.83 \pm 0.67 ^e	5.17 \pm 0.49 ^d	4.58 \pm 0.62 ^e
16	7.26 \pm 0.66 ^{cd}	7.17 \pm 0.81 ^d	10.08 \pm 0.89 ^c	9.50 \pm 0.81 ^d
32	10.57 \pm 1.21 ^c	12.42 \pm 1.37 ^c	12.92 \pm 1.40 ^c	14.73 \pm 1.64 ^c
64	15.50 \pm 1.19 ^b	18.00 \pm 2.09 ^b	17.92 \pm 1.43 ^b	19.58 \pm 1.47 ^b
128	20.40 \pm 2.46 ^a	23.73 \pm 1.66 ^a	21.31 \pm 1.55 ^a	22.93 \pm 1.14 ^a
<i>F</i>	36.25	53.47	49.65	70.74
<i>df</i>	6, 89	6, 79	6, 79	6, 79
<i>P</i>	< 0.0001	< 0.0001	< 0.0001	< 0.0001

* Values followed by different letters within the same columns are significantly different ($P < 0.01$, SNK).

Table 2. Parameters (mean \pm SE) obtained from logistic regression of functional response of predatory mite *Typhlodromus bagdasarjani* to different densities of *Tetranychus urticae* on different host plants.

Host plants	Parameters	Estimates (\pm SE)	χ^2	<i>P</i>
Cucumber	P_0	0.3821 \pm 0.1925	3.94	0.0472
	P_1	0.0147 \pm 0.0149	0.96	0.3260
	P_2	-0.00108 \pm 0.000290	13.76	0.0002
	P_3	6.506E-6 \pm 1.456E-6	19.98	< 0.0001
Eggplant	P_0	0.5266 \pm 0.2121	6.17	0.0130
	P_1	-0.0602 \pm 0.0169	12.66	0.0004
	P_2	0.000872 \pm 0.000328	7.07	0.0078
	P_3	-4.04E-6 \pm 1.636E-6	6.11	0.0134
Tomato	P_0	1.8594 \pm 0.2472	56.57	< 0.0001
	P_1	-0.1208 \pm 0.0180	45.06	< 0.0001
	P_2	0.00171 \pm 0.000336	25.89	< 0.0001
	P_3	-7.47E-6 \pm 1.651E-6	20.48	< 0.0001
Watermelon	P_0	1.4868 \pm 0.2393	38.59	< 0.0001
	P_1	-0.0903 \pm 0.0182	24.63	< 0.0001
	P_2	0.00118 \pm 0.000346	11.67	0.0006
	P_3	-5.17E-6 \pm 1.71E-6	9.14	0.0025

Our findings revealed that different host plants could affect the type of functional response of *T. bagdasarjani*. Results of logistic regression to distinguish between type II and III functional responses are shown in Table 2. These results showed that on the cucumber, the proportion of prey consumed increased with increasing densities of prey ($P_1 > 0$), resulting in a type III functional response. On the other hand, the linear coefficient of equation (1) on other host plants was negative ($P_1 < 0$), indicating a type II functional response (Table 2). The curve of the percentage of prey consumed by the female predators is shown in Figure 1.

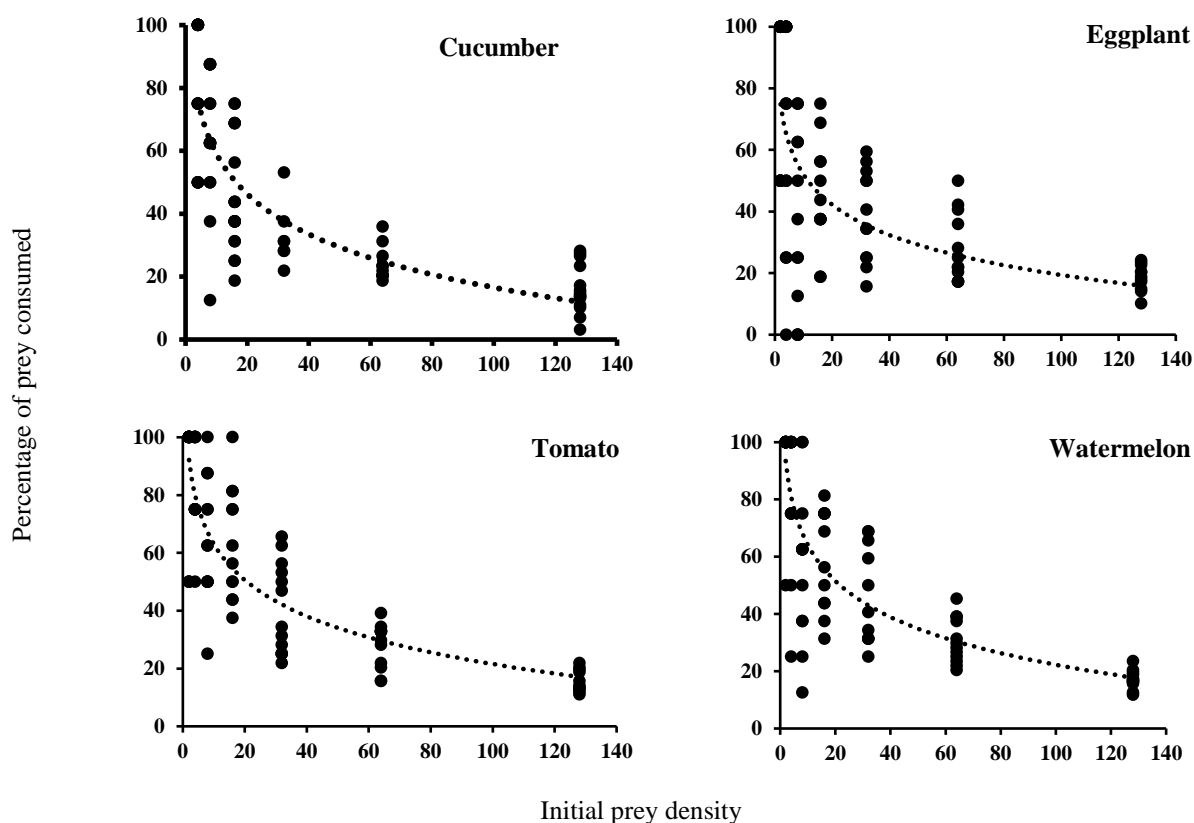


Figure 1. The percentage of prey consumed by *Typhlodromus bagdasarjani* at different densities of *Tetranychus urticae* on different host plants.

Table 3. Quantitative values of functional response parameters (mean \pm SE) of predatory mite *Typhlodromus bagdasarjani* to different densities of *Tetranychus urticae* on different host plants.

Host plants	Functional response parameters			
	a (h^{-1}) (95% confidence limits)	T_h (h) (95% confidence limits)	T/T_h (prey/day)	R^2
Cucumber	0.00499 ± 0.00152 (0.00198–0.00800)	1.3408 ± 0.0793 (1.1835–1.4980)	17.89976	0.811
Eggplant	0.0284 ± 0.00493 (0.0186–0.0382)	0.6322 ± 0.0850 (0.4632–0.8013)	37.96267	0.884
Tomato	0.0492 ± 0.00965 (0.0300–0.0684)	0.9242 ± 0.0794 (0.7664–1.0820)	25.96841	0.893
Watermelon	0.0550 ± 0.00906 (0.0370–0.0730)	0.9267 ± 0.0607 (0.8060–1.0474)	25.89835	0.930

The attack rate (a) and handling time (T_h) of predatory mite on four plants are presented in Table 3. There was no significant difference between the values of these parameters for *T. bagdasarjani* on

the eggplant, tomato, and watermelon. The attack rate on the cucumber was different in each density of prey and it is not comparable with those estimated for type II functional response on other hosts. Accordingly, a simple model $a = bN_0$ was used to estimate the searching efficiency of *T. bagdasarjani* at each prey density on cucumber. The maximum number of prey consumed by *T. bagdasarjani* over 24 hours was 37.96 (prey) on eggplant since this plant showed the shortest handling time (0.63 h). Among three plants showing type II functional response, tomato and watermelon had similar attack rates and handling times (Table 3).

DISCUSSION

Our findings showed that different host plants can affect the functional response of *T. bagdasarjani*. Hence, this predatory mite showed both type II and type III functional responses, supporting the hypothesis that a natural enemy can exhibit different responses in regards to the kind of host plants. Type II functional response is common for most phytoseiid mites (Kouhjadi-Gorji *et al.* 2009; Ahn *et al.* 2010; Farazmand *et al.* 2012; Fathipour *et al.* 2017). Similarly, *T. bagdasarjani* showed a type II response to different densities of *T. urticae* on watermelon, tomato, and eggplant. Although the effect of age or temperature on the functional response of predatory mites has been studied (Kouhjadi-Gorji *et al.* 2009; Jafari *et al.* 2012; Fathipour *et al.* 2017), there is no study about the effect of different host plants on the functional response of *T. bagdasarjani*.

When it comes to biological control issues, the functional response describes how a predator responds to the change in the density of its prey (Juliano 2001) in which types II and III functional responses are favorable for biological control programs (Fernández-Arhex and Corley 2003; Reis *et al.* 2003; Pervez and Omkar 2005; Kouhjadi-Gorji *et al.* 2009; Ahn *et al.* 2010). As well as type II, a type III functional response was also reported for different ages of *Amblyseius swirskii* Athias-Henriot and *Phytoseiulus persimilis* Athias-Henriot (Fathipour *et al.* 2017, 2018). In this line, our findings revealed that different host plants affected the type of functional response of *T. bagdasarjani*; type III on the cucumber. In contrast with this observation, Farazmand *et al.* (2012) reported a type II functional response for *T. bagdasarjani* feeding on egg and nymphal stages of *T. urticae* on cucumber. A possible reason for explaining such differences is variation in plant variety, namely “Pis” (Farazmand *et al.* 2012) and “Negin” (present study). In another study, the functional response of *Neoseiulus californicus* (McGregor) was affected by two different host plants, strawberry and tomato (Cedola *et al.* 2001; Ahn *et al.* 2010). A similar finding was also reported by Sobhani *et al.* (2013) in the case of predatory insect species, *Episyrphus balteatus* (De Geer) (Diptera: Syrphidae). van Haren *et al.* (1987) stated that tomato can affect the functional response since it has glandular trichomes producing a sticky exudate creating a trap for predatory mite. Cedola *et al.* (2001) confirmed this statement and linked the low efficacy of *N. californicus* on tomato leaves with the glandular trichomes of leaves. Such similar findings emphasize the pronounced effects of host plant characteristics on the behavioral parameters of predatory mites.

The handling time has the highest value on cucumber compared to the other three plants, indicating that the predatory mite has non-searching activities (e.g., resting and restricting its movement on trichomes). The longer trichomes of cucumber which impede the movement of predators could be noticed as a possible reason for this observation. In addition, prey can use these trichomes as shelter, so predators must spend more time searching for them (Sobhani *et al.* 2013). The presence of these trichomes, however, leads to a restriction in the movement of predatory mites, resulting in *T. bagdasarjani* feeding on prey enclosed in its niche. Accordingly, in low-density prey, the predation rate of *T. bagdasarjani* is low and by increasing the prey density, the rate of predation increases, leading to type III functional response. In this line, the predation capacity of *P. persimilis* on gerbera was lower at high trichome density than at low ones when the density of *T. urticae* was low, but it was not affected at high *T. urticae* density (Krips *et al.* 1999). Similar to our findings, the

role of trichomes in cucumber leaves on the functional response of *N. cucumeris* and their restrictive effects on predation parameters has been mentioned (Madadi *et al.* 2007).

The information presented in the current study expands our knowledge about the effects of host plants on the predation behavior of the indigenous predator *T. bagdasarjani*. However, further studies under semi-field and field conditions are urgently needed to provide a more realistic picture of the effectiveness of this predatory mite as a biocontrol agent in integrated pest management programs.

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واکنش تابعی وابسته به میزبان در هرناهی شکارگر *Typhlodromus bagdasarjani* (Acari: Tetranychidae) با تغذیه از هرناهی *Phytoseiidae* (Acari: Tetranychidae)

افسون آزادی قورت^۱، امین صدارتیان جهرمی^{*} و آزاده فرازمنند^۲

۱. گروه گیاهپزشکی، دانشکده کشاورزی، دانشگاه یاسوج، یاسوج، ایران؛ رایانامه‌ها: Sedaratian@yu.ac.ir و azadi297@gmail.com

۲. بخش جانورشناسی کشاورزی، مؤسسه تحقیقات گیاهپزشکی کشور، سازمان تحقیقات، آموزش و ترویج کشاورزی، تهران، ایران؛ رایانامه:

afarazmand@iripp.ir

* نویسنده مسئول

چکیده

هرناهی شکارگر *Typhlodromus (Anthoseius) bagdasarjani* Wainstein & Arutunjan گونه‌ای بومی است که به صورت طبیعی روی درختان توت و انجیر در مناطق شهری مشاهده می‌شود. پژوهش حاضر با هدف ارزیابی اثرات احتمالی میزبان‌های مختلف گیاهی شامل خیار، گوجه‌فرنگی، بادمجان و هندوانه بر واکنش تابعی هرناهی شکارگر *T. bagdasarjani* با تغذیه از تراکم‌های مختلف (۲، ۴، ۸، ۱۶، ۳۲، ۶۴ و ۱۲۸) مراحل نابالغ (لارو + پوره سن یکم) هرناهی *Tetranychus urticae* Koch صورت پذیرفت. بررسی‌ها در شرایط آزمایشگاهی با دمای ۱ ± ۲۵ درجه سلسیوس، رطوبت نسبی ۵ ± ۶۰ درصد و دوره نوری ۱۶ ساعت روشنایی و ۸ ساعت تاریکی انجام شد. نتایج حاصل از رگرسیون لجستیک نشان داد که واکنش تابعی هرناهی شکارگر روی میزبان‌های گوجه‌فرنگی، بادمجان و هندوانه از نوع دوم و روی خیار از نوع سوم می‌باشد. مقادیر زمان دستیابی به طعمه (T_h) و قدرت جستجوی طعمه (a) با استفاده از معادله راجرز برآورد شدند. بیشترین و کمترین مقادیر زمان دستیابی به طعمه (T_h) در واکنش تابعی نوع دوم به ترتیب روی هندوانه (۰/۶۱ ± ۰/۹۲۷ ساعت) و بادمجان (۰/۸۵ ± ۰/۶۳۲ ساعت) ثبت شد. بر همین اساس، بیشترین و کمترین میزان قدرت جستجوی طعمه در این نوع از واکنش تابعی نیز به ترتیب روی هندوانه (۰/۰۹ ± ۰/۰۵۵ بر ساعت) و بادمجان (۰/۰۵ ± ۰/۰۲۸ بر ساعت) به دست آمد. بیشترین میزان حمله به طعمه (T/T_h) نیز روی بادمجان محاسبه شد (۳۷/۹۶۳ طعمه/روز). روی خیار، زمان دستیابی به طعمه برابر با ۰/۰۷۹ ± ۱/۳۴۱ ساعت برآورد شد. بیشترین میزان حمله روی این گیاه میزبان نیز ۱۷/۹۰ طعمه/روز تخمین زده شد. یافته‌های پژوهش حاضر مؤید تأثیر گیاهان میزبان بر واکنش تابعی هرناهی شکارگر *T. bagdasarjani* می‌باشد و بیانگر آن است که این گونه می‌تواند به منظور کاهش جمعیت کنه *T. urticae* روی گیاه خیار مؤثرتر باشد.

واژگان کلیدی: خیار، بادمجان، رفتارهای شکارگری، هرناهای شکارگر، هرناهای تارتن، گوجه‌فرنگی، هندوانه.

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