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Original Research Article

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Functional response of the predatory mite *Cydnoseius negevi* (Swirski & Amitai) (Acari: Phytoseiidae) to the *Oligonychus afrasiaticus* (Mcgregor) and *Tetranychus urticae* Koch (Acari: Tetranychidae)

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Abstract

The study of functional response characteristics of natural enemies is one of the most important approaches to assess their efficiency in regulating the pest population as they are key aspects in the dynamics of predator-prey interactions. In the present study, the functional response type and parameters, and maximum feeding capacity of the predatory mite *Cydnoseius negevi* (Swirski & Amitai) (Acari: Phytoseiidae) deutonymph and adult female were assessed at different densities of movable stages of the date palm mite (DPM) *Oligonychus afrasiaticus* (McGregor) and two-spotted spider mite (TSSM) *Tetranychus urticae* Koch (Acari: Tetranychidae). The experiments were carried out at 30 ± 2°C and relatively low humidity of 35 ± 5 % RH under controlled conditions, for the first time. The logistic regression model was used to determine the type of functional response exhibited by *C. negevi*. Both the stages of predator showed Type II functional response when fed the DPM and TSSM individuals at different stages. Roger's random-predator equation was used to define the handling time (*Th*) and attack rate (*a*) coefficients of type II functional response by fitting the equation into the non-linear least square regression model. The longest *Th* was shown by deutonymph and adult females of *C. negevi* when they fed on the DPM and TSSM females, and TSSM females, respectively. Furthermore, no significant differences were recorded for most of the *a* values of the deutonymph and adult female of *C. negevi* among different stages of DPM and TSSM. The maximum feeding capacity of *C. negevi* adult female was significantly higher for DPM female when compared with that of TSSM. According to previous and current studies, *C. negevi* could be a potential predator at a wide range of humidity.

Keywords: Biological control, Prey, Density, Feeding capacity, Handling time, Attack rate

Introduction

The date palm mite (DPM) *Oligonychus afrasiaticus* (McGregor) and two-spotted spider mite (TSSM) *Tetranychus urticae* Koch (Acari: Tetranychidae) are severe pests of the date palm, *Phoenix dactylifera* and various agricultural crops in Saudi Arabia (SA), respectively (Alatawi, 2011; Alatawi and Kamran, 2018). They severely affect both the quality and quantity of crop production by impairing their commercial value in national and international markets (Khoualdia et al., 1997; Palevsky et al., 2005). The arid and hot climate of SA, which supports the outbreak of spider mites, is one of the main factors that hinders the application of bio-control programs using phytoseiid predators against DPM and TSSM pests. Furthermore, most of these predators have been used successfully against spider mites only at relatively humid climatic condition in the world (Hoy, 2011). Therefore, searching for local phytoseiid species adapted to arid and hot climate, which is prevalent in most of SA, are highly necessary (Negm et al., 2012).

The predatory mite *Cydnoseius negevi* (Swirski & Amitai) (Acari: Phytoseiidae) is distributed over a wide range of hot and arid areas in SA and other Middle East countries. Its abundance and association with the DPM are indications of an adaptation that could positively enhance the efficiency of predators against mite pests (Alatawi et al., 2017).

The biological aspects, life table parameters, and predation rate of *C. negevi* have been studied against several pests and different diet sources, such as plant pollen (El-Banhawy et al., 1999; Negm et al., 2014; Alatawi et al., 2018). In particular, *C. negevi* successfully reproduced and developed on date palm pollen (Alatawi et al., 2018), and on the DPM under low relative humidity (35% RH). Furthermore, its performance was better than that of *Neoseiulus barkeri* Hughes (Acari: Phytoseiidae) (Negm et al., 2014).

Studying the functional response characteristics is one of the most important approaches to assess the efficiency of biocontrol agents in regulating the pest population as they are key aspects of predator-prey interactions (Murdoch and Oaten, 1975; Berryman, 1992). Furthermore, it enhances the practical predictive potential of a predator used as a candidate for biocontrol programs (Sepúlveda and Carrillo, 2008).

Usually, the moderate to high relative humidity is necessary for phytoseiid mites to establish their population (Helle and Sabelis, 1985). Thus, most of their functional response studies have been conducted at relatively high humidity ranging from 60% to 80% RH. However, studies on the fluctuations in predator and prey populations under natural conditions are necessary (Vangansbeke et al., 2013; Audenaert et al., 2014).

The functional response of *C. negevi* has been reported only against the TSSM nymphs at relatively high humidity 70 ± 5% RH (Rasmy et al., 2014). Despite a strong association with the DPM in the date palm orchards, to the best of our knowledge, the functional response of the predatory mite *C. negevi* against DPM has not been reported.

The present study aimed to define the functional response type and parameters, and feeding capacity of the predatory mite *C. negevi* against moveable life stages of DPM and TSSM at low humidity.

Material and Methods

Predator and prey sources

The species of mite used in the present study—*C. negevi*, TSSM, and DPM—were acquired from the date palm orchards at Riyadh, SA. Initial populations were collected from Bermuda grass *Cynodon dactylon* (Poaceae), black nightshade *Solanum nigrum* L. (Solanaceae) (both growing under the date palm trees), and highly infested date fruits, respectively.

Maintenance of colonies

The colony of *C. negevi* was maintained in the laboratory and were fed the pollen of date palm and different stages of the two prey species TSSM and DPM at 27 ± 2°C in small arenas as described by Marafeli et al. (2011). The TSSM colony was maintained on eggplants *Solanum melongena* L. (Solanaceae) in a green house. The DPM individuals were collected from infested date palm fruits in field.

Assessment of functional response, predation rate, and maximum feeding capacity of *C. negevi*

The experiments were performed in a climate-controlled chamber (BINDER$^{®}$, Germany) at 30 ± 2°C, 35 ± 5 % RH, and 14:10 h light/dark period. Functional response and maximum feeding capacity were assessed using newly emerged *C. negevi* deutonymphs and adult females feeding on the larvae, nymphs, and females of the pest mites DPM and TSSM in small rearing units. The experimental unit consisted of a black acrylic lid of 2 cm diameter positioned on a Petri dish of 15 cm diameter. The different stages of DPM and TSSM were released on the abaxial surface of date palm and common bean leaf discs, placed on the black acrylic lids, respectively. In addition, the leaf discs were surrounded with damp cotton wool. Furthermore, the Petri dishes were constantly filled with distilled water to stop mites from leaving the arena and to keep the leaf disc fresh following Marafeli et al. (2011).

Until the maximum feeding capacity of each stage of the predator *C. negevi* (deutonymphs and adult females) was reached, different densities of each prey stage (larvae, nymphs, and adult females) of DPM (5, 10, 25, 35, 45, 60, and 70) and TSSM (5, 10, 25, 35, 45, and 60) were offered separately. That is, each prey stage of DPM and TSSM was offered individually to each stage of the predator. The control treatment (without predator) for each prey stage and density of DPM and TSSM was maintained to determine natural mortality. To standardize the functional response of *C. negevi* adult female and deutonymph, both the stages were starved individually for 8 h in separate rearing arenas, and then transferred to different experimental units containing different densities and stages of prey species. The predatory mite was taken out of the arena after 24 h and the live prey were counted.

Statistical analysis of data

A logistic regression of the proportion of prey consumed (*Na*/*N0*) as a function of initial prey density presented (*N0*) was used to determine the type and curve shapes of the functional response exhibited by *C. negevi* deutonymph and adult females to different stages of DPM and TSSM. After correcting the natural mortality of prey according to Xia et al. (2003), the data were analyzed by polynomial function following Juliano (2001), to calculate *Na*/*N0* and *N0*.

$$\frac{N_a}{N_0} = \frac{\exp\ (p_0 + p_1 N_0 +\ p_2\ N_0^2 + p_3 N_0^3)}{1 + \exp\ (p_0 + p_1 N_0 +\ p_2\ N_0^2 + p_3 N_0^3)}$$

Whereas, *P1*, *P2*, *P3* and *P0* stand for linear, quadratic, cubic coefficients and intercept, respectively. These coefficients were estimated by the maximum likelihood with PROC logistic regression model using the SigmaPlot® software version 12.2. The linear and quadratic coefficients were used to determine the functional response types (II and III). If *P1* value is less than zero, it indicates that the prey proportion fed declines monotonically with its initial prey density provided, and this trend reflects type II functional response. If $P1 > 0$ and $P2 < 0$, it indicates that the prey proportion fed is proportional to the density of prey, and this trend displays type III functional response (Juliano, 2001).

After defining functional response type, its parameters; handling time (*Th*) and attack rate (*a*) coefficients, of type II functional response were calculated by Roger's random-predator equation (Roger, 1972) after fitting the equation parameters into nonlinear least square regression (NLIN Procedure, SAS Institute, 2012).

$$Na = No(1 - \exp[a\ (Th\ \times\ Na\ -\ T)]$$

Where, *Na* = number of preys fed, *N0* = number of offered preys, *Th* = handling time, *a* = attack rate, and *T* = searching time (24 h). After determining the *a* and *Th* from the original data (*mt*), the differences among the values of each *a* and *Th* were verified for significance by estimating the variance by the Jackknife technique (Meyer et al. 1986). The Jackknife pseudo-value (*mj*) was estimated for the samples (*n*) using the equations:

$$m_{ja} = n\ \times\ m_{ta} -\ (n\ -\ 1)m_{ia}$$
$$m_{jT_h}\ =\ n\ \times\ m_{tT_h} -\ (n - 1)m_{iT_h}$$

The mean values of ($n - 1$) Jackknife pseudo-values of *a* and *Th* for each prey stage were subjected to one-way analysis of variance (ANOVA), followed by the least significant difference (LSD) comparison test ($P < 0.05$) (SPSS, Version 21.0). The maximum feeding capacity of each prey stage (larva, nymph, and adult female) of DPM and TSSM consumed by each *C. negevi* deutonymphs and adult female was analyzed by one-way ANOVA followed LSD comparison test ($P < 0.05$) (SPSS, version 21.0).

Results

The logistic regression analysis showed a significantly negative linear coefficient ($P1 < 0$) for both deutonymph and adult female of *C. negevi* (Table 1). The prey proportion fed by the predator declined as the prey density increased for all life stages of DPM and TSSM (Fig. 1, A and B). These results indicated that both deutonymph and adult female of *C. negevi* exhibited a type II functional response (Fig. 2, A and B). However, the graphical analysis of number of preys consumed versus offered prey density showed that the shape of functional response curves for the deutonymph and adult female of *C. negevi* to TSSM adult female were in between type II and type III functional response (Fig. 2, B).

The functional response parameters, handling time (*Th*) and attack rate (*a*) coefficients, for the deutonymph and adult female of *C. negevi* feeding on different stages of DPM and TSSM are demonstrated numerically as shown in Table 2.

The *Th* of *C. negevi* deutonymph was not significantly different among the immature individuals of both DPM and TSSM (0.62–1.34), except for the adult females of DPM and TSSM, which showed longer *Th* of 1.98 and 2.66, respectively. A similar trend was observed for the *C. negevi* female (0.33–0.82), except on the TSSM female where the *Th* was longer (2.54).

Non-significant differences were recorded in the attack rate (*a*) values of *C. negevi* deutonymph and adult female among most treatments of DPM and TSSM (Table 2, A and B).

The maximum feeding capacity of the deutonymph of *C. negevi*. for each prey stage (larva, nymph, and adult female) of DPM and TSSM was 21,17, and 13; and 19, 19, and 8; respectively, at a prey density of 45. Whereas,the adult female of *C. negevi* was 34, 30, and 25; and 24, 18, and 8; respectively, at a prey density of 60 and 45 (Table 3). The maximum feeding capacity of *C. negevi* adult female was significantly different within different stages of each prey species and between each stage of DPM and TSSM (Table 3, A and B). However, the maximum feeding capacity of each *C. negevi* deutonymph and adult female was higher for DPM female when compared with that of TSSM female (Table 3, A and B).

Table 1: Maximum likelihood estimates from logistic regression of proportion of both prey species *O. afrasiaticus* (DPM) and *T. urticae* (TSSM) consumed as a function of initial prey densities by deutonymph and female of *Cydnoseius negevi*.

Predator stage	Prey	Prey stage	Model summary				Estimated parameter			
			R^2	F-value	d.f	P	*P0**	*P1**	*P2**	*P3**
Deutonymph	DPM	Larva	0.82	30.66	3,20	<0.001	5.99	-0.04	0.01	-0.01
		Nymph	0.83	33.55	3,20	<0.001	5.39	-0.17	0.02	-0.02
		Female	0.70	15.50	3,20	<0.001	5.21	-0.06	0.01	-0.02
	TSSM	Larva	0.84	34.81	3,20	<0.001	5.06	-0.03	0.02	-0.03
		Nymph	0.86	42.05	3,20	<0.001	4.42	-0.14	0.02	-0.01
		Female	0.62	10.83	3,20	<0.001	2.53	-0.23	0.02	-0.02
Female	DPM	Larva	0.90	73.85	3,24	<0.001	5.99	-0.13	0.03	-0.01
		Nymph	0.85	45.14	3,24	<0.001	6.35	-0.12	0.02	-0.02
		Female	0.72	20.39	3,24	<0.001	5.55	-0.05	0.02	-0.02
	TSSM	Larva	0.95	57.85	3,20	<0.001	5.10	-0.01	0.02	-0.03
		Nymph	0.92	38.06	3,20	<0.001	4.74	-0.13	0.02	-0.03
		Female	0.59	7.95	3,16	<0.001	3.67	-0.02	0.01	-0.01

Maximum likelihood estimated coefficients: *P0* = intercept, *P1* = linear, *P2* = quadratic and *P3* = cubic.

Table 2: **Mean estimates values ± SE of functional response parameters, attack rate (*a*) and handling time (*Th*) for *C. negevi*; A) deutonymph and B) adult female feeding on each stage (larva, nymph, and female) of *O. afrasiaticus* (DPM) and *T. urticae* (TSSM).**

A) *C. negevi* deutonymph

Prey stage	Prey species	(*a*)	(*Th*)	P	R^2
Larva	DPM	0.040 ± 0.023 a	0.623 ± 0.416 a	0.001	0.82
	TSSM	0.083 ± 0.047 b	1.121 ± 0.232 a	0.001	0.71
Nymph	DPM	0.030 ± 0.012 a	0.761 ± 0.349 a	0.001	0.92
	TSSM	0.041 ± 0.014a	1.336 ± 0.254 a	0.001	0.68
Female	DPM	0.109 ± 0.092 b	1.982 ± 0.336 ab	0.001	0.50
	TSSM	0.013 ± 0.008 a	2.658 ± 1.294 b	0.003	0.55

B) *C. negevi* adult female

Prey stage	Prey species	(*a*)	(*Th*)	P	R^2
Larva	DPM	0.078 ± 0.024 ab	0.339 ± 0.108 a	<.0001	0.94
	TSSM	0.080 ± 0.031 b	0.717 ± 0.158 a	<.0001	0.86
Nymph	DPM	0.042 ± 0.013 a	0.395 ± 0.175 a	<.0001	0.94
	TSSM	0.072 ± 0.043 ab	1.315 ± 0.289 a	0.001	0.62
Female	DPM	0.054 ± 0.025 ab	0.821 ± 0.225 a	<.0001	0.81
	TSSM	0.049 ± 0.020 ab	2.539 ± 0.368 b	0.001	0.56

Means followed by different small letters within the column(s) are significantly different (ANOVA followed by LSD: P<0.05).

Table 3: The average number (*Na*) ± S.E consumed and maximum mean capacity of *C. negevi* A) deutonymph and B) adult female for *O. afrasiaticus* (DPM) and *T. urticae* (TSSM) consumed at different stages and density levels (*No*) during 24 hours.

A) *C. negevi* deutonymph

		Prey stages		
Prey Density	**Prey Species**	**Larvae**	**Nymph**	**Adult (Female)**
5	DPM	4.25 ± 0.25 a A	4.00 ± 0.41 a A	3.75 ± 0.25 bc A
	TSSM	4.25 ± 0.48 a A	3.25 ± 0.75 a B	1.25 ± 0.45 a B
10	DPM	9.50 ± 0.29 b A	6.50 ± 0.65 ab B	8.13 ± 0.41 e B
	TSSM	8.25 ± 0.48 b A	5.75 ± 0.48 ab B	2.25 ± 1.45 ab C
25	DPM	10.71 ± 0.54 b A	8.25 ± 0.85 bc A	6.88 ± 0.86 de B
	TSSM	10.50 ± 0.65 b A	7.75 ± 0.48 bc B	3.50 ± 2.58 bc C
35	DPM	11.25 ± 0.95 b A	10.75 ± 0.48 c A	11.43 ± 0.71 fg A
	TSSM	16.75 ± 0.48 c A	11.00 ± 0.91 c B	4.25 ± 2.73 bc C
45	DPM	20.89 ± 1.12 d A	16.25 ± 1.93 d AB	12.73 ± 0.46 g B
	TSSM	18.75 ± 1.65 cd A	16.50 ± 1.85 d B	7.50 ± 2.06 e B
60	DPM	21.25 ± 0.86 d A	17.00 ± 1.29 d B	10.36 ± 0.71 f C
	TSSM	16.00 ± 1.83 c A	19.00 ± 1.78 d B	5.00 ± 3.70 cd B

B) *C. negevi* adult female

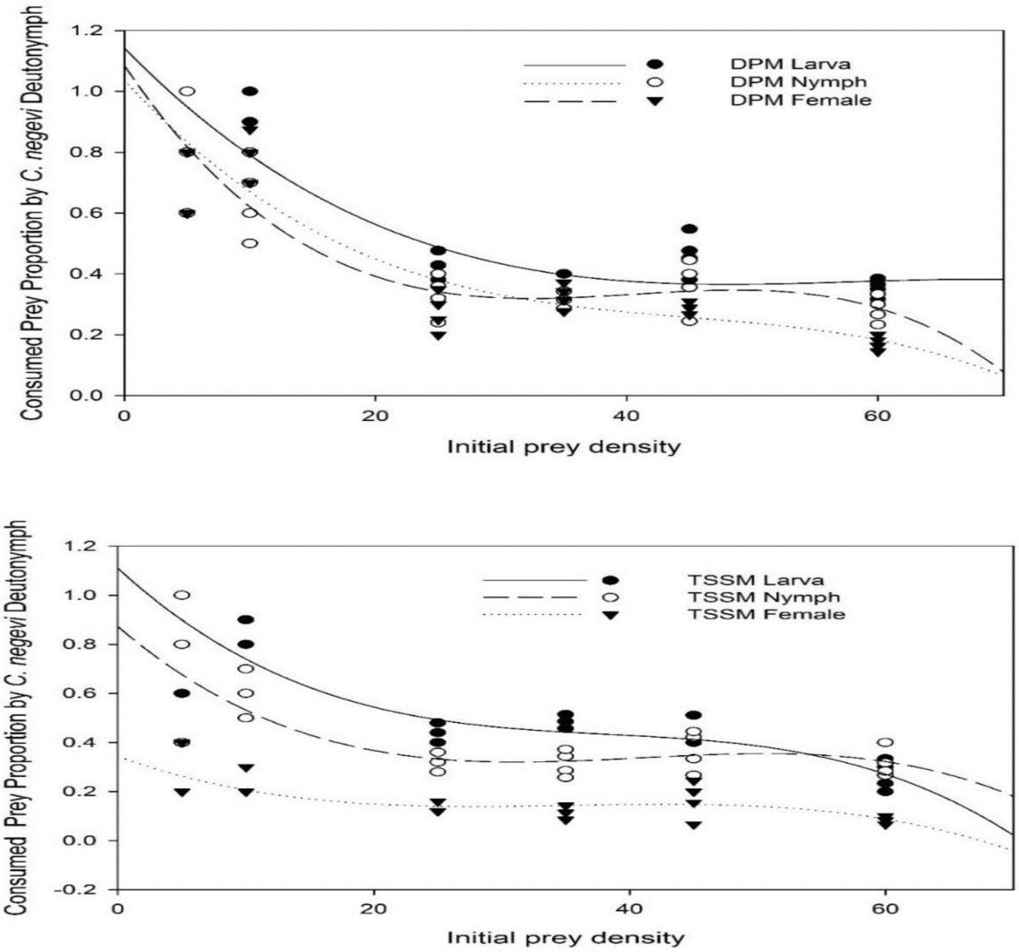
		Prey stages		
Prey Density	**Prey species**	**Larvae**	**Nymph**	**Adult (Female)**
5	DPM	4.69 ± 0.31 a A	4.75 ± 0.25 a A	4.75 ± 0.25 a A
	TSSM	4.75 ± 0.25 a A	4.00 ± 0.41 a AB	3.50 ± 0.29 a B
10	DPM	9.16 ± 0.53 ab A	8.75 ± 0.48 ab A	7.49 ± 0.70 ab A
	TSSM	8.50 ± 0.50 ab A	6.25 ± 0.25 ab B	4.50 ± 0.28 a C
25	DPM	15.22 ± 2.39 c A	12.50 ± 1.55 cd A	11.41 ± 1.80 bc A
	TSSM	13.00 ± 1.47 bc A	10.50 ± 1.32 bc B	5.75 ± 0.25 a B
35	DPM	21.17 ± 5.12 d A	16.09 ± 1.25 de A	16.13 ± 1.81 d A
	TSSM	20.75 ± 2.10 d A	13.50 ± 0.65 cd B	8.00 ± 0.82 ab C
45	DPM	30.00 ± 3.42 e A	20.81 ± 2.04 f A	15.80 ± 3.57 cd B
	TSSM	23.75 ± 1.49 d A	17.50 ± 0.96 ef B	8.25 ± 1.65 ab C
60	DPM	33.67 ± 1.90 e A	29.72 ± 3.53 g A	24.54 ± 0.95 e B
	TSSM	23.00 ± 1.08 d A	12.75 ± 1.65 cd B	-

70	DPM	28.95 ± 1.94 e A	27.15 ± 2.00 g B	18.69 ± 2.13 d C

Means followed by different small letters within the column(s) are significantly different (ANOVA followed by LSD: P<0.05).

Means followed by different capital letters within the row (s) are significantly different (ANOVA followed by LSD: P<0.05).

A) *C. negevi* deutonymph



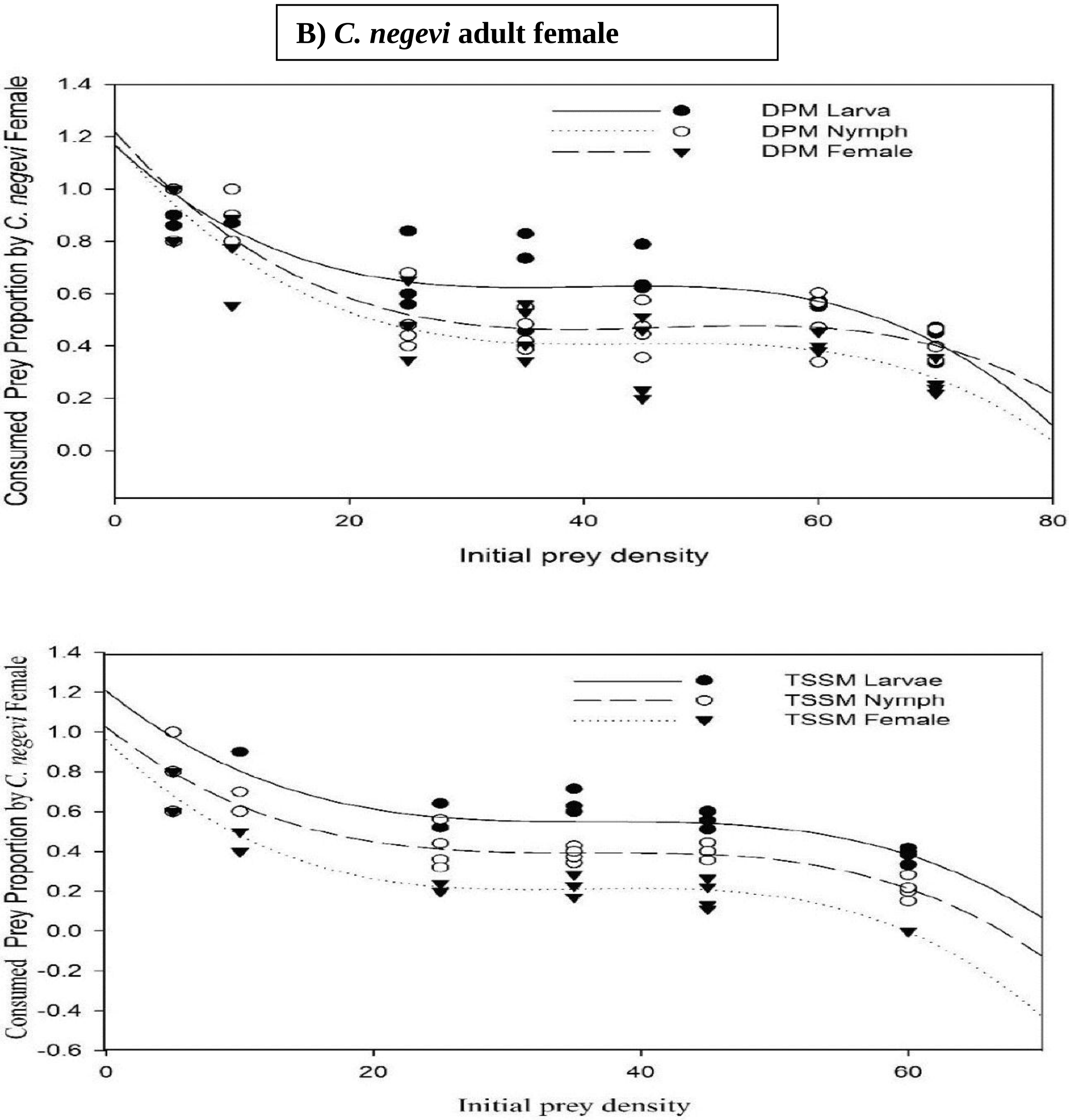
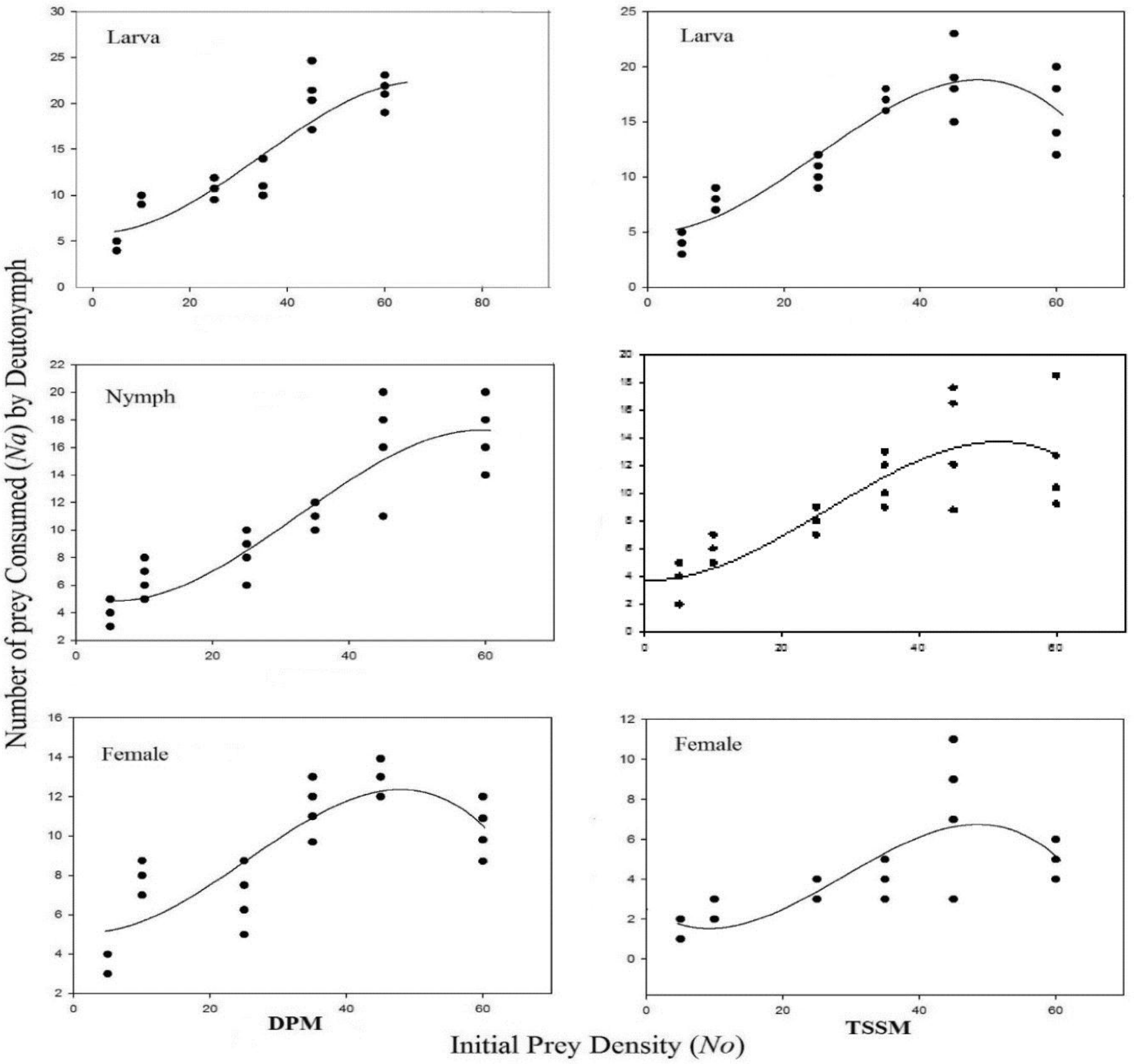


Figure 1: Mean proportion of each prey stage (larva, nymph, and female) of *O. afrasiaticus* (DPM) and *T. urticae* (TSSM) consumed by *C. negevi* A) deutonymph and B) adult female at different prey densities.

A) ***C. negevi*** **deutonymph**



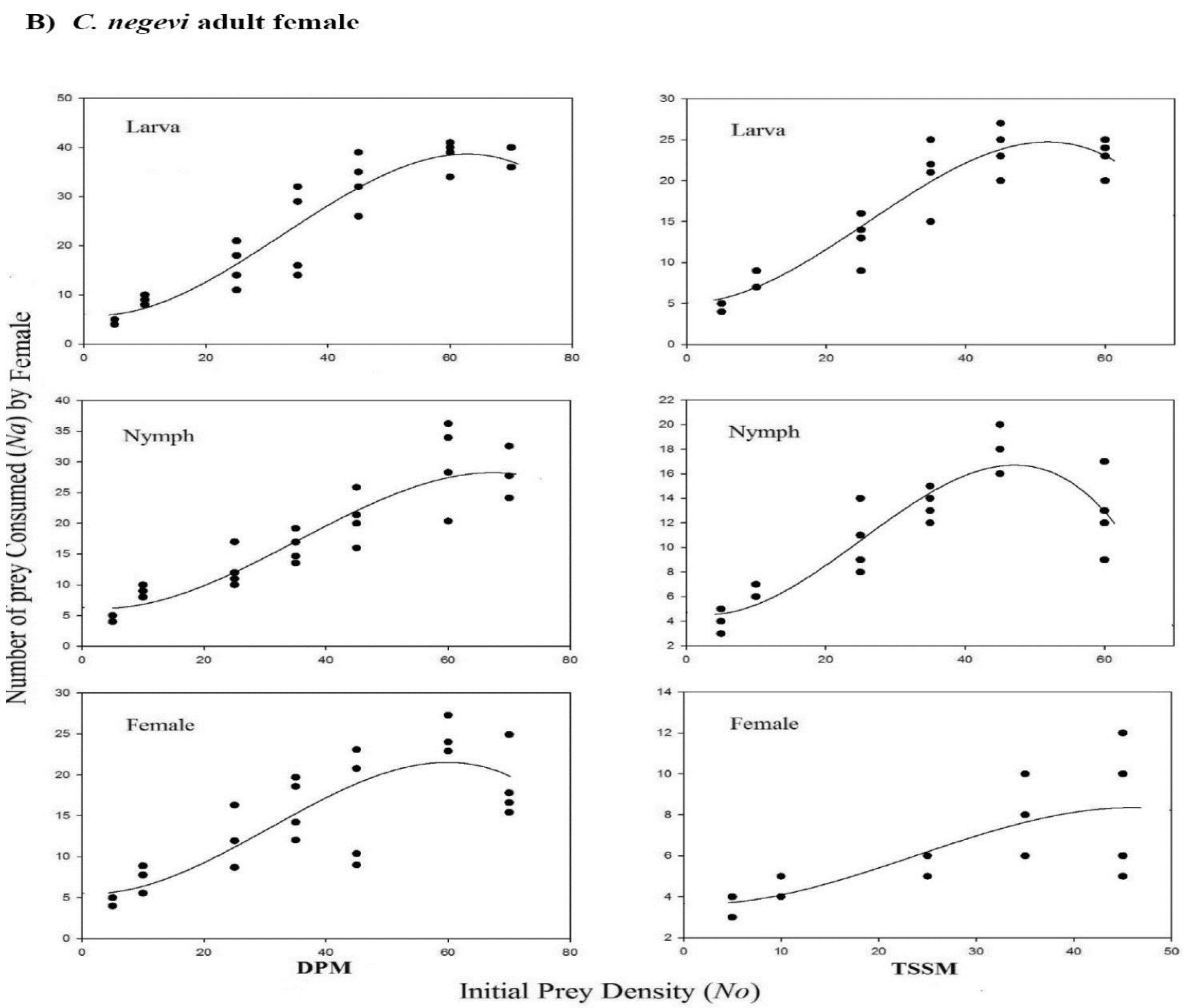


Figure 2: **Functional responses curves of *C. negevi* A) deutonymph and B) adult female to each stage (larva, nymph, and female) of *O. afrasiaticus* (DPM) and *T. urticae* (TSSM) prey species (Points represent the observed numbers of prey ‘consumed at each initial prey density, and lines were predicted by the random predator equation).**

Discussion

To the best of our information, the present study is the first to evaluate the functional response of the phytoseiid predator *C. negevi* to all mobile life stages of DPM and TSSM at a relatively low humidity 35 ± 5% RH.

However, few functional response studies on phytoseiid mites have been conducted at relatively low humidity i.e., *Metaseiulus flumenis* (Chant) against immature stages of a major pest of date palm fruit, the banks grass mite *O. pratensis* (Banks), at 50 ± 10% RH (Ganjisaffar and Perring, 2015*); Neoseiulus californicus* (McGregor)against the eggs of TSSM at extreme humidity levels (i.e., 30, 50, 70, and 90% RH) (Döker et al., 2016); *Neoseiulus picanus* (Ragusa) against the eggs of TSSM at 50% RH (Tello-Mercado et al., 2017); and *N. fallacis* (Garman), *Phytoseiulus persimilis* Athias-Henriot, and *N. californicus* against the eggs of TSSM in a greenhouse at 40% RH during day and 70% RH during night (Audenaert et al., 2014). In the present study, the polynomial logistic regression confirmed that type II functional response specified and designated all the data tested (Table 1). A high proportion of each life stage (larva, nymph, and adult female) of DPM and TSSM was consumed at their low densities (inverse density-dependent) (Fig. 1). Type II functional response has been observed in most of the phytoseiid predators (Sabelis, 1986). At relatively low and extreme humidity, the functional response type II was recorded for all the phytoseiid predatory mites against the eggs of TSSM and immature stages of *O. pratensis* in all studies mentioned above.

Furthermore, the functional response type II was also found for each life stage of *C. negevi*—protonymph, deutonymph, and adult female—that fed on the TSSM nymphs, but at high relative humidity 70 ± 5% RH (Rasmy et al., 2014). In the present study, the functional response of *C. negevi* was not affected by different levels of humidity. A similar observation was made by Döker et al. (2016) in *N. californicus* against the eggs of TSSM at extremely high humidity.

However, in the present study, the graphical relationship between the number of preys consumed and prey density of both deutonymphs and females of *C. negevi* against the females of TSSM exhibited an inclination toward type III response (sigmoid curve). That is, the shape of type II decelerating curve was in between types II and III as shown in Fig. 2, A and B. Synonymous results have also been reported by other studies (Trexler et al., 1988; Omkar and Pervez, 2004). Generally, type III functional response exhibits a sigmoidal increase only at the initial level, but not throughout the range (positive-density dependence). Later, it shows negative-density dependence, as shown in Type II curves, due to predator satiation (Pervez and Omkar, 2005). Though very rarely, type II response can be determined with a positive *P1* when *P2* or *P3* values are negative and sufficiently large (Juliano, 2001).

Such likelihood usually causes difficulties in discriminating the functional response types because the curve lies between types II and III (Trexler et al., 1988; Casas and Hulliger, 1994; Juliano, 2001). To avoid unclear inferences, functional responses type II and III should be distinguished at low prey densities offered and high number of replications (Pervez and Omkar, 2005; Dick et al., 2014). This would boost the reliability of curve-fitting of each tested functional type.

However, mathematically, the logistic model can easily differentiates the type II and III functional responses and increases the credibility of correctness of the curves (Shah and Khan, 2013). Furthermore, it should be used before analyzing the data through a particular Holling equation.

The coefficient of attack rate (*a*) and handling time (*Th*) coefficients are the parameters used to determine the magnitude of functional response (Pervez and Omkar, 2005). The *Th* parameter usually provides more information about the efficiency of a predator against its prey (Holling, 1959; Veeravel and Baskaran, 1997).

In the present study, the *a* and *Th* values did not vary considerably within and between the stages of DPM and TSSM when exposed to both deutonymph and adult female of *C. negevi* (Table 2, A and B). However, the *Th* of each life stage of *C. negevi* was shorter for all the stages of DPM when compared with that of TSSM. Furthermore, there were variations in the *Th* within different stages of DPM when compared with that of TSSM, with the shortest *Th* on the larvae of both the prey species (Table 2, A and B).

Significantly longer *Th* was required for each predator stage (deutonymph and adult female of *C. negevi*) against TSSM females (Table 2, A and B). The predators require more *Th* when the prey is large (Holling, 1961). This also explains the very low prey predation rate and maximum capacity for the TSSM females when compared with those of the DPM females (Table 3, A and B). According to Sabelis and Helle (1985), the phytoseiid mites rarely feed on spider mite adults.

The *Th* of both deutonymph and adult female of *C. negevi* against the nymphs of TSSM observed in the present study (1.34 and 1.32, respectively) was similar to those reported by Rasmy et al. (2014) (1.79 and 1.07, respectively) at 35% and 70% RH, respectively. Furthermore, at extreme humidity, *N. californicus* against the eggs of TSSM showed no significant difference in its *Th* (Döker et al., 2016). This indicates that the predatory mite *C. negevi* can adapt to a wide range of humidity.

In the present study, the *a* coefficient did not vary significantly among the treatments (Table 2, A and B), probably because of similar and small-sized experimental arenas (Shah and Khan, 2013). Such non-significant differences in the *a* coefficient have been reported by different studies (Montserrat et al., 2000; Pervez and Omkar, 2005).

The maximum predation rate of the *C. negevi* deutonymph was significantly higher for the DPM female than the TSSM female. Furthermore, the *C. negevi* adult consumed significantly more number of DPM individuals at different stages (Table 3, A and B).

The maximum number of preys consumed by the *C. negevi* deutonymph and adult female based on the functional response curves made by Rasmy et al.

(2014) indicated that the average number of TSSM nymphs consumed were about 12 and 19, respectively, at maximum density level (50 preys). In the present study, it was 19 and 18, respectively. This suggests that the maximum feeding capacity can be better understood based on *Th* and is not affected by the RH. The differences in the maximum feeding capacity of *C. negevi* for DPM and TSSM females indicates its association with the DPM in date palm agro-ecosystem (Negm et al., 2014; Alatawi et al., 2017). The TSSM females were more active and larger in size than the DPM females, which was elucidated by the longer *Th* of *C. negevi* on the TSSM than on the DPM (Table 3B). It was also reported that more time is required by the predators to attack and kill larger preys (Holling, 1961) and the attack rate could reduce with increase in size of prey due to improved defense response or ability of prey to escape (Pastorok, 1981; Sabelis, 1992). Furthermore, the slower mobility of *Eutetranychus orientalis* (Klein) as compared to TSSM was considered as one of the main reasons for the increase in predation rate of *Euseius gossipi* (El-Badry) on *E. orientalis* (ElBadry et al., 1968).

The present study shows that the *C. negevi* female fed more efficiently on immature individuals of DPM and TSSM. Moreover, maximum feeding capacity and shorter *Th* were observed on different stages of DPM when compared with those of the TSSM. This indicates the association of *C. negevi* with the DPM. Furthermore, *C. negevi* predated efficiently at a wide range of RH, and could be a potential biological control agent of the DPM

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References

Alatawi FJ, 2011. Phytophagous and predaceous mites associated with vegetable crops from Riyadh, Saudi Arabia. Saudi J. Biol. Sci. 18: 239–246.

Alatawi FJ, Basahih J and Kamran M, 2017. The superfamily Phytoseioidea (Acari: Mesostigmata) from Saudi Arabia: a new species, new records and a key to the reported species. Acarologia. 57: 275–294.

Alatawi FJ, Basahih J and Kamran M, 2018. Suitability of date palm pollen as an alternative food source for the predatory mite *Cydnoseius negevi* (Swirski and Amitai) (Acari: Phytoseiidae) at a low relative humidity. Acarologia. 58(2): 357–365.

Alatawi FJ and Kamran M, 2018. Spider mites (Acari: Tetranychidae) of Saudi Arabia: two new species, new records and a key to all known species. J. Nat. Hist. 52(7): 429–455.

Audenaert JA, Vangansbeke D, Verhoeven R, De Clercq P, Tirry L and Gobin B, 2014. Variability in greenhouse temperature and humidity affects predation efficiency of *Phytoseiulus persimilis* and *Neoseiulus californicus* on *Tetranychus urticae*. IOBC-WPRS Bull. in the press.

Berryman AA, 1992. On choosing models for describing and analyzing ecological time series. Ecology. 73: 694–698.

Casas J and Hulliger B, 1994. Statistical analysis of functional response experiments. Biocont. Sci. Technol. 4: 133–145.

Dick JTA, Alexander ME, Jeschke JM, Ricciardi A, MacIsaac HJ, Robinson TB, Kumschick S, Weyl OL, Dunn AM, Hatcher MJ and Paterson RA, 2014. Advancing impact prediction and hypothesis testing in invasion ecology using a comparative functional response approach. Biol. Invasions. 16: 735–753.

Döker İ, Kazak C and Karut K, 2016. Functional response and fecundity of a native *Neoseiulus californicus* population to *Tetranychus urticae* (Acari: Phytoseiidae, Tetranychidae) at extreme humidity conditions. Syst. Appl. Acarol. 21: 1463–1472.

Elbadry EA, Afifi AM, Issa GI and Elbenhawy EM, 1968. Effectiveness of the predaceous mite *Amblyseius gossipi* as a predator of three tetranychid mites (Acarina: Phytoseiidae). J. Appl. Entomol. 62(4): 189-194.

El-Banhawy EM, Hafez SM and Saber SA, 1999. Effect of the nymph prey density of the two spotted spider mite *Tetranychus urticae* Koch (Acari: Phytoseiidae) on the consumption and reproduction rates of the predacious mite *Cydnoseius negevi* (Swirski and Amitai) in absence and presence of nymphs of the white fly *Bemisia tabaci* (Genn.). Anz. Schaedlingskd. Pflanzenschutz. 72: 55–56.

Ganjisaffar F and Perring TM, 2015. Prey stage preference and functional response of the predatory mite *Galendromus flumenis* to *Oligonychus pratensis*. Biol. Control. 82: 40–45.

Helle W and Sabelis MW, 1985. Spider mites: their biology natural enemies and control, pp. 103–129. In W. Helle and M. W. Sabelis (eds.), World Crop Pests, vol. 1B. Elsevier, Amsterdam.

Holling CS, 1959. The components of predation as revealed by a study of small-mammal predation of the European pine sawfly. Can. Entomol. 91: 293–320.

Holling CS, 1961. Principles of insect predation. Annu. Rev. Entomol. 6: 163–182.

Hoy MA, 2011. Agricultural acarology: introduction to integrated mite management, vol. 7. CRC Press, Florida.

Juliano SA, 2001. Non-linear curve fitting: predation and functional response curve, pp. 178 – 196. In: S. M. Scheiner and J. Gurevitch (eds.), Design and Analysis of Ecological Experiment. Oxford University press, New York.

Khoualdia O, 1997. Premières observations sur Oryctes agamemnon, ravageur du palmier dattier en Tunisie. Fruits. 52: 111–115.

Marafeli PDP, Reis PR, Da Silveira EC, De Toledo MA and Souza-Pimentel GC, 2011. *Neoseiulus californicus* (McGregor, 1954) preying in different life stages of *Tetranychus urticae* Koch, 1836 (Acari: Phytoseiidae, Tetranychidae). Acarologia. 51: 499–506.

Meyer JS, Ingersoll CG, McDonald LL and Boyce MS, 1986. Estimating uncertainty in population growth rates: jackknife vs. bootstrap techniques. Ecology. 67: 1156–1166.

Montserrat M, Albajes R and Castañé C, 2000. Functional response of four heteropteran predators preying on greenhouse whitefly (Homoptera: Aleyrodidae) and western flower thrips (Thysanoptera: Thripidae). Env. Entomol. 29: 1075–1082.

Murdoch WW and Oaten A, 1975. Predation and population stability. Adv. Ecol. Res. 9: 1–131.

Negm MW, Alatawi FJ and Aldryhim YN, 2012. A new species of *Neoseiulus* Hughes, with records of seven species of predatory mites associated with date palm in Saudi Arabia (Acari, Phytoseiidae). Zootaxa. 3356: 57–64.

Negm MW, Alatawi FJ and Aldryhim YN, 2014. Biology, predation and life table of *Cydnoseius negevi* and *Neoseiulus barkeri* on the old world date mite, *Oligonychus afrasiaticus*. J. Insect Sci. 14: 1–6.

Omkar P and Pervez A, 2004. Functional and numerical responses of *Propylea dissecta* (Mulsant) (Col., Coccinellidae). J. Appl. Entomol. 128: 140–146.

Palevsky E, Borochov-Neori H and Gerson U, 2005. Population dynamics of *Oligonychus afrasiaticus* in the southern Arava Valley of Israel in relation to date fruit characteristics and climatic conditions. Agri. Forest Entomol. 7: 283–290.

Pastorok RA, 1981. Prey vulnerability and size selection by *Chaoborus* larvae. Ecology 62: 1311–1324.

Pervez A and Omkar P, 2005. Functional responses of coccinellid predators: an illustration of a logistic approach. J. Insect Sci. 5: 1–6.

Rasmy AH, Abou-Elella GM and Osman MA, 2014. Functional response of the phytoseiid mite *Typhlodromus negevi* Swirski and Amitai to the two-spotted spider mite *Tetranychus urticae* (Acari: Tetranychidae). Arch. Phytopathol. Plant Prot. 47: 1327–1334.

Rogers D, 1972. Random search and insect population models. J. Anim. Ecol. 41: 353–360.

Sabelis MW, 1985. Reproductive strategies. In W. Helle and M. W. Sabelis, (eds) Spider mites. Their biology, natural enemies and control, pp 265–278, vol. 1A. Elsevier, Amsterdam.

Sabelis MW, 1986. The functional response of predatory mites to the density of two-spotted spider mites. In Dynamics of Physiologically Structured Populations, pp. 298–321. Springer, Berlin.

Sabelis MW, 1992. Predatory arthropods. In Natural Enemies: The population biology of predators, parasites and diseases, pp. 225–264.

SAS Institute, 2012. SAS Enterprise Guide 5.1. SAS Institute Inc., Cary, North Carolina.

Sepúlveda F and Carrillo R, 2008. Functional response of the predatory mite *Chileseius camposi* (Acarina: Phytoseiidae) on densities of it prey, *Panonychus ulmi* (Acarina: Tetranychidae). Rev. Biol. Tropical. 56: 1255–1260.

Shah MA and Khan AA, 2013. Functional response-a function of predator and prey species. Bioscan. 8: 751–758.

SPSS. 2008. SPSS Base 16.0 for Windows User's Guide. SPSS Inc.

Sigma plot®, 12. Systat Software, San Jose, CA.

Tello-Mercado VE, Zarzar-Maza ME and Suarez-Pantoja AM, 2017. Functional response of *Cydnodromus picanus* (Acari: Phytoseiidae) on two-spotted spider mite, *Tetranychus urticae* (Acari: Tetranychidae). Acta Agronómica. 66: 275–281.

Trexler JC, Charles EM and Travis J, 1988. How can the functional response best be determined? Oecologia. 76: 206–214.

Vangansbeke D, De Schrijver L, Spranghers T, Audenaert J, Verhoeven R, Nguyen DT, Gobin B, Tirry L and De Clercq P, 2013. Alternating temperatures affect life table parameters of *Phytoseiulus persimilis*, *Neoseiulus californicus* (Acari: Phytoseiidae) and their prey *Tetranychus urticae* (Acari: Tetranychidae). Exp. Appl. Acarol. 61: 285–298.

Veeravel R and Baskaran P, 1997. Searching Behaviour of Two Coccinellid Predators, *Coccinella transversalis* Fab. and *Cheilomenes sexmaculatus* Fab., on Egg Plant Infested with *Aphis gossypii* Glov. Int. J. Trop. Insect Sci. 17: 363–368.

Xia JY, Rabbinge R and Van Der Werf W, 2003. Multistage Functional Responses in a Ladybeetle-Aphid System: Scaling Up from the Laboratory to the Field. Env. Entomol. 32: 151–162

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