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The influence of temperature on the functional response and prey consumption of *Neoseiulus barkeri* (Acari: Phytoseiidae) on *Tetranychus urticae* (Acari: Tetranychidae)

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Abstract

The foraging behavior of a natural enemy is greatly affected by temperature. The influence of different constant temperatures on the functional response and prey consumption of the mated female of *Neoseiulus barkeri* Hughes on nymphal stages of *Tetranychus urticae* Koch was evaluated. Four ambient temperatures (20, 25, 30 and 35 ± 1°C) and six prey densities (2, 4, 8, 16, 32 and 64 individuals) were used during a 24-h period in functional response experiments. The effect of seven constant temperatures (15, 20, 25, 27, 30, 35 and 37 ± 1°C) on prey consumption of *N. barkeri* on nymphal stages of *T. urticae* was also determined. Using the logistic regression, the type II functional response was determined for adult female of *N. barkeri* at all temperatures. The type II Rogers' model was used to estimate the values of the searching efficiency (a) and handling time (T_h). The value of the searching efficiency increased with increasing temperature from 20 to 30°C (0.0364 to 0.0731 h^{-1} respectively), then decreased at 35°C (0.0646 h^{-1}). The handling time of this predator decreased when the temperature increased from 20 to 35°C, and the minimum value was observed at 35°C (0.5548 h). Similarly, temperature had a significant effect on the prey consumption of adult females of *N. barkeri* over the range of 15-37ºC. The minimum and maximum daily prey consumption of whole immature stages of *N. barkeri* was observed at 15°C and 35°C respectively. The highest and the lowest number of total preys consumed by all immature stages of *N. barkeri* were 14.61 and 8.79 preys that occurred at 20°C and 15°C respectively. During the oviposition period, the total prey consumption increased with increasing temperature from 15 (160.43 preys) to 30°C (286.71 preys) and then declined and reached to 191.57 preys at 37°C. The results of this study underscore the effect of temperature on searching efficiency and prey consumption of *N. barkeri*.

Key words: constant temperatures, functional response, prey consumption, *Neoseiulus barkeri*, *Tetranychus urticae*

چکیده

رفتار کاوشگری دشمنان طبیعی به شدت تحت تأثیر دما قرار می‌گیرد. تأثیر دماهای مختلف بر واکنش تابعی و میزان شکارگری افراد ماده‌ی کنه‌ی شکارگر *Neoseiulus barkeri* Hughes با تغذیه از مراحل نمفی کنه‌ی *Tetranychus urticae* Koch ارزیابی شد. آزمایش واکنش تابعی برای افراد ماده‌ی بالغ کنه‌ی شکارگر در چهار دمای ثابت ۲۰، ۲۵، ۳۰ و ۱ ± ۳۵ درجه‌ی سلسیوس و با استفاده از شش تراکم طعمه ۲، ٤، ۸، ١٦، ۳۲ و ٦٤ فرد طی ٢٤ ساعت انجام شد. همچنین اثر هفت دمای ثابت ۱۵، ۲۰، ۲۵، ۲۷، ۳۰، ۳۵ و ۱ ± ۳۷ درجه‌ی سلسیوس با ۵ ± ٦٥ درصد رطوبت نسبی و دوره‌ی نوری ۱۲ ساعت تاریکی و ۱۲ ساعت روشنایی بر میزان تغذیه‌ی مراحل مختلف رشدی کنه‌ی شکارگر *N. barkeri* از مراحل نمفی کنه‌ی تارتن دولکه‌ای بررسی شد. نوع واکنش تابعی افراد ماده‌ی بالغ با استفاده از رگرسیون لجستیک در تمام دماهای مورد آزمایش نوع دوم تعیین شد. مقادیر قدرت جستجو (a) و زمان دستیابی (T_h) با استفاده از نوع دوم مدل Rogers تعیین شد. مقدار قدرت جستجو با افزایش دما از ۲۰ درجه‌ی سلسیوس (۰/۰۳٦٤ h^{-1}) تا ۳۰ درجه‌ی سلسیوس، افزایش یافت و در دمای اخیر به بالاترین مقدار خود رسید (۰/۰۷۳۱ h^{-1})، سپس در ۳۵ درجه‌ی سلسیوس (۰/۰٦٤٦ h^{-1}) کاهش یافت. زمان دست‌یابی با افزایش دما از ۲۰ تا ۳۵ درجه‌ی سلسیوس کاهش یافت و کم‌ترین مقدار آن در دمای ۳۵ درجه‌ی سلسیوس مشاهده شد (۰/۵۵٤۸ ساعت). اثر دما بر میزان مصرف طعمه‌ی افراد ماده‌ی بالغ معنی‌دار بود. کم‌ترین و بیش‌ترین میزان مصرف روزانه‌ی

طعمه توسط مراحل مختلف رشدی کنه‌ی *N. barkeri* به‌ترتیب در دماهای ۱۵ و ۳۵ درجه‌ی سلسیوس مشاهده شد. پایین‌ترین و بالاترین میزان کل مصرف طعمه توسط تمام مراحل رشدی کنه‌ی شکارگر برابر ۸/۷۹ و ١٤/٦١ طعمه بود که به‌ترتیب در دماهای ۱۵ و۲۰ درجه‌ی سلسیوس مشاهده شد. در طول دوره‌ی تخم‌ریزی با افزایش دما از ۱۵ تا ۳۰ درجه‌ی سلسیوس، میزان مصرف طعمه از ١٦٠/٤٣ تا ٢٨٦/٧١ طعمه افزایش یافت، سپس با کاهش در ۳۷ درجه‌ی سلسیوس به ۱۹۱/۵۷ طعمه رسید. نتیجه‌ی نهایی این پژوهش، آشکارسازی تأثیر قابل توجه دما بر قدرت جستجو و میزان شکارگری *N. barkeri* می‌باشد.

واژگان کلیدی: دماهای ثابت، واکنش تابعی، مصرف طعمه، *Neoseiulus barkeri*، *Tetranychus urticae*

Introduction

The species *Neoseiulus barkeri* Hughes is a generalist predator belonging to the type III life style phytoseiid mites, which is capable of feeding on mite pests and some small insects, e.g. thrips and whiteflies as well as various pollens (Bonde, 1989; Fan & Petitt, 1994; Gerson *et al*., 2003). It is widely distributed and reported from all continents (Moraes *et al*., 2004). This species has been reported from several Iranian provinces on different crops such as cucumber, okra, apple and raspberry (Kamali *et al*., 2001; Hajizadeh, 2007). Momen (1995) reported this species on cucumber in greenhouses of Fleninge and Storp in South Sweden.

Field surveys in several parts of Lorestan province showed that this predatory mite can be found naturally in association with *Tetranychus urticae* Koch and *Thrips tabaci* Lindeman on cucumber leaves (Jafari *et al*., 2010). The species *N. barkeri* has been successfully used in augmentative biological control against onion thrips, *T. tabaci* (Hansen, 1988; Bonde, 1989) and *T. urticae* (Fouly & EL-Laithy, 1992; Momen, 1995). Karg *et al*. (1987) also studied the efficacy of this predator in controlling *T. urticae* on cucumber.

The functional response of different species of phytoseiid mites has been extensively studied by Everson (1979), Zhang *et al*. (1998, 1999a, 1999b, 2000), Shirdel (2003), Skirvin & Felon (2003), Badii *et al*. (2004), Gotoh *et al*. (2004), Sepulveda & Carrillo (2008), and Kouhjani Gorji *et al*. (2009). Fan & Petitt (1994) determined a type II functional response for *N. barkeri* on eggs, larvae and adults of *T. urticae* at 25°C.

Temperature is the major abiotic factor affecting biology of poikilothermic animals. The impact of environmental variables like temperature on the biology of pests and their natural enemies is important in determining the efficacy of biological control agents. Despite of extensive studies on the role of temperature on the biology of phytoseiid mites (see above), the functional response of *N. barkeri* at different temperatures has not yet been studied.

The capacity of prey consumption of a predator especially in augmentation biological control, where a predator is repeatedly introduced to consume a prey, is one of the most important factors in biological control programs (Fan & Petitt, 1994). The aim of this study was to evaluate the effect of different constant temperatures on functional response and prey consumption of the Iranian populations of *N. barkeri* as an efficient predator of spider mites, especially of *T. urticae.*

Materials and methods

Rearing of mites

To establish the stock culture of *N. barkeri* and *T. urticae,* the cucumber leaves containing the prey and predator mites were cut and immediately transferred to the laboratory from cucumber fields in Sarabe Chengai in the vicinity of the city of Khorramabad in June 2008. The colony of two-spotted spider mites, *T. urticae*, was maintained on cucumber plants in greenhouse at 27 ± 2ºC and under a natural photoperiod. The adults of *N. barkeri* were later transferred onto the detached cucumber leaves containing ample number of all stages of *T. urticae* as prey in a growth chamber at 27 ± 1ºC, 65 ± 5% RH and a photoperiod of 12: 12 h (L: D). The predator and prey individuals were reared for two generations before using in the experiments. The identification of *N. barkeri* was confirmed by the last author.

Functional response experiments

The functional response experiments were carried out at four constant temperatures (20, 25, 30 and 35ºC) under relative humidity of 65 ± 5% and a photoperiod of 12: 12 h (L: D). Each test arena consisted of a piece of cucumber leaf (3 × 3 cm = 9 cm^2), placed upside down on water saturated foam mat covered with wet filter paper, inside a plastic petri dish (6 cm in diameter) with a hole in its center (0.5 cm in diameter). To keep the leaves fresh and to prevent the mites from leaving the surface, the margins of the cucumber leaves were covered with strips of wet cotton. The lid of each petri dish was covered by fine mesh for ventilation. Each experimental arena was placed in a larger petri dish (9 cm in diameter) filled with water. To examine the effect of temperature on functional response of *N. barkeri*, six different densities (2, 4, 8, 16, 32 and 64) of the nymphal stages (protonymphs and deutonymphs) of the two-spotted spider mites were offered to a three-day-old mated female predator, which had starved for 24 h prior to the experiments. After 24 h the predator in each arena was removed and the number of consumed preys recorded. Each treatment was replicated 15 times and all experiments were carried out simultaneously.

Statistical analysis of functional response

To discriminate between the types of the functional response, the positive or negative sign of the linear coefficient was determined by logistic regression (Juliano, 2001). For this reason, the data was fitted to the following model: $N_a / N_t = [\exp(P_0 + P_1N_t + P_2N_t^2 + P_3N_t^3)] / [1 + \exp(P_0 + P_1N_t + P_2N_t^2 + P_3N_t^3)]$; where N_t is the initial prey density, N_a is the number of prey eaten, N_a / N_t is the probability of being eaten. P_0, P_1, P_2 and P_3 are the intercept, linear, quadratic and cubic coefficients, respectively, which estimated using the method of maximum likelihood. If $P_1 < 0$, the proportion of prey consumed declines gradually as increasing the initial prey offered, thus exhibiting the type II functional response, but if $P_1 > 0$ the proportion of prey consumed is positively density dependent, thus describing a type III functional response (Juliano, 2001).

After determining the type of functional response, the Royama-Rogers' type II model was used to estimate the searching efficiency (a) and handling time (T_h) (Royama, 1971; Rogers, 1972) as follows: $N_a = N_t \{1 - \exp[-aTp_t / (1 + aT_hN_t)]\}$; where N_t is the initial prey density, N_a is the number of prey eaten, T is the time available for searching during the experiment (in this experiment = 24 h), T_h is the amount of time that predator handles each prey individual (handling time) and P_t is the number of predators (Rogers, 1972). The functional response parameters were estimated using nonlinear regression of JMP v. 7.0 (SAS Institute, 2007). The curves of the observed number and percentage of prey eaten by *N. barkeri* females to different densities of the nymphal stages of *T. urticae* at four temperatures were depicted by SigmaPlot software.

Prey consumption experiments

The experimental arena was similar to the functional response experiment. The prey consumption experiments were conducted under laboratory condition at seven constant temperatures 15, 20, 25, 27, 30, 35 and 37°C, under 65 ± 5 RH and a photoperiod of 12: 12 h (L: D). After the emergence of larvae, the ample quantity of the nymphal stages of two-spotted spider mites (protonymphs and deutonymphs) were offered daily for different life stages of *N. barkeri* and the number of eaten prey was recorded. For the larva, protonymph, deutonymph and adult female of the predator, 10, 20, 30 and 50 preys a day were offered respectively. The number of offered preys was derived from a preliminary experiment. Each treatment was replicated 20 and 15 times for immature and adult stages of the predator respectively.

Statistical analysis of prey consumption

The analysis of variance (ANOVA) was used to compare the prey consumption on various life stages of *N. barkeri* at different temperatures, using SAS software (SAS Institute, 2003). The Duncan multiple range test was used for mean comparison.

Results

Functional response of *N. barkeri* at four temperatures

The logistic regression analysis of the functional response of the females of *N. barkeri* led to a negative value of P_1 at all temperatures (table 1), which indicated the type II functional response. The number of prey consumed by the predator females at each temperature generally increased with increasing prey density, however the proportion of prey consumption to initial prey density decreased as prey density increased (fig. 1). The analysis of functional response data suggested significant difference between preys eaten at different temperatures in each prey density (table 2).

Table 1. Maximum likelihood estimates from logistic regression of the proportion of *T. urticae* nymphal stages consumed by *N. barkeri* female at four constant temperatures.

		Parameter		
Temperature (°C)	**Intercept (P_0)**	**Linear (P_1)**	**Quadratic (P_2)**	**Cubic (P_3)**
20	2.16	-0.63	0.077	-0.0029
25	4.16	-0.81	0.055	-0.0010
30	5.43	-1.06	0.074	-0.0014
35	3.38	-0.51	0.038	-0.0008

The Royama-Rogers' type II model showed an acceptable fit to the data at all temperature examined (table 3). The estimated values of the searching efficiency, handling time and the values of the coefficients of R^2, R^2_{adj} and P_{value} are presented in table 3.

The results indicated that the value of the searching efficiency increased linearly with increasing temperatures from 20 to 30°C and reached a maximum level at 30°C (0.0731 h^{-1}) then decreased at 35°C (0.0646 h^{-1}). The value of the handling time decreased with increasing temperature from 20 to 35°C. The maximum and minimum estimated values of the handling

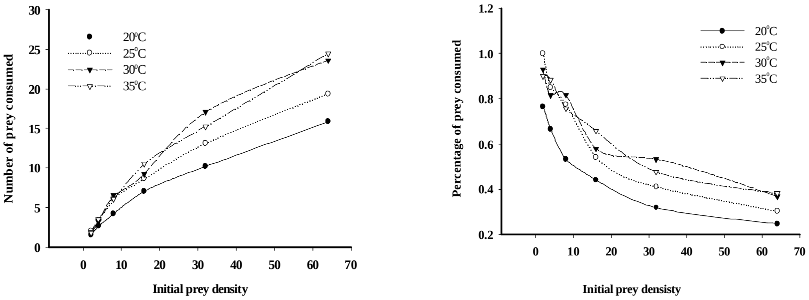

Figure 1. Functional response and percentage of prey consumed by *N. barkeri* females on different densities of nymphal stages of *T. urticae* at four constant temperatures.

Table 2. Mean number of prey consumed per day (± SE) by the female of *N. barkeri* on different densities of nymphal stages of *T. urticae* at four constant temperatures (n = 15).

Prey density	Temperature (°C)			
	20	25	30	35
2	1.53 ± 0.17 b	2.00 ± 0.00 a	1.86 ± 0.09 ab	1.80 ± 0.14 ab
4	2.66 ± 0.27 b	3.40 ± 0.29 ab	3.26 ± 0.23 ab	3.53 ± 0.19 a
8	4.26 ± 0.40 b	6.20 ± 0.35 a	6.53 ± 0.39 a	6.06 ± 0.37 a
16	7.06 ± 0.56 b	8.66 ± 0.61 ab	9.27 ± 0.60 a	10.53 ± 0.86 a
32	10.20 ± 0.74 c	13.13 ± 0.82 bc	17.06 ± 1.31 a	15.26 ± 1.34 ab
64	15.86 ± 1.01 c	19.40 ± 1.16 b	23.60 ± 1.00 a	24.46 ± 1.05 a

The means followed by different letters in each row are significantly different ($P < 0.05$, Duncan's multiple range test after one-way ANOVA).

time were 0.9216 and 0.5548 h that occurred at 20°C and 35°C respectively. The theoretical maximum predation rate (T / T_h) is the upper asymptote of the functional response curve and represents the high potential of a predator for consuming its prey during a period of 24-h (Cave & Gaylor, 1987). The theoretical maximum predation rate ranged from 26.04 preys day^{-1} at 20°C to 43.25 preys day^{-1} at 35°C.

Prey consumption of *N. barkeri* at seven temperatures

The daily and total prey consumption of different stages of *N. barkeri* on nymphal stages of *T. urticae* at seven constant temperatures are displayed in tables 4 and 5 respectively. The average number of prey consumed daily by immature stages of *N. barkeri* was affected by temperature in which it increased as temperature increased from 15 to 35°C, then decreased at 37°C. The highest and lowest daily prey consumption of whole immature stages of *N. barkeri*

Table 3. Estimated (± SE) searching efficiency (*a*) and handling time (T_h) of *N. barkeri* female on nymphal stages of two-spotted spider mite at four constant temperatures.

Temp. (°C)	$a \pm SE$	$T_h \pm SE$	a / T_h	T / T_h	*RSS*	R^2	R^2_{adj}	*P*
20	0.0364 ± 0.0055 (0.0144-0.0584)	0.9216 ± 0.0985 (0.5274-1.3159)	0.0395	26.04	1.287	0.991	0.989	< 0.0001
25	0.0644 ± 0.0143 (0.0071-0.1216)	0.8248 ± 0.0856 (0.4823-1.1672)	0.0781	29.98	2.355	0.989	0.986	< 0.0001
30	0.0731 ± 0.0131 (0.0207-0.1254)	0.5979 ± 0.0556 (0.3756-0.8207)	0.1223	40.14	1.899	0.994	0.993	< 0.0001
35	0.0646 ± 0.0121 (0.0164-0.1128)	0.5548 ± 0.0639 (0.2992-0.8103)	0.1164	43.25	2.471	0.993	0.991	< 0.0001

a = searching efficiency, T_h = handling time.

was recorded at 35°C and 15°C respectively. The daily prey consumption in pre-oviposition period at different temperatures varied from 1.63 to 12.4 preys at 15°C and 37°C respectively. The daily prey consumption in oviposition period increased with raising temperature from 15 to 30°C, but its value declined at 30 to 37°C. The maximum daily prey consumption in oviposition period was 19.13 preys at 30°C. At all temperatures tested, the value of the daily prey consumption in post-oviposition period was less than the oviposition period.

The total prey consumption also was affected by temperature. The total prey consumption of whole immature stages of *N. barkeri* at different temperatures varied from 8.79 to 14.61 preys that occurred at 15°C and 20°C respectively. The total prey consumption of ovipositing females increased with increasing temperature from 15°C (160.43 preys) to 30°C (286.71 preys) and then declined at 37°C (191.57 preys). The total prey consumption of adult females increased with increasing temperature from 15 to 30°C but decreased at 30-37°C.

Discussion

This first study on the effect of different temperatures on the functional response and prey consumption of *N. barkeri* indicated that the functional response of females of *N. barkeri* on nymphal stages of *T. urticae* was type II at different temperatures. Fan & Petitt (1994) similarly reported that *N. barkeri* exhibited type II functional response to different densities of eggs, larvae and adults of the two-spotted spider mites on pepper leaf discs at 25°C. The type II functional response has also been reported for several phytoseiid mite species such as *Euseius hibisci* (Chant), *Phytoseius plumifer* (Canestrini & Fanzago), *Phytoseiulus persimilis* Athias-Henriot, *Chileseius camposi* Gonzalez & Schuster, *Neoseiulus cucumeris* (Oudemans), *N. longispinosus* Evans, *N. californicus* (McGregor), *Typhlodromus bambusae* Ehara and *T. bagdasarjani* Wainstein & Arutunjan (Zhang *et al.*, 1998, 1999a, 1999b, 2000; Shirdel, 2003; Skirvin & Felon, 2003; Badii *et al.*, 2004; Gotoh *et al.*, 2004; Sepulveda & Carrillo, 2008; Kouhjani Gorji *et al.*, 2009). Sabelis (1986) stated that most phytoseiid predators exhibit type II functional response, which was observed in the present study on *N. barkeri* as well.

The summary of the estimated parameters of the functional response for some phytoseiid mite species are displayed in table 6. The type and magnitude of the functional response in a predator may vary under different temperatures (Mohaghegh *et al.*, 2001). The effect of temperature on functional response could be described by an extended model indicating that temperature affects both searching efficiency and handling time of the predatory mites. This study confirmed that the parameters of the functional response of *N. barkeri* were greatly affected by temperature. The effect of temperature on values of the functional response parameters of other phytoseiid mites has been previously reported by different researchers (e.g., Everson, 1979; Zhang *et al.*, 1998, 1999a, 1999b; Skirvin & Felon, 2003; Gotoh *et al.*, 2004; Kouhjani Gorji *et al.*, 2009).

Our results showed that the searching efficiency of *N. barkeri* increased with increasing temperature from 20 to 30°C and then decreased at 35°C, but the value of the handling time decreased with increasing temperature from 20 to 35°C that resulted in more predation at 30°C and 35°C. It was confirmed by the highest number of prey consumed daily by *N. barkeri* at the temperatures ranged from 30-35°C while the estimated a / T_h value in the functional response experiment suggested that the highest efficiency of *N. barkeri* against *T. urticae* was at 30-35°C. The similar result has been reported for *N. longispinosus* on *Schizotetranychus nanjingensis* Ma & Yuan (Zhang *et al*., 1999a).

Fan & Petitt (1994) reported that the value of the handling time for *N. barkeri* at 25°C was 0.2448 and 8.28 h on larval and adult stages of *T. urticae* respectively. Hassell (1978) stated that different factors including the size of a prey may affect the handling time of natural enemies, so it might be concluded that the handling time of *N. barkeri* would be increased with prey aging. However, this hypothesis may not be true in all cases (e.g., Zhang *et al.*, 1998).

The theoretical maximum predation rate (T / T_h) in functional response experiment for the mated adult female of *N. barkeri* was slightly higher than the daily prey consumption obtained from prey consumption experiment that is identical to Kouhjani Gorji *et al*. (2009) findings on *P. plumifer*. Fouly & El-Laithy (1992) observed that the total number of prey

Table 4. The mean (± SE) daily prey consumption of different life stages of *N. barkeri* on nymphal stages of *T. urticae* at seven constant temperatures.

Life stages	**Temperature (°C)**						
	15	**20**	**25**	**27**	**30**	**35**	**37**
Larva	0.22 ± 0.07 d	0.84 ± 0.13 d	1.05 ± 0.12 cd	1.37 ± 0.12 bc	1.77 ± 0.24 ab	2.20 ± 0.16 a	2.00 ± 0.22 a
Protonymph	0.55 ± 0.10 d	1.62 ± 0.23 c	2.37 ± 0.32 c	3.67 ± 0.39 b	3.77 ± 0.39 b	4.90 ± 0.53 a	4.07 ± 0.52 ab
Deutonymph	0.53 ± 0.11 d	2.02 ± 0.19 c	3.35 ± 0.35 bc	3.85 ± 0.47 ab	4.65 ± 0.60 ab	5.40 ± 0.69 a	5.25 ± 0.75 a
Immature stages	1.38 ± 0.14 d	4.50 ± 0.32 cd	6.67 ± 0.53 c	8.78 ± 0.48 bc	10.20 ± 0.94 b	12.63 ± 0.93 a	11.50 ± 1.17 ab
Pre-oviposition	1.63 ± 0.28 c	3.46 ± 0.31 c	8.53 ± 1.28 b	7.26 ± 0.96 b	7.73 ± 0.96 b	8.93 ± 1.33 b	12.40 ± 1.73 a
Oviposition	3.06 ± 0.38 d	4.36 ± 0.38d	10.80 ± 0.94 c	14.73 ± 1.71 bc	19.13 ± 1.93 a	18.46 ± 1.80 ab	17.33 ± 2.38 ab
Post-oviposition	1.80 ± 0.32 c	3.16 ± 0.30 c	6.40 ± 0.71 b	6.97 ± 1.02 b	10.73 ± 1.60 a	12.73 ± 1.62 a	7.33 ± 0.98 b
Female longevity	6.77 ± 0.54 d	11.41 ± 0.87 cd	25.31 ± 1.93 bc	28.30 ± 2.84 b	37.60 ± 3.04 ab	40.70 ± 4.01 a	39.73 ± 4.46 a

The means followed by different letters in each row are significantly different ($P < 0.05$, Duncan's multiple range test after one-way ANOVA).

Table 5. The mean (± SE) total prey consumption of different life stages of *N. barkeri* on nymphal stages of *T. urticae* at seven constant temperatures.

Life stages	**Temperature (°C)**						
	15	**20**	**25**	**27**	**30**	**35**	**37**
Larva	0.54 ± 0.13 c	1.61 ± 0.19 a	1.07 ± 0.18 b	0.96 ± 0.13 b	1.07 ± 0.12 b	1.57 ± 0.15 a	1.29 ± 0.14 ab
Protonymph	3.86 ± 0.48 b	5.14 ± 0.42 a	3.75 ± 0.40 b	4.71 ± 0.24 ab	4.00 ± 0.34 b	4.57 ± 0.35 ab	4.07 ± 0.37 b
Deutonymph	4.39 ± 0.25 c	7.86 ± 0.54 a	5.46 ± 0.62 bc	6.57 ± 0.35 b	5.29 ± 0.50 bc	6.00 ± 0.47 b	5.50 ± 05.5 bc
Immature stages	8.79 ± 0.58 d	14.61 ± 0.68 a	10.29 ± 0.66 cd	12.25 ± 0.37 b	10.36 ± 0.63 cd	12.29 ± 0.57 b	10.86 ± 0.53 bc
Pre-oviposition	13.07 ± 0.65 bc	15.79 ± 0.74 b	22.71 ± 1.33 a	15.00 ± 1.32 bc	11.79 ± 0.93 c	13.29 ± 1.46 bc	12.43 ± 1.42 bc
Oviposition	160.43 ± 9.14 e	165.57 ± 4.83 de	201.86 ± 7.46 c	253.21 ± 10.7 6b	286.71 ± 13.86 a	258.00 ± 13.70 b	191.57 ± 10.07 cd
Post-oviposition	46.00 ± 3.64 f	56.57 ± 2.61 ef	69.29 ± 4.18 cd	82.43 ± 3.39 b	94.21 ± 6.04 a	77.29 ± 6.00 bc	61.43 ± 4.10d e
Female longevity	219.50 ± 9.21 e	237.93 ± 5.48 de	293.86 ± 9.21 c	350.64 ± 11.67 b	392.71 ± 10.91 a	348.57 ± 16.28 b	265.43 ± 11.34 cd
Total stages	228. 29 ± 9.23 d	252.54 ± 5.51 d	304.14 ± 8.89 c	362.89 ± 11.81 b	403.07 ± 10.93 a	360.86 ± 16.26 ab	276.29 ± 12.47 c

The means followed by different letters in each row are significantly different ($P < 0.05$, Duncan's multiple range test after one-way ANOVA).

consumed during whole immature stages, female longevity and whole life span of the female (both immature stages and female longevity) of *N. barkeri* at 26°C was 9.43, 152.12 and 161.43 nymphal stages of *T. urticae* respectively that contradict the values obtained from this study (table 5). These differences can be attributed to longer adult longevity (26.25 versus 32.28 days) and higher number of deposited eggs (13.2 versus 36.80 eggs) (Jafari *et al.*, 2010).

Table 6. Summary of the estimated parameters of functional response of some phytoseiid mites.

Species	**Temp. (°C)**	**Prey**	**Prey stages**	***a***	**T_h**	**References**
N. barkeri	25 30	*T. urticae*	Nymp. stag.	0.0644 h^{-1} 0.0731 h^{-1}	0.8248 h 0.5979 h	The present study
N. barkeri	25	*T. urticae*	Egg Larva Adult	0.9501 day^{-1} 1.0469 day^{-1} 1.3033 day^{-1}	0.0107 day 0.0102 day 0.3742 day	Fan & Petitt (1994)
E. hibisci	25	*T. urticae*	Larva Protonymph	0.460 day^{-1} 0.351 day^{-1}	0.133 day 0.197 day	Badii *et al.* (2004)
P. plumifer	25	*T. urticae*	Nymp. stag.	0.059 h^{-1}	0.651 h	Kouhjani Gorji *et al.* (2009)
T. bambusae	22-24 28-30	*S. nanjingensis*	Adult female	0.394 day^{-1} 1.174 day^{-1}	0.202 day 0.114 day	Zhang *et al.* (1999b)
C. camposi	20	*Panonychus ulmi*	-	0.24 day^{-1}	0.16 day	Sepulveda & Carillo (2008)
N. californicus	20 25 30	*T. urticae*	Egg	1.1614 day^{-1} 1.30 00 day^{-1} 1.1816 day^{-1}	0.0350 day 0.0290 day 0.0206 day	Gotoh *et al.* (2004)
T. bagdasarjani	24	*T. urticae*	Egg Larva Adult female Adult male	0.0453 h^{-1} 0.0466 h^{-1} 0.0188 h^{-1} 0.0357 h^{-1}	0.38 h 0.30 h 2.67 h 0.60 h	Shirdel (2003)
Euseius finlandicus	24	*T. urticae*	Egg Larva Adult male	0.0375 h^{-1} 0.0456 h^{-1} 0.0418 h^{-1}	0.69 h 0.45 h 0.82 h	Shirdel (2003)
N. longispinosus	-	*Aponychus corpuzae*	Protonymph Deutonymph	0.825 day^{-1} 1.333 day^{-1}	0.444 h 0.182 h	Zhang *et al.* (1998)

Nymp. stag. = Nymphal stages.

Regardless of the simplicity of the laboratory conditions, the functional response does not alone show the true regulative power of a predator (Sepulveda & Carrillo, 2008) because this kind of foraging behavior is greatly influenced by different factors in the field such as large searching areas, host plants, and weather condition. Therefore, great caution is to be taken when the results obtained from laboratory experiments is being implemented in the complex and heterogeneous field conditions (O’Neil, 1997; Lester & Harmsen, 2002).

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