J. Crop Prot. 2020, 9 (1): 101-113

Research Article

Functional response and consumption rate of *Orius laevigatus* (Hemiptera: Anthocoridae) feeding on the melon aphid *Aphis gossypii* (Hemiptera: Aphididae) at three different temperatures

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Abstract: In this study, the effect of three temperatures was investigated on the functional response of *Orius laevigatus* to *Aphis gossypii* in climatic chambers at 20, 25, and 30 ± 1 °C, 60 ± 5% RH, and 16:8 h photoperiod. Different densities of first and second instar nymphs of *A. gossypii* (2, 4, 8, 16, 32, and 64) on cucumber leaf discs (6 cm in diameter) were separately offered to male and female predators. After 24 h, the number of consumed preys was recorded. Ten replicates per each aphid density were used. Based on the results, predator male and female exhibited types II, III, II and III, II, III functional responses at 20, 25 and 30 °C, respectively. Handling times (T_h) for males were 0.7798, 0.9177 and 0.4476 h and for females were 0.6874, 0.3921 and 0.2831 h at 20, 25 and 30 °C, respectively. Using the indicator variable method, pairwise comparisons of handling times of both males and females were significantly different. The theoretical maximum predation rate (T/T_h) of both males and females were obtained at 30 °C. The results revealed that *O. laevigatus* is more likely to be an effective biocontrol agent of *A. gossypii* at higher temperatures around 30 °C. However, additional studies under natural conditions are needed to provide further details of the predator-prey interactions.

Keywords: Predatory bug, melon aphid, cucumber, predator-prey interaction, temperature

Introduction

Cucumber plants in both open fields and greenhouses are attacked by various sucking pests (Rajabpour *et al.,* 2011). The melon aphid, *Aphis gossypii* Glover (Hemiptera: Aphididae) is the most important one, which is widely distributed in tropical, subtropical and temperate regions (Satar *et al.,* 1999). In Iran, this pest occurs in different regions especially north and south of the country (Taghizadeh Afshari *et al*. 2009). The adults and nymphs of *A. gossypii* settle on the underside of cucumber leaves or the growing tips of shoots and suck phloem sap from the host plant. Infested plants usually experience severe yield loss due to direct and indirect damages. Foliar chlorosis and leaf curling are the results of direct damage, which may hinder the efficient photosynthetic ability of plants (Blackman and Eastop, 2000). Moreover, the aphids transmit several viruses such as cucumber mosaic virus (CMV), resulting in indirect damage of the infested plants (Escriu *et al.,* 2000). Pesticides are generally used to control *A. gossypii* on the

Handling Editor: Yaghoub Fathipour

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Received: 11 May 2019, Accepted: 8 December 2019
Published online: 16 December 2019

[DOR: 20.1001.1.22519041.2020.9.1.11.8]

crop. However, aphids develop resistance to commercial insecticides (Wang *et al.,* 2002). Therefore, biological control seems a promising alternative to the use of insecticides (Karami *et al.,* 2018).

The predatory bug *Orius laevigatus* Fieber (Hemiptera: Anthocoridae) is an important biological control agent in some regions of Iran such as Fars and Khorasan (Ghahari *et al.,* 2009), the nymphs and adults of which can feed on a wide range of insect pests, such as *Bemisia tabaci* (Gennadius), *Thrips tabaci* (Lindeman), *Frankliniella occidentalis* (Pergande), *Tetranychus urticae* Koch, and *A. gossypii* (Venzon *et al.,* 2002; Perdikis *et al.,* 2008; Hosseini *et al.,* 2010). Moreover, the predator can feed on pollen as an alternative diet (Cocuzza *et al.,* 1997b). Mass introduction of *O. laevigatus* can usually provide adequate control of pests in cucumber greenhouses (Rajabpour *et al.,* 2011).

The functional response is one of the important methods for evaluating the efficiency of a predator against a prey (Wiedenmann and Smith, 1997). It refers to changes in the number of prey consumed by a predator per unit time in relation to initial prey density (Solomon, 1949), and it shows whether a predator is capable to regulate the density of its prey or not (Jervis and Kidd, 1996). Holling (1961) proposed three general types of functional response curves including type I, II, and III. Among these three types of functional response, types II and III have received the most attention (Fathipour *et al*., 2017). Functional response of natural enemies is influenced by both biotic (De Clercq *et al.,* 2000, Hassanpour *et al.,* 2011, Mottaghinia *et al.,* 2015) and abiotic factors (Li *et al.,* 2007, Jafari *et al.,* 2012).

Insects are poikilotherms, so one important feature of insects' life is their behavioral adaptation to the ubiquitous, seasonally changing environment (Tommasini and van Lenteren, 2003). Obviously, temperature has an important role in development and activities of *Orius* species and may be used for their mass production in biological control program (Carvalho *et al.,* 2005). Some studies have only investigated the effect of temperature on biological characteristics of *O. laevigatus*. For example, Alauzet *et al.* (1994) showed that the best development and reproduction rates of *O. laevigatus* occurred at the temperature of 20 to 30 °C. Similarly, Cocuzza *et al.* (1997a) reported that survival, fecundity, and prey consumption of *O. laevigatus* were high at the temperature of 25 °C. Montserrat *et al.* (2000) studied the functional response of four heteropteran predators including, *Dicyphus tamaninii* Wagner, *Macrolophus caliginosus* Wagner, *Orius majusculus* (Reuter), and *O. laevigatus* on greenhouse whitefly and western flower thrips. However, no other study has investigated the effect of temperature on the functional response of *O. laevigatus* preying upon aphid species. The objective of this study was to evaluate the predatory capacity of *O. laevigatus* through the study of its functional response at three temperatures to provide information on the potential use of the predator in integrated pest management (IPM) programs of *A. gossypii*.

Materials and Methods

Plants and insects

Seeds of cucumber (*Cucumis sativus* cv. Zohal) were sown in 20-cm-diameter plastic pots containing a mixture of field soil and cattle manure (3: 1% by volume). Plants were reared in a greenhouse at 25 ± 3 °C, 60 ± 10% RH, 16L: 8D photoperiod, and irrigated as needed.

Aphis gossypii used in this experiment was originally collected from infested cucumber greenhouses in the suburb of Ardabil, Iran. Aphids were transferred on grown plants by a fine brush. Before initiating the experiments, the aphids were reared on plants for more than three generations.

Orius laevigatus was obtained from a commercial supplier (Koppert Biological Systems, Berkel en Rodenrijs, The Netherlands). Adults and nymphs were fed on frozen eggs of *Anagasta kuehniella* Zeller (Lepidoptera: Pyralidae). They were also provided with pollen every 3 days. The pollen was collected from a maize field and dried at 50 °C for 24 hours in an oven to prevent mould growth in the rearing container. The predators were kept and reared in

[DOR: 20.1001.1.22519041.2020.9.1.11.8]

clear plastic cages (height 18 cm, and diameter 8 cm) with two holes (2 cm diameter) in the lid and container body, which was covered by fine-mesh net for ventilation. Fresh bean pods of *Phaseolus vulgaris* L. were offered daily to the predators as oviposition substrate and moisture source. In order to reduce levels of cannibalism by predators, folded paper strips were added to each cage. Bean pods with eggs were incubated for five days until egg hatching. After that, nymphs were kept and fed in above-mentioned conditions up to adult emergence. Prior to the experiment, *O. laevigatus* was reared on *A. gossypii* as food for one generation. All insect cultures were reared in a controlled environment room at 25 ± 2 °C, 50 ± 10% RH and L16: D8 h photoperiod.

Experimental design

The experimental units were Petri dishes (8 cm in diameter) with a 2-cm-diameter hole in the lid, which was covered by fine-mesh net for ventilation. In each Petri dish, one leaf disc (6 cm in diameter) was centered upside down on wet cotton. Experiments were carried out in a climatic chamber at three temperature regimes of 20, 25, and 30 ± 1 °C, 55 ± 5% RH and a 16L: 8D h photoperiod. These temperatures were chosen because an optimum development and reproduction rate of O. laevigatus, as reported by Alauzet *et al*. (1994), happens between 20 and 30 °C. The preliminary experiments indicated nearly 100% survival of prey in the absence of predator. Adults of *O. laevigatus* were used in the experiments, because they are the most voracious stage of the predator. Before starting the experiment, the adults were starved for 24 h. For obtaining the same-aged adults, first instar nymphs (< 24 h old) of the predator were reared singly in Petri dishes (6 cm diameter) until they reached the adult stage. Predation was assessed by introduction of a single adult of *O. laevigatus* to each Petri dish (6 cm diameter and with a screen-covered hole in the lid for ventilation), provided with six different densities (2, 4, 8, 16, 32, and 64) of *A. gossypii* nymphs (a mixture of first and second instar nymphs). Since the response of adult male and female predators to the same temperature may be different, so both sexes were tested. There were ten replicates per each aphid density, temperature and predator sex. To prevent insects from escaping, each Petri dish was sealed with parafilm around the edge. After 24 h, the predators were removed from experimental arenas and the number of killed aphids was recorded.

Statistical analysis

The type of functional response was determined by logistic regression analysis of the proportion of prey consumed (N_e) as a function of the initial prey density (N_0) using the categorical modeling procedure (PROC CATMOD) of the Statistical Analysis System (SAS Institute, 2001) as follows (Trexler and Travis, 1993):

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

where P_0, P_1, P_2, and P_3 are the constant, linear, quadratic and cubic coefficients, respectively. If the linear coefficient (P_1) is negative, a type II functional response is evident, while a positive linear coefficient (P_1) indicates a type III functional response (Juliano, 2001).

A random predator equation (Royama, 1971; Rogers, 1972) was fitted to the results using nonlinear least square regression procedure (PROC NLIN; SAS Institute, 2001) to estimate attack rate (a) and handling time (T_h) of the predator. For the type II and type III functional responses, the following models were used to fit the data:

$$N_e = N_0\{1 - exp[\alpha(T_h N_e - T)]\}$$

$$N_e = N_0\left[1 - exp\left(\frac{(d + bN_0)(T_h N_e - T)}{(1 + cN_0)}\right)\right]$$

where N_e is the number of prey consumed, N_0 is the initial prey density, a is the attack rate, T_h is the handling time per prey, T is the total time available for the predator (T = 24 h in this experiment), and b, c, and d are constants.

[DOR: 20.1001.1.22519041.2020.9.1.11.8]

In the case where the data revealed a type III functional response, the parameters *c* and *d* were not significantly different from 0, so a reduced type III model was used to fit the experimental data:

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

Using the indicator variable method (Juliano, 2001), pairwise comparisons of functional response parameters (in similar types) of males and females of *O. laevigatus* were performed as follows:

$$N_e = N_0\{1 - exp[-(\alpha + D_a(j))(T - T_h + D_{Tj}(j)N_e)]\}$$

where *j* is an indicator variable that takes on a value of 0 for the first data set and 1 for the second data set. The parameters D_a and D_{Th} estimate the differences between the data sets being compared for the values of the parameters *a* and T_h, respectively. In other words, the attack rate for one stage is *a*, and that for another stage is $a + D_a$. Testing for a significant difference in searching efficiencies between two stages is accomplished by testing the null hypothesis that D_a includes 0 or not (Juliano, 2001).

The data were subjected to the one-way analysis of variance (ANOVA) using SPSS ver. 16.0 (SPSS, 2007) statistical software. When differences among treatments were significant, comparison among means were conducted using Tukey's test at P < 0.05.

Results

The mean number of aphid nymphs consumed by male predator at 30 °C increased significantly with increase in the number of preys offered (from 16 to 64 preys). Similar trend was observed for female predator at 25 and 30 °C. (Tables 1 and 2). At highest prey density, the highest numbers of prey consumed by both male and female predators were obtained at 30 °C.

The linear coefficient (P_1) of the logistic regression of *O. laevigatus* females at 25 °C, and those of males at 20 and 30 °C were negative, which indicated the type II functional response (Table 3). At these temperatures, the percentage of aphids consumed by both sexes of the predator declined as aphid density increased (Fig. 1).

Table 1 Prey consumption by adult male of *Orius laevigatus* when feeding on various densities of *Aphis gossypii* at different temperatures.

Prey density	Number of prey consumed (Mean ± SE)		
	20 °C	25 °C	30 °C
2	1.6 ± 0.22Ac	1.8 ± 0.13Ad	1.9 ± 0.1Ad
4	3.5 ± 0.22Ac	3.2 ± 0.39Acd	3.5 ± 0.31Ad
8	6.6 ± 0.43Abc	7.3 ± 0.26Ac	6.5 ± 0.4Ad
16	12.2 ± 1.12Ab	14.4 ± 0.58Ab	14.3 ± 0.91Ac
32	19.3 ± 1.65Aa	22.7 ± 1.82Aa	24.3 ± 2.1Ab
64	24.5 ± 2.60Ba	25.9 ± 2Ba	36.5 ± 2.74Aa

Values followed by different lowercase letters in the same column and uppercase letters in the same row are significantly different (Tukey's test, $P < 0.05$).

Table 2 Prey consumption by adult female of *Orius laevigatus* when feeding on various densities of *Aphis gossypii* at different temperatures.

Prey density	Number of prey consumed (Mean ± SE)		
	20 °C	25 °C	30 °C
2	1.6 ± 0.22Ac	1.8 ± 0.2Ad	1.7 ± 0.21Ad
4	2.7 ± 0.52Ac	3.7 ± 0.21Ad	3.2 ± 0.25Ad
8	5.7 ± 0.84Ac	7.2 ± 0.33Acd	7.5 ± 0.22Acd
16	14.2 ± 0.68Ab	13.9 ± 0.67Ac	13.4 ± 1.18Ac
32	18.9 ± 2.54Bb	23.5 ± 2.24ABb	27.2 ± 1.39Ab
64	32.9 ± 4.06Ba	37.7 ± 3.14ABa	45.1 ± 3.16Aa

Values followed by different lowercase letters in a same column and uppercase letters in a same row are significantly different (Tukey's test, $P < 0.05$).

[DOR: 20.1001.1.22519041.2020.9.1.11.8]

Furthermore, the logistic regression analysis led to a positive value of P_1 for the females of *O. laevigatus* at 20 and 30 °C and for the males at 25 °C, which showed type III functional response (Table 3). At the mentioned temperatures, the percentage of the prey consumed by the predator at low prey densities was relatively low, then increased, and finally leveled off and decreased at a density over 16 and 32 aphids for males and females, respectively (Fig. 1).

The coefficients of attack rate and handling time were the parameters used to determine the magnitude of the functional response of *O. laevigatus* (Fathipour *et al*., 2017). At different temperatures, the predator responded differently to increasing aphid density. Handling time decreased as temperature increased for both males (except from 20 to 25 °C) and females. The shortest handling times were recorded at 30 °C for both males and females. However, the longest ones were at 20 and 25 °C for females and males, respectively (Table 4).

The results for the comparison of functional response parameters (attack rates (for the functional response type II; the males), and the parameter of *b* (for the functional response type III; the females), and handling times) showed that the values estimated for D_{Th} were significantly different from zero and the handling time of *O. laevigatus* decreased significantly when the temperature increased from 20 to 30 °C. However, the values estimated for D_a as well as D_b were not significantly different from zero. The handling times of both males and females estimated at 30 °C was considerably shorter than those at 20 °C (Table 5).

The theoretical maximum predation rate (T/T_h) of the females of *O. laevigatus* increased with increasing the temperature. For the males, the T/T_h values ranged from 26.12 to 53.62 preys day^{-1}, the highest value of which was obtained at 30 °C (Table 4).

Table 3 Maximum likelihood estimates from logistic regressions of the proportion of *Aphis gossypii* nymphs preyed by *Orius laevigatus* as a function of initial prey density at different temperatures.

Sex	Temperature (°C)	Parameters[1]	Estimate ± SE	χ^2	P-value
Male	20	P_0	1.9953 ± 0.28100	50.43	< 0.0001
		P_1	-0.0591 ± 0.01690	12.24	0.0005
		P_2	0.00032 ± 0.00021	2.41	0.1209
	25	P_0	1.2764 ± 0.53720	5.65	0.0175
		P_1	0.1723 ± 0.08550	4.06	0.0438
		P_2	-0.0085 ± 0.00324	6.84	0.0089
		P_3	0.00008 ± 0.00003	7.12	0.0076
	30	P_0	2.4772 ± 0.34480	51.61	< 0.0001
		P_1	-0.0476 ± 0.02030	5.50	0.0191
		P_2	0.00024 ± 0.00020	1.00	0.3185
Female	20	P_0	-0.2031 ± 0.42020	0.23	0.6289
		P_1	0.3124 ± 0.07070	19.51	< 0.0001
		P_2	-0.0136 ± 0.00270	24.68	< 0.0001
		P_3	0.00014 ± 0.00003	25.64	< 0.0001
	25	P_0	3.0231 ± 0.37990	63.31	< 0.0001
		P_1	-0.0838 ± 0.02160	15.10	< 0.0001
		P_2	0.00066 ± 0.00025	6.71	0.0096
	30	P_0	1.7818 ± 0.31150	32.71	< 0.0001
		P_1	0.0117 ± 0.02000	0.34	0.5579
		P_2	-0.00041 ± 0.00025	2.65	0.1034

[1] P_0, P_1, P_2, and P_3 are the constant, linear, quadratic and cubic coefficients, respectively.

[DOR: 20.1001.1.22519041.2020.9.1.11.8]

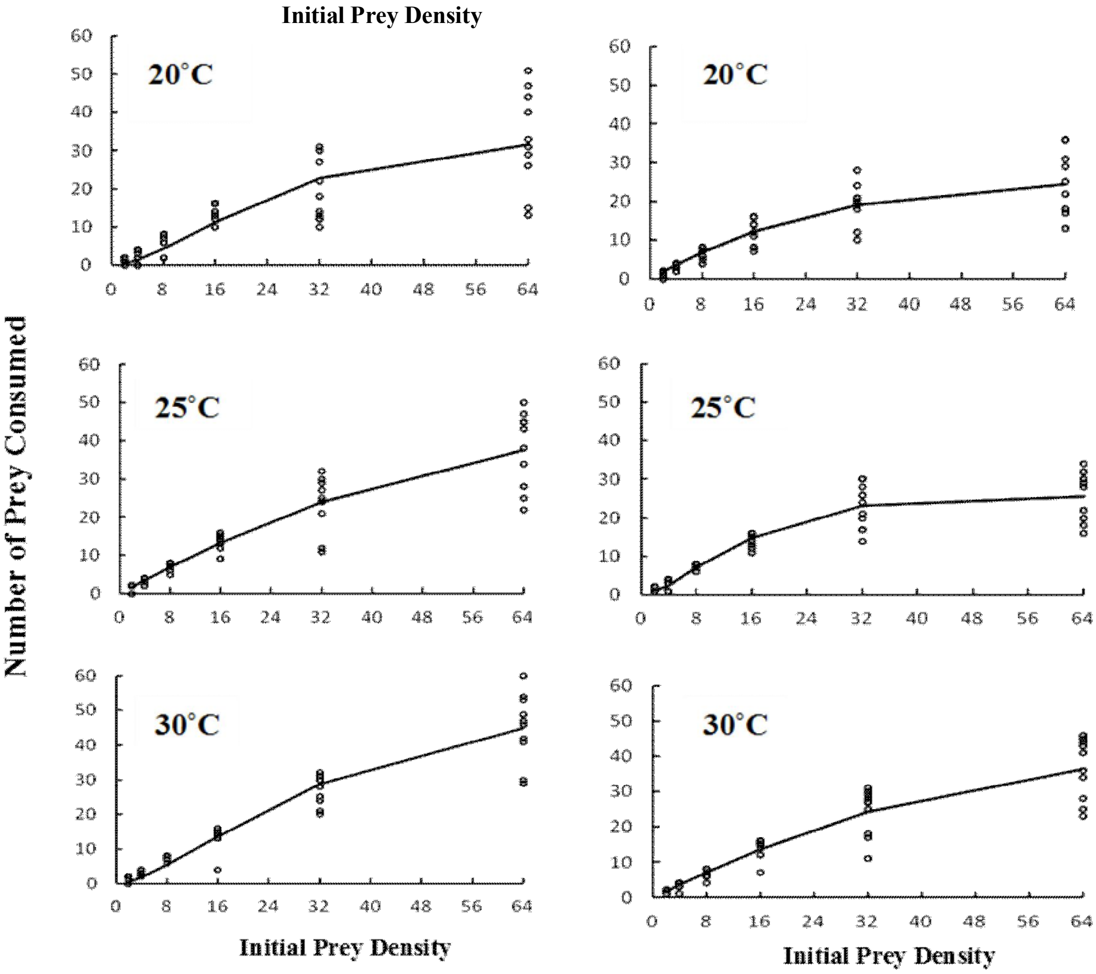

Figure 1 Functional response of females (left) and males (right) of *Orius laevigatus* on different densities of *Aphis gossypii* nymphs at three temperatures. The data points and solid lines represent the number of *Aphis gossypii* killed and the predictions of the models, respectively.

Table 4 Parameters of functional response of *Orius laevigatus* feeding on *Aphis gossypii* at different temperatures.

Sex	Temp. (°C)	Functional Response Type	a ± SE (95% CI)[1]	T_h (± SE) (95% CI)[2]	T/T_h	R^2
Male	20	II	0.1002 ± 0.0264 (0.0473 - 0.1531)	0.7798 ± 0.0869 (0.6058 - 0.9538)		
	25	III	0.0148 ± 0.0045 (0.0060 - 0.0237)	0.9177 ± 0.0384 (0.8420 - 0.9956)	26.12	0.88
	30	II	0.1101 ± 0.0265 (0.0571 - 0.1632)	0.4476 ± 0.0655 (0.3165 - 0.5788)	53.62	0.89
Female	20	III	0.0047 ± 0.0014 (0.0018 - 0.0075)	0.6874 ± 0.0610 (0.5653 - 0.8094)	34.91	0.66
	25	II	0.0955 ± 0.0234 (0.0486 - 0.1424)	0.3921 ± 0.0755 (0.2409 - 0.5430)	61.21	0.87
	30	III	0.1092 ± 0.0266 (0.0560 - 0.1624)	0.2831 ± 0.0696 (0.1437 - 0.4225)	84.78	0.92

[1] CI: Confidence intervals, α: attack rate. [2] T_h: handling time of the predator.

[DOR: 20.1001.1.22519041.2020.9.1.11.8]

Table 5 The parameters estimated using combined equation for comparison of functional response parameters of *Orius laevigatus* males and females feeding on *Aphis gossypii* at two temperatures of 20 and 30 °C.

Sex	Temperature (°C)	Parameter	Estimate	Standard Error	Approximate 95% Confidence Limits	
					Lower	Upper
Male	20 - 30	D_a	0.0086	0.0379	- 0.0665	0.0837
		D_{Th}	-0.3352	0.1101	-0.5532	-0.1172
Female	20 - 30	D_b	0.0418	0.0364	- 0.0303	0.1140
		D_{Th}	-0.1309	0.1352	-0.3987	-0.1369

Discussion

The results revealed that the mean number of *A. gossypii* nymphs killed by *O. laevigatus* males and females increased with an increase in prey density and temperature. The mean number of preys eaten by both males and females was 1.6 ± 0.22 at the density of 2 preys at 20 °C and reached a maximum of 36.5 ± 2.74 (for male) and 45.1 ± 3.16 (for female) from total number of 64 preys at 30 °C. Higher consumption rate of females may be associated with additional food requirements for egg production (Pakyari and Enkegaard, 2012).

In the present study, the type of functional response of *O. laevigatus* at different temperatures varied between type II and III for both adult males and females. Data provided a good fit to type II functional response model at 25 °C for the females of *O. laevigatus* and at 20 and 30 °C for the males. In this type of response, the predation rate decreases monotonically with increasing prey density. Furthermore, data from 20 and 30 °C for the females and 25 °C for the males of *O. laevigatus* fit a type III response in which predation rate increases at low prey densities, and then decreases at higher prey densities with a sigmoid curve that potentially regulates the prey population. Several factors including predator learning, prey switching as well as the availability of prey to refuge have been suggested to generate type III functional response (Holling, 1965; Messina and Hanks, 1998).

The type of functional response of a natural enemy may vary from one type to another as environmental conditions, especially temperature change (Thompson, 1978). According to McCaffrey and Horsburgh (1986) *O. insidiosus* showed either type II or III responses to densities of the European red mite, *Panonychus ulmi* Koch at different temperatures. Similarly, Hassanpour *et al.* (2015) reported that the functional responses of both male and female of *O. laevigatus* towards *T. urticae* were type II at 20 and 25 °C and type III at 30 °C.

Both type II and III functional responses have been reported for other *Orius* species. For example, the type of functional response of *O. albidipennis* Reuter to *Megalurothrips sjostedti* Trybom (Gitonga *et al.,* 2002), *O. insidiosus* (Say) to *Aphis glycines* Matsumura (Rutledge and O'Neil, 2005), *O. albidipennis* to *T. tabaci* and *Aphis pomi* De Geer (Lotfi *et al.,* 2013), *O. insidiosus* to *A. gossypii* (Veiga *et al.,* 2014), *O. tristicolor* (White) to *Tuta absoluta* (Meyrick) (Queiroz *et al.,* 2015) was type II and the type of functional response of *O. albidipennis* (Reuter) to *T. urticae*, *A. gossypii* (Noruzi *et al.,* 2014), and *T. absoluta* (Salehi *et al.,* 2016) was type III.

In this study, the type of the functional response of *O. laevigatus* varied under different temperatures. The effect of temperature on both attack rate and handling time of predators has been previously reported by different researchers (e.g., Mohaghegh *et al.,* 2001; Jafari *et al.,* 2012; Ziaei Madbouni *et al.,* 2017).

Based on the results, the parameter of *b* estimated for predator female (type III functional response) increased with increasing temperature from 20 to 30 °C, but the values of the handling time decreased with increasing temperature. The same trend was observed for the handling time of *O. laevigatus* males with increasing temperature. Similarly, Ahn *et al.* (2010) reported that the handling time of the predatory mite, *Neoseiulus californicus* (McGregor) when attacking *T. urticae* decreased significantly with increasing temperature. This reveals that both males and females of *O. laevigatus* were more active at high temperatures and spent more time searching and feeding, whereas at low temperatures non-searching activities such as resting increased. The handling time is a good indicator of the consumption rate and predator efficacy, since it determines the cumulative effect of different components such as time taken during capturing, killing, subduing and digesting the prey by the predator (Veeravel and Baskaran, 1997). Therefore, significant variation in the handling time estimated for a predator on prey at different temperatures reveals that any one of the above-mentioned components of the handling time might have been affected by temperature. Also, in the present study, the highest handling time estimated for females at 20 °C might be as a result of an increase in non-searching activities such as resting.

The highest maximum predation rate (T/T_h) of males and females happened at 30 °C. These results show that both males and females of *O. laevigatus* are expected to be more efficient at 30 °C than at the two lower temperatures used in this study. However, females with their density-dependent predation can have the highest efficiency against *A. gossypii* at 30 °C. Hassanpour *et al.* (2015) reported that the maximum predation rates of both males and females of *O. laevigatus* to *T. urticae* occurred at 25 °C. These results confirm the influence of temperature and prey type in predation rate of predators.

In the present study, the temperature had a significant impact on functional response and predation of *O. laevigatus* to *A. gossypii*. It has been reported that *O. laevigatus* is well adapted to low temperatures (Cocuzza *et al.,* 1997a), but the results of this study suggested that the optimum temperature for adults of *O. laevigatus* according to the highest value of predation rate and the lowest value of handling time was around 30 °C. Therefore, at high temperatures especially in greenhouses, *O. laevigatus* could forage and consume aphids at higher rates, which could be considered a good point for this predator, because previous studies showed that the optimum aphid development temperature is 25 to 30 °C (Kersting *et al.,* 1999; Nimbalkar *et al.,* 2010). In this study, only the females presented type III response at this temperature and seem more suitable for suppressing *A. gossypii* populations, but males with their type II response could be efficient in pest control, because many predators previously used as successful biological control agents showed the type II functional responses (De Clercq *et al.,* 2000; van Lenteren *et al.,* 2016). It is important to note that beside climatic conditions, some other factors such as habitat heterogeneity (Lipcius and Hines, 1986), competition (Pervez and Omkar, 2005), density and distribution of the prey (Yasuda and Ishikawa, 2001), and physical and biochemical characteristics of host plants (Rutledge and O'Neil, 2005) can affect the ability of predator to suppress prey population growth. Although the present study provided preliminary information on the efficacy of *O. laevigatus* on *A. gossypii*, the functional response is not the only criterion determining the failure or success of a biological control agent and additional data must be collected in the natural conditions. In addition, functional response experiments in small-scale setups (such as Petri dish) may have little resemblance of those measured in natural conditions. Therefore, supplementary studies under complex field conditions are needed to provide further details of the predator-prey interactions (O'Neil 1989).

Acknowledgements

We would like to thank the University of Mohaghegh Ardabili, Ardabil, Iran for financial support of this study.

Statement of Conflicting Interests

The authors state that there is no conflict of interest.

Funding

This work was financially supported by the University of Mohaghegh Ardabili (Grant number 1129).

Authors' Contributions

All authors have contributed significantly, and that all authors are in agreement with the content of the manuscript.

References

Ahn, J. J., Kim, K. W. and Lee, J. H. 2010. Functional response of *Neoseiulus californicus* (Acari: Phytoseiidae) to *Tetranychus urticae* (Acari: Tetranychidae) on strawberry leaves. Journal of Applied Entomology, 134: 98-104.

Alauzet, C., Dargagnon, D. and Malausa, J. C. 1994. Bionomics of a polyphagous predator: *Orius laevigatus* (Het.: Anthocoridae). Entomophaga, 39: 33-40.

Blackman, R. L. and Eastop, V. F. 2000. Aphids on the World's Crops: An Identification and Information Guide. Wiley, London.

Carvalho, L. M., Bueno, V. H. P. and Mendes, S. M. 2005. Development, nymphal consumption and thermal requirements of *Orius thyestes* Herring (Hemiptera: Anthocoridae). Neotropical Entomology, 34: 607-612.

Cocuzza, G. E., De Clercq, P., Lizzio, S., van de Veire, M., Tirry, L. Degheele, D. and Vacante, V. 1997a. Life tables and predation activity of *Orius laevigatus* and *O. albidipennis* at three constant temperatures. Entomologia Experimentalis et Applicata, 85: 189-198.

Cocuzza, G. E., De Clercq, P., van de Veire, M., de Cock, A., Degheele, D. and Vacante, V. 1997b. Reproduction of *Orius laevigatus* and *Orius albidipennis* on pollen and *Ephestia kuehniella* eggs. Entomologia Experimentalis et Applicata, 82: 101-104.

De Clercq, P., Mohaghegh, J. and Tirry, L. 2000. Effect of host plant on the functional response of the predator *Podisus nigrispinus* (Heteroptera: Pentatomidae). Biological Control, 18: 65-70.

Escriu, F., Perry, K. L. and García-Arenal, F. 2000. Transmissibility of cucumber mosaic virus by *Aphis gossypii* correlates with viral accumulation and is affected by the presence of its satellite RNA. Phytopathology, 90: 1068-1072.

Fathipour, Y., Karimi, M., Farazmand, A. and Talebi, A. A. 2017. Age-specific functional response and predation rate of *Amblyseius swirskii* (Phytoseiidae) on two-spotted spider mite. Systematic & Applied Acarology, 22: 159-169.

Ghahari, H., Carpintero, D. and Ostovan, H. 2009. An annotated catalogue of the Iranian Anthocoridae (Hemiptera: Heteroptera: Cimicomorpha). Acta Entomologica Musei Nationalis Pragae, 49: 43-58.

Gitonga, L. M., Overholt, W. A., Löhr, B., Magambo, J. K. and Mueke, J. M. 2002. Functional response of *Orius albidipennis* (Hemiptera: Anthocoridae) to *Megalurothrips sjostedti* (Thysanoptera: Thripidae). Biological Control, 24: 1-6.

Hassanpour, M., Mohaghegh, J., Iranipour, Sh., Nouri-Ganbalani, G., and Enkegaard, A. 2011. Functional response of *Chrysoperla carnea* (Neuroptera: Chrysopidae) to *Helicoverpa armigera* (Lepidoptera: Noctuidae): Effect of prey and predator stages. Insect Science, 18: 217-224.

Hassanpour, M., Yaghmaee, A., Golizadeh, A., Rafiee-Dastjerdi, H. and Mottaghinia, L. 2015. Temperature-dependent functional response of the predatory bug *Orius laevigatus* (Fieber) preying upon the two-spotted spider mite, *Tetranychus urticae* (Koch). Journal of Applied Researches in Plant Protection, 5: 17-34 (in Persian with English abstract).

Holling, C. S. 1961. Principles of insect predation. Annual Review of Entomology, 6: 163-182.

Holling, C. S. 1965. The functional response of the predators to prey density and its role in mimicry and population regulation. Memoirs of the Entomological Society of Canada, 45: 1-60.

Hosseini, M., Ashouri, A., Enkegaard, A., Weisser, W. W., Goldansaz, S. H., Nassiri Mahalati, M. and Sarraf Moayeri, H. R. 2010. Plant quality effects on intraguild predation between *Orius laevigatus* and *Aphidoletes aphidimyza*. Entomologia Experimentalis et Applicata, 135: 208-216.

Jafari, S., Fathipour, Y. and Faraji, F. 2012. The influence of temperature on the functional response and prey consumption of *Neoseiulus barkeri* (Acari: Phytoseiidae) on *Tetranychus urticae* (Acari: Tetranychidae). Journal of Entomological Society of Iran, 31: 39-52.

Jervis, M. A. and Kidd, N. A. C. 1996. Phytophagy. In: Jervis, M. A. and Kidd, N. A. C. (Eds.), Insect Natural Enemies-Practical Approaches to Their Study and Evaluation. Chapman & Hall, U. K. pp. 375-394.

Juliano, S. A. 2001. Non-linear curve fitting: predation and functional response curves. In: Scheiner, S. M. and Gurevitch, J. (Eds), Design and Analysis of Ecological Experiments. Chapman and Hall. pp. 178-196.

Karami, A., Fathipour, Y., Talebi, A. A. and Reddy, G. V. P. 2018. Parasitism capacity and searching effciency of *Diaeretiella rapae* parasitizing *Brevicoryne brassicae* on susceptible and resistant canola cultivars. Journal of Asia-Pacific Entomology, 21: 1095-1101.

Kersting, U., Satar, S. and Uygun, N. 1999. Effect of temperature on development rate and fecundity of apterous *Aphis gossypii* Glover (Homoptera: Aphididae) reared on *Gossypium hirsutum* L. Journal of Applied Entomology, 123: 23-27.

Li, D. X., Tian, J. and Shen, Z. R. 2007. Functional response of the predator *Scolothrips takahashii* to hawthorn spider mite, *Tetranychus viennensis*: effect of age and temperature. BioControl, 52: 41-61.

Lipcius, R. N. and Hines, A. H. 1986. Variable functional responses of a marine predator in dissimilar homogeneous microhabitats. Ecology, 67: 1361-1371.

Lotfi, F., Haghani, M. and Ostovan, H. 2013. Functional Response of *Orius albidipennis* (Hemiptera: Anthocoridae) to *Thrips tabaci* and *Aphis pomi*. Journal of Entomological Research, 6: 343-351 (in Persian with English abstract).

McCaffrey, J. P. and Horsburgh, R. L. 1986. Functional response of *Orius insidiosus* (Hemiptera: Anthocoridae) to the European red mite, *Panonychus ulmi* (Acari: Tetranychidae), at different constant temperatures. Environmental Entomology, 15: 532-535.

Messina, F. J. and Hanks, J. B. 1998. Host plant alters the shape of the functional response of an aphid predator (Coleoptera: Coccinellidae). Environmental Entomology, 27: 1196-1202.

Mohaghegh, J., De Clercq, P. and Tirry, L. 2001. Functional response of the predators *Podisus maculiventris* (Say) and *Podisus nigrispinus* (Dallas) (Het., Pentatomidae) to the beet armyworm, *Spodoptera exigua* (Hübner) (Lep.,Noctuidae): Effect of temperature. Journal of Applied Entomology, 125: 131-134.

Montserrat, M., Albajes, http://www.bioone.org/doi/abs/10.1603/0046-225X-29.5.1075-aff1 R. and Castañé, C. 2000. Functional response of four heteropteran predators preying on greenhouse whitefly (Homoptera: Aleyrodidae) and western flower thrips (Thysanoptera: Thripidae). Environmental Entomology, 29: 1075-1082.

Mottaghinia, L., Hassanpour, M., Razmjou, J., Hosseini, M. and Chamani, E. 2015. Functional response of *Aphidoletes aphidimyza* Rondani (Diptera: Cecidomyiidae) to *Aphis gossypii* Glover (Hemiptera: Aphididae): Effects of vermicompost and host plant cultivar. Neotropical Entomology, 45: 88-95.

Nimbalkar, R. K., Shinde, S. S., Wadikar, M. S., Tawar, D. S. and Muley, S. P. 2010. Effect of constant temperature on development and reproduction of the cotton aphid (*Aphis gossypii*) (Glover) (Hemiptera: Aphididae) on *Gossypium hirsutum* in laboratory conditions. Journal of Ecobiotechnology, 2: 29-34.

Noruzi, F., Madadi, H. and Talaei-Hassanloui, R. 2014. Functional response of predatory bug, *Orius albidipennis* (Reuter) to melon aphid, *Aphis gossypii* (Glover) and two spotted spider mite, *Tetranychus urticae* Koch. Journal of Applied Research in Plant Protection, 3: 69-77 (in Persian with English abstract).

O'Neil, R. J. 1989. Comparison of laboratory and field measurements of the functional response of *Podisus maculiventris* (Heteroptera: Pentatomidae). Journal of the Kansas Entomological Society, 62: 148-155.

Pakyari, H. and Enkegaard, A. 2012. Effect of different temperatures on consumption of two spotted mite, *Tetranychus urticae,* eggs by the predatory thrips, *Scolothrips longicorni*s. Journal of Insect Science, 12: 98.

Perdikis, D., Kapaxidi, E. and Papadoulis, G. 2008. Biological control of insect and mite pests in greenhouse Solanaceous crops. The European Journal of Plant Science and Biotechnology, 2: 125-144.

Pervez, A. and Omkar. 2005. Functional responses of coccinellid predators: an illustration of a logistic approach. Journal of Insect Science, 5 (5): 1-6.

Queiroz, O. S., Ramos, R. S., Gontijo, L. M. and Picanço, M. C. 2015. Functional response of three species of predatory pirate bugs attacking eggs of *Tuta absoluta* (Lepidoptera: Gelechiidae). Environmental Entomology, 44: 246-251.

Rajabpour, A., Seraj, A. A., Allahyari, H. and Shishehbor, P. 2011. Evaluation of *Orius laevigatus* Fiber (Heteroptera: Anthocoridae) for biological control of *Thrips tabaci* Lindeman (Thysanoptera: Thripidae) on greenhouse cucumber in south of Iran. Asian Journal of Biological Sciences, 4: 457-467.

Rogers, D. J. 1972. Random search and insect population models. Journal of Animal Ecology, 41: 369-383

Royama, T. 1971. A comparative study of models for predation and parasitism. Researches on Population Ecology, 1: 1-91.

Rutledge, C. E. and O'Neil, R. J. 2005. *Orius insidiosus* (Say) as a predator of the soybean aphid, *Aphis glycines* Matsumura. Biological Control, 33: 56-64.

Salehi, Z., Yarahmadi, F., Rasekh, A. and Sohani, N. Z. 2016. Functional responses of *Orius albidipennis* Reuter (Hemiptera, Anthocoridae) to *Tuta absoluta* Meyrick (Lepidoptera, Gelechiidae) on two tomato cultivars with different leaf morphological characteristics. Entomologia Generalis, 36: 127-136.

SAS Institute, 2001. SAS/STAT user's guide. Cary, NC: SAS Institute.

Satar, S., Kersting, U. and Uygun, N. 1999. Development and fecundity of *Aphis gossypii* Glover (Hemiptera: Aphididae) on three Malvaceae hosts. Turkish Journal of Agriculture and Forestry, 23: 637-643.

Singh, M. C., Singh, J. P. Pandey, S. K. Mahay, D. and Shrivastva, V. 2017. Factors affecting the performance of greenhouse cucumber cultivation-a review. International Journal of Current Microbiology and Applied Sciences, 6: 2304-2323.

Solomon, M. E. 1949. The natural control of animal populations. Journal of Animal Ecology, 18: 1-35.

SPSS. 2007. SPSS base 16.0 user's guide. SPSS Incorporation, Chicago.

Taghizadeh Afshari, A., Soleiman-Negadian, E. and Shishebor, P. 2009. Population density and spatial distribution of *Aphis gossypii* Glover (Homoptera: Aphididae) on cotton in Gorgan, Iran. Journal of Agricultural Science and Technology, 11: 27-38.

Thompson, D. J. 1978. Towards a realistic predator-prey model: the e□ects of temperature on the functional response and life history of larvae of the damselfly, *Ischnura elegans*. Journal of Animal Ecology, 47: 757-767.

Timms, J. E., Oliver, T. H., Straw, N. A. and Leather, S. R. 2008. The effects of host plant on the coccinellid functional response: Is the conifer specialist *Aphidecta obliterata* (L.) (Coleoptera: occinellidae) better adapted to spruce than the generalist *Adalia bipunctata* (L.) (Coleoptera: Coccinellidae)? Biological Control, 47: 273-281.

Tommasini, M. G. and van Lenteren, J. C. 2003. Occurrence of diapause in *Orius laevigatus*. Bulletin of Insectology, 56: 225-51.

Trexler, J. C. and Travis, J. 1993. Nontraditional regression analysis. Ecology, 74: 1629-1637.

[DOR: 20.1001.1.22519041.2020.9.1.11.8]

van Lenteren, J. C., Hemerik, L., Lins, Jr. J. C. and Bueno, V. H. P. 2016. Functional responses of three neotropical mirid predators to eggs of *Tuta absoluta* on tomato. Insects, 7: 34.

Veeravel, R. and Baskaran, P. 1997. Functional and numerical responses of *Coccinella transversalis* and *Cheilomenes sexmaculata* Fabr. feeding on the melon aphid, *Aphis gossypii* Glov. Insect Science and its Application, 17: 335-339.

Veiga, A. C. P., de Laurentis, V. L., Vacari, A. M., Volpe, H. X. L., Ramalho, D. G. and De Bortoli, A. A. 2014. Behavior of *Orius insidiosus* preying on Aphis gossypii reared on transgenic and conventional cotton varieties. Acta Scientiarum, 36: 273-279.

Venzon, M., Janssen, A. and Sabelis, M. W. 2002. Prey preference and reproductive success of the generalist predator *Orius laevigatus*. Oikos, 97: 116-124.

Wang,http://www.bioone.org/doi/abs/10.1603/0022-0493-95.2.407-aff1 K-Y., Liu, T-X., Yu, C-H., Jiang, X-Y. and Yi, M-Q. 2002. Resistance of *Aphis gossypii* (Homoptera: Aphididae) to fenvalerate and imidacloprid and activities of detoxification enzymes on cotton and cucumber. Journal of Economic Entomology, 95: 407-413.

Wiedenmann, R. N. and Smith, J. W. 1997. Attributes of natural enemies in ephemeral crop habitats. Biological Control, 10: 16-22.

Yasuda, H. and Ishikawa, H. 2001. Effects of prey density and spatial distribution on prey consumption of the adult predatory ladybird beetle. Journal of Applied Entomology, 123: 585-589.

Ziaei Madbouni, M. A., Samih, M. A., Namvar, P. and Biondi, A. 2017. Temperature-dependent functional response of *Nesidiocoris tenuis* (Hemiptera: Miridae) to different densities of pupae of cotton whitefly, *Bemisia tabaci* (Hemiptera: Aleyrodidae). European Journal of Entomology, 114: 325-331.

[DOR: 20.1001.1.22519041.2020.9.1.11.8]

واکنش تابعی و نرخ مصرف سن *Orius laevigatus* (Hemiptera: Anthocoridae) در تغذیه از شته جالیز *Aphis gossypii* (Hemiptera: Aphididae) در سه دمای مختلف

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دریافت: ۲۱ اردیبهشت ۱۳۹۸؛ پذیرش: ۱۷ آذر ۱۳۹۸

چکیده: در این تحقیق، اثر دماهای مختلف روی واکنش تابعی سن شکارگر *Orius laevigatus* نسبت به شته جالیز، *Aphis gossypii* در اتاقک رشد در دماهای ۲۰، ۲۵ و ۱ ± ۳۰ درجه سلسیوس، رطوبت نسبی ۵ ± ۶۰ درصد و دوره نوری ۱۶ ساعت روشنایی و ۸ ساعت تاریکی مورد بررسی قرار گرفت. تراکم‌های مختلفی از پوره‌های سنین اول و دوم شته (۲، ۴، ۸، ۱۶، ۳۲ و ۶۴) روی دیسک برگی خیار (به قطر ۶ سانتی‌متر) به‌صورت جداگانه در اختیار افراد نر و ماده کامل شکارگر قرار داده شد. پس از ۲۴ ساعت، تعداد طعمه‌های خورده شده شمارش و ثبت شد. آزمایش برای هر تراکم شته در ۱۰ تکرار انجام شد. واکنش تابعی افراد نر نسبت به این شته در دماهای فوق به‌ترتیب از نوع ۲، ۳ و ۲ و برای افراد ماده از نوع ۳، ۲ و ۳ تعیین شد. زمان دستیابی افراد نر در دماهای فوق به‌ترتیب ۰/۷۷۹۸، ۰/۹۱۷۷ و ۰/۴۴۷۶ و افراد ماده به‌ترتیب ۰/۶۸۷۴، ۰/۳۹۲۱ و ۰/۲۸۳۱ ساعت تخمین زده شد. مقایسه دو به دو با استفاده از معادله ترکیبی نشان داد که در هر دو جنس نر و ماده اختلاف در پارامتر زمان دستیابی معنی‌دار است. بیش‌ترین نرخ شکارگری نظری (T/T_h) هر دو جنس نر و ماده در دمای ۳۰ درجه سلسیوس به‌دست آمد. نتایج نشان داد که سن شکارگر *O. laevigatus* در دماهای بالاتر در حدود ۳۰ درجه سلسیوس، می‌تواند به‌عنوان عامل بیوکنترل مناسب برای شته جالیز عمل نماید. با این حال، به‌دست آوردن جزئیات بیش‌تری از برهم‌کنش‌های این شکارگر-شکار نیازمند انجام مطالعات بیش‌تری در شرایط طبیعی می‌باشد.

واژگان کلیدی: سن شکارگر، شته جالیز، خیار، برهم‌کنش شکارگر- شکار، دما

[DOR: 20.1001.1.22519041.2020.9.1.11.8]