Journal of Plant Protection and Pathology

Functional Responses of *Coccinella undecimpunctata* and *Chrysoperla carnea* to their Aphid Prey under Semi-Field Conditions

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ABSTRACT

Understanding the interactions between predator and prey is the basis for creating a strategy for the biocontrol of aphids. One of the most informative methods to understand these interactions is the functional response. In this study, the predation efficiency, of the second-instars of *Coccinella undecimpunctata* L. and *Chrysoperla carnea* (Stephen) to *Aphis craccivora* and *Aphis gossypii* were evaluated. The experiments were carried out under semi-greenhouse conditions at predator: prey ratios ranging from 1: 20 to 1: 100 per cage. The decline in the predation rates with increasing density of *A. craccivora* by each of both predators fits the type II and type I functional responses for *C. undecimpunctata* and *C. carnea*, respectively. While, both predator species exhibited a type I responses to changing in *A. gossypii* densities. The type II functional response estimates showed that *C. carnea* had greatest attack rate and shorter handling time on *A. craccivora* than those for the type I of *C. undecimpunctata*. On *A. gossypii*, these values were better for *C. undecimpunctata* larvae than *C. carnea*. Theoretically, the highest number of prey that could be eaten by a single predatory larva of *C. undecimpunctata* and *C. carnea* within a day (T/T_h) was 18.31 and 9.30 of *A. craccivora*, and 24.89 and 16.91 of *A. gossypii*, respectively. Although, the type of response was generally a type I with a constant mortality rate regardless the prey density increased or not, this type might be turned to type II, on long-term, as the predator establishes.

Keywords: Aphidophagous, *Aphis craccivora*, *Aphis gossypii*, attack rate, handling time
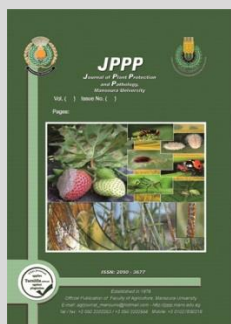
INTRODUCTION

The common bean (*Phaseolus vulgaris*. L) is among the most important leguminous crops as a main source of protein (Singh, 1999). The cowpea aphid, *Aphis craccivora* (Koch.) (Homoptera: Aphididae) is among the most injurious insect pests infesting leguminous plants (Soliman, 2004). As well, squash (*Cucurbita pepo* L.) is among the most important cucurbitaceous crops in Egypt. Its production increased during the past years especially in new reclaimed land for local consumption and exportation (El- Maghraby *et al*., 1989 and El-Lakwah *et al*., 2011). It attacked by many insect pest species, especially *Aphis gossypii* Glover (Nyoike and Liburd, 2010).

The green lacewing, *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae) is a key specialist biocontrol agent. Its larvae used primarily through augmentative periodic releases against various aphid species in indoor and outdoor crop systems (Principi and Canard, 1984; Medina *et al*., 2002; Rimoldi *et al*., 2008; Van der Blom, 2008; Turquet *et al*., 2009). The eleven-spotted ladybird, *Coccinella undecimpunctata* L. (Coleoptera: Coccinellidae) is an important generalist predator. However, aphids come among its preferred list of prey (Hodek and Honek, 1996). Thus, it is an interesting biocontrol agent in the context of integrated pest management, IPM, of aphids (Cabral *et al*., 2011).

Successful employment of aphidophagous predators in agroecosystems has a huge economic impact in aphid biocontrol. An increased attention has given to aphidophagous predators, particularly ladybeetles, over the time. This is due to many biological attributes they have, such as their ability to voraciously consume a wide range of prey and to have a fast numeric response (e.g., Hodek and Honěk, 1996). Aphids can change their populations over time and space, and aphidophagous predators can respond to these changes in aphid's population with several ways (Borges *et al*., 2006).

Understanding the interactions between predator and prey under both lab and field conditions is required for creating a strategy for the biocontrol of aphids. One of the most effective methods to understand these interactions is functional response (Timms *et al*., 2008; Bayoumy, 2011; Osman and Bayoumy, 2011). The functional response is characterized as the variation in killing rates in response to changes in prey density (Holling, 1959). Most of functional response studies have been conducted under laboratory conditions, however few of them have examined the predator's response to its prey under field or semi-field conditions. From the practical point of view, determining the type of functional response may provide useful insights about the timing of predator release and the effective predator: prey ratio, both of them could maximize the quality of aphid control. Thus, the current study aims to assess the predation efficiency of *C. undecimpunctata* and *C. carnea* on varying densities of the cowpea and cotton aphid preys under semi- greenhouse conditions via determining the functional response and its valuable parameters.

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MATERIALS AND METHODS

1. The cowpea aphid (*Aphis craccivora*) infestation

The current experiments were performed in the greenhouse of Pesticide Department, Faculty of Agriculture, Mansoura University. The common bean, *Phaseolus vulgaris* (L.) was cultivated in an area of 360 m² during October, 2018. Under greenhouse conditions, seeds of common bean were planted in lines, 6.0 m × 60 cm, and the distance between each two plants in the same line was 30 cm. Seedlings were watered daily until they were one-month old before infestation with aphids. All agricultural practices were followed as recommended. Once the plants reached the suitable age, they were infested with the first-instar nymphs of the cowpea aphid, *A. craccivora*. The aphid applied in the feeding experiments was obtained from the stock culture that established at the laboratory of Economic Entomology Department on the broad bean (*Vicia fabae* L.). The tiny newly laid first instar nymphs were collected, transferred to healthy leaves of broad bean in the lab, and one-day later these leaves transferred to the greenhouse. The artificial infestation in the greenhouse was conducted by clipping heavily infested leaves of broad beans with *A. craccivora* and placing them on fresh plants of common bean. These plants were tracked daily until the viviparous apterae started to give birth. Following aphid birth, each leaf of the plant was carefully inspected using hand lens, viviparous adults were omitted, and the required numbers of nymphs for each plant were recorded. Then, each plant was caged using wooden cage (100 cm x 50 cm x 65 cm). These cages were covered with white mesh screen containing a hole in the top to facilitate the introduction of natural enemies.

2. The cotton aphid (*Aphis gossypii*) infestation

The previously described greenhouse was used to cultivate the squash plants, *Cucurbita pepo* (L.). The squash plants (variety Mabroka hybrid F1) were cultivated in an area of 360 m² during august, 2019. Under greenhouse conditions, seeds of squash were planted in lines, 6.0 m × 60 cm, and the distance between each two plants in the same line was 75 cm. Seedlings were watered daily until they were three weeks old before infestation with aphids. All agricultural practices were followed as recommended. Once the plants reached the suitable age (three weeks-old), they were infested with the cotton aphid, *A. gossypii*. The aphid used in the infestation was obtained from eggplant plants at the University Farm. The tiny newly laid first instar nymphs were carefully collected, transferred to healthy leaves of squash in the lab, and one day later, these leaves were transferred to the squash plants in the greenhouse. The artificial infestation in the greenhouse was performed by clipping heavily infested leaves of squash with *A. gossypii* and placing them on the top of fresh plants of squash. These plants were monitored daily until the viviparous apterae started to give birth. Following aphid birth, each leaf of the plant was carefully inspected using hand lens, viviparous adults were removed, and the required numbers of nymphs for each plant were counted. Then, each plant was caged using wooden cage (100 cm x 50 cm x 65 cm). These cages were covered with white mesh screen containing a hole in the top to facilitate the introduction of natural enemies.

3. Predator colony

Two aphidophagous predators were used in the evaluations. The green lacewing, *C. carnea* was established from ca. 20 adults obtained from the mass production lab of green lacewing (Cairo University). The lacewings were introduced in a jar (20 cm diam. × 40 cm ht.) to assure mating and maintained in 25.0 ± 1.0°C, 60 ± 10% RH, and 16:8 L:D photoperiod. Black mesh screens were used to close the necks of jars by a rubber band. In jars, lacewings were provisioned with sponge pieces swabbed with a mixed diet, composited of brewer yeast and honey, and cotton wicks soaked with water every two days. Eggs were daily harvested by shearing their stalk with small scissors inside a 9.0 cm Petri dishes and then maintained at the same previously mentioned conditions. After hatching, larvae were isolated in 5.5 Petri dishes and daily provided with cowpea aphids until they reached their second instar that used in the experiments. In addition, this initial population was maintained under the same physical conditions for further experiments.

The eleven-spotted ladybird, *Coccinella undecimpunctata* L. was established from 20 adults captured from the experimental garden of Mansoura University in plastic bottles. These beetles were transferred to the lab, each individual beetle was isolated in a 9.0 cm Petri dish, and each beetle was fed with *A. craccivora* ad libitum to lay eggs. The laid eggs were collected by transferring females to clean dishes. These eggs were maintained at the same described conditions. After hatching, larvae were separated in groups of five into a 5.5 cm Petri dishes with *A. craccivora*, renewed daily. These neonate larvae were incubated under the same conditions until they reach the second instar. In addition, this initial population was kept under the same physical conditions for further experiments.

4. Predation efficiency

The predation efficiency, in terms of functional response and its parameters, of the second instar of each predator species was measured. Based on the numbers of aphid on each of plant species (i.e., broad bean and squash), the numbers of introduced predators were adjusted to be 1 : 20, 1 : 40, 1 : 60, 1 : 80, and 1: 100 predator: prey ratio (P: P ratio). Each ratio replicated four times. Control treatments were prepared without predator attack to estimate the natural prey mortalities. Mortality in control treatments was subtracted from the number of consumed prey in treatments having predators. The plants were checked daily until all aphid items consumed and also to make sure that the predators still alive in the cage. The number of prey consumed (N_a) and the number of prey remaining alive on the plant were daily determined for each P: P ratio.

Based on the number of aphid consumed in the first twenty-four hours, the functional response was extracted based on the method of Juliano (2001). To determine the relationship type between the predation rates and numbers of prey offered (Trexler *et al.*, 1988), polynomial (logistic) regression (CATMOD procedure in SAS, SAS Institute, 2007) was performed as follows:

$$\frac{N_a}{N_0} = \frac{\exp(B_0 + B_1 N_0 + B_2 N_0^2 + B_3 N_0^3)}{1 + \exp(N_0 + B_1 N_0 + B_2 N_0^2 + B_3 N_0^3)} \quad (1)$$

where

N_a is the number of prey devoured, N_0 is the initial prey provided, and B_0, B_1, B_2, and B_3 are the constant, linear, quadratic, and cubic parameters, respectively. By the sign of the linear term, the type of response can be determined. If not significantly different from zero, this means a type I; if it was significantly negative, it means a type II; and if the linear was significantly positive and the quadratic term is significantly negative, it means a type III response (Juliano, 2001).

The values of attack rate (a) and handling time (T_h) of the type II functional response were determined by the random predator equation (2) in a non-linear least-squares estimation using PROC NLIN procedure in SAS (Rogers, 1972).

$$Na / TP = N_0 \{1 - \exp [a (T_h N_a - T)]\} \qquad (2)$$

Where

T is the exposure time and P is equal to single predator.

The highest number of prey that can be eaten by a single predatory larva during a day (T) was counted as T/T_h (Hassell, 2000).

Statistical analysis

Before ANOVA taken place, the predation rates by each predatory species at different prey densities were primarily checked for test of normality and equality of variance using Shapiro–Wilks and Levene tests, respectively. Means were isolated by Fisher LSD test ($\alpha = 0.05$). The t-test ($\alpha = 0.05$) was performed to analyze the variations in predation rates by each predatory species at each prey density. Statistics were conducted using the SigmaStat functions of SigmaPlot 12 (Systat Software, San Jose, CA, U.S.A., 2011).

RESULTS AND DISCUSSION

Results

Predation efficiency

Functional response of second-instar larvae of *Coccinella undecimpunctata* and *Chrysoperla carnea* to the cowpea aphid, *Aphis craccivora*

Figure (1) shows the number of prey consumed at different prey densities offered for each individual of second-instar *C. undecimpunctata* (A) and *C. carnea* (B) during 24 h in semi-field release experimental design. This number was increased for *C. undecimpunctata* as the number of prey increased, whereas this number increased as the number of prey increased until reach a plateau, then decreased for *C. carnea*.

Figure (2) shows the proportion of prey consumed at different prey densities offered for each individual of second-instar *C. undecimpunctata* (A) and *C. carnea* (B) during 24 h in semi-field release experimental design. The two-way ANOVA showed that prey density ($F_{4,30} = 27.86$, $P < 0.001$) and predator species ($F_{1,30} = 7.86$, $P = 0.009$) significantly affected the proportions of prey killed, whereas the interaction between both independent variables did not affect ($F_{4,30} = 2.21$, $P = 0.09$). The proportions of prey killed by second-instar *C. undecimpunctata* as well as by second-instar *C. carnea* significantly declined as prey density increased ($F_{4,15} = 7.68$, $P = 0.001$ and $F_{4,15} = 41.66$, $P < 0.001$, respectively). The predation efficiency (consumption rates) was compared between both predator species at each prey density using *t*-test. The results showed that *C. undecimpunctata* significantly consumed more preys in density of 40 ($t= 4.59$, $P= 0.004$) and 60 ($t= 2.96$, $P= 0.04$) prey, whereas there were no significant differences at 20 ($t= 0.74$, $P= 0.48$), 80 ($t= 1.37$, $P= 0.22$), and 100 ($t= 2.31$, $P= 0.06$) preys. Regardless the availability in prey density, generally there was no significant difference between both predator species in the killing efficiency of *A. craccivora* ($t= 1.41$, $P= 0.17$).

The accelerating decline in the predation rates by each of both predator species in related to density of prey fits the type II and I functional responses for *C. undecimpunctata*

and *C. carnea*, respectively. Applying a polynomial model gave the best fitting to the numbers and proportions of prey consumed by second-instar of *C. undecimpunctata* and *C. carnea*. Polynomial analysis showed that the linear regression of response curve for *C. undecimpunctata* and *C. carnea* was significantly negative ($P_1 < 0.05$) and non-significant ($P_1 > 0.05$), which well describe the type II and I responses, respectively (Table 1).

By using Roger's model to estimate type II functional response parameters, *C. carnea* larvae had greater attack rate ($a = 0.1054$ h^{-1}) and shorter handling time ($T_h = 1.3110$ h) than the type I response of *C. undecimpunctata* ($a = 0.00984$ h^{-1} and $T_h = 2.5781$ h) (Table 2). Theoretically, the highest number of prey that can be eaten by a single larva of *C. undecimpunctata* and *C. carnea* within a day (T/T_h) was 18.31 and 9.30 of *A. craccivora*, respectively.
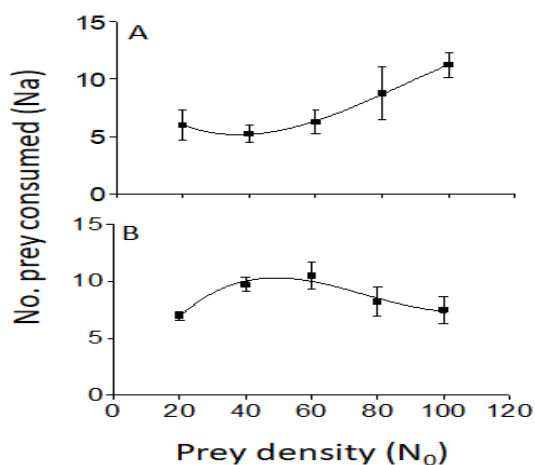

Fig. 1. Mean numbers (±SE) of *Aphis craccivora* consumed by the second-instar *Coccinella undecimpunctata* (A) and *Chrysoperla carnea* (B) at varying prey densities.
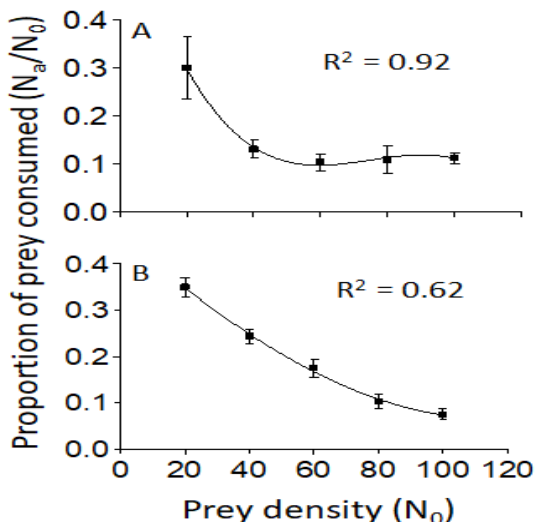

Fig. 2. Proportions (±SE) of *A. craccivora* consumed by the second-instar *C. undecimpunctata* (A) and *C. carnea* (B) at different prey densities. The lines obtained by the third order of polynomial model describe the best-fit type II functional response *C. undecimpunctata*: R2= 0.98, and *C. carnea*: R2= 0.62).

Table 1. Results of the polynomial regression analysis of the predation rates by a single larva as a function of the density of *A. craccivora* during a 24-h searching period in experimental cage containing infested bean plants.

Predator species	Coefficient	Value	SE	Chi-Square (χ^2)	P-value
	Constant (P_0)	1.4701	1.0944	1.80	0.1792
Coccinella	Linear (P_1)	-0.1551	0.0689	5.07	0.0244
undecimpunctata	Quadratic (P_2)	0.00216	0.00124	3.04	0.0811
	Cubic (P_3)	-0.000009	0.000006	2.09	0.1486
	Constant (P_0)	-0.03490	1.0112	0.12	0.7300
Chrysoperla	Linear (P_1)	-0.00894	0.0626	0.02	0.8864
carnea	Quadratic (P_2)	-0.00031	0.00114	0.07	0.7842
	Cubic (P_3)	0.0000018	0.0000006	0.09	0.7682

A significant negative value of linear term means that the slope of the curve is declining. Thus, a type II functional response is approved.

Table 2. The attack rate (*a*) and handling time (*Th*) of predators exhibited a type II functional response in relation to changing in *Aphis craccivora* densities.

Predator species	Parameter	Value	Asymptotic SE	Asymptotic 95% CI	
				Lower	Upper
Coccinella	a	0.00984	0.00398	0.00147	0.0182
undecimpunctata	T_h	2.5781	0.3053	1.9367	3.2196
Chrysoperla	a	0.1045	0.0385	-0.1865	0.3955
carnea	T_h	1.3110	0.5795	0.0936	2.5284

Functional response of second-instar larvae of *Coccinella undecimpunctata* and *Chrysoperla carnea* to the cotton aphid, *Aphis gossypii*

Figure (3) shows the number of prey consumed at different prey densities offered for each individual of second-instar *C. undecimpunctata* (A) and *C. carnea* (B) during 24 h in semi-field release experimental design. This number was increased for *C. undecimpunctata* and *C. carnea* as the number of prey increased until reach a plateau, then decreased. Figure (4) shows the proportion of prey consumed at different prey densities offered for each individual of second-instar *C. undecimpunctata* (A) and *C. carnea* (B) during 24 h in semi-field release experimental design. The two-way ANOVA showed that prey density ($F_{4,30} = 9.39$, $P < 0.001$) and the interaction between prey density and predator species ($F_{4,30} = 6.04$, $P = 0.001$) significantly affected the predation of *A. gossypii*, whereas predator species did not affect ($F_{1,30} = 1.93$, $P = 0.18$). on the other hand, the two-way ANOVA showed that there were significant effects of prey density ($F_{4,30} = 26.39$, $P < 0.001$) and the interaction between prey density*predator species on the proportions of prey killed, whereas the predator species had no significant effect ($F_{1,30} = 1.21$, $P = 0.28$).
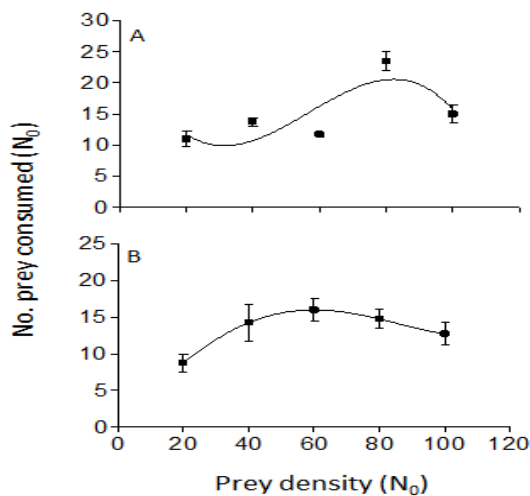

Fig. 3. Mean numbers (±SE) of *A. gossypii* consumed by the second-larval instar of *C. undecimpunctata* (A) and *C. carnea* (B) at varying prey densities.
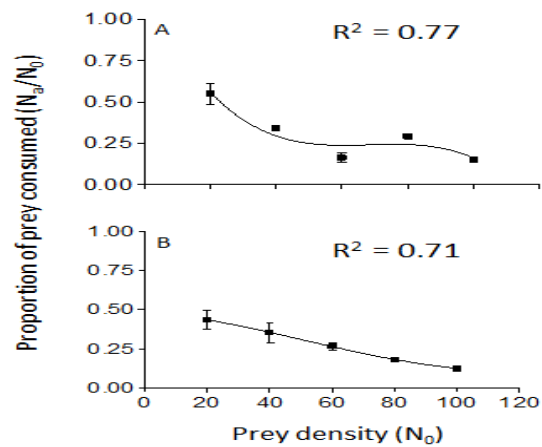

Fig. 4. Mean proportions (±SE) of *A. gossypii* consumed by the second-larval instar *C. undecimpunctata* (A) and *C. carnea* (B) at different prey densities. The lines obtained by the third order of logistic model represent the good-fit of type II functional response (*C. undecimpunctata*: $R^2 = 0.77$, and *C. carnea*: $R^2 = 0.71$).

The prey killing rates by second-instar *C. undecimpunctata* as well as by second-instar *C. carnea* significantly declined as prey density increased ($F_{4,15} = 22.69$, $P < 0.001$ and $F_{4,15} = 9.15$, $P < 0.001$, respectively). The predation efficiency (consumption rates) was compared between both predator species at each prey density using *t*-test. The results showed that *C. carnea* significantly consumed more aphids at density of 60 prey ($t = 2.68$, $P = 0.04$) than *C. undecimpunctata*, whereas *C. undecimpunctata* consumed more preys than *C. carnea* at density of 80 prey ($t = 4.39$, $P = 0.005$). Whereas no significant differences at 20 ($t = 1.29$, $P = 0.25$), 40 ($t = 0.19$, $P = 0.85$), and 100 ($t = 1.04$, $P = 0.34$) preys were detected. Regardless the viability in prey density, generally there were no significant differences between both predators in the killing efficiency of *A. gossypii* ($t = 0.56$, $P = 0.58$).

The decline in the predation rates by each of both predator species in relation to density of prey fits the type I

functional responses for *C. undecimpunctata* and *C. carnea*. Applying a polynomial model showed a good-fit to the numbers and proportions of prey consumed by second-instar of *C. undecimpunctata* and *C. carnea*. Model analysis showed that the slopes of the linear curves for *C. undecimpunctata* and *C. carnea* were non-significant ($P_1 >$ 0.05), which well describe the type I functional response (Table 3).

The type I functional response parameters showed that *C. undecimpunctata* beetles had the greatest attack rate ($b= 0.0538$ h^{-1}) and the shorter handling time ($T_h= 0.964$ h) than *C. carnea* ($b= 0.0265$ h^{-1} and $T_h= 1.4119$ h) (Table 4).

Theoretically, the highest prey number that can be consumed by a single larva of *C. undecimpunctata* and *C. carnea* within a day (T/T_h) was 24.89 and 16.91 of *A. gossypii*, respectively.

Table 3. Results of the polynomial regression analysis of the predation rates by a single predatory larva as a fraction of the prey density during a 24-h searching period in a cage containing infested squash plants with *Aphis gossypii* in the greenhouse.

Predator species	Coefficient	Value	SE	Chi-Square (χ^2)	P-value
Coccinella undecimpunctata	Constant (P_0)	-0.0882	0.9193	0.01	0.9236
	Linear (P_1)	-0.00306	0.0554	0.00	0.09561
	Quadratic (P_2)	0.00029	0.000987	0.09	0.7696
	Cubic (P_3)	0.0000014	0.0000053	0.07	0.7982
Chrysoperla carnea	Constant (P_0)	-3.1068	0.9482	10.74	0.9236
	Linear (P_1)	-0.2097	0.0563	13.85	0.9561
	Quadratic (P_2)	0.00337	0.000987	11.63	0.7696
	Cubic (P_3)	0.00002	0.000005	11.08	0.7982

A non-significant negative value of linear term means that the slope of the curve is constant. Thus, a type I functional response is issued.

Table 4. The attack rate (*a*) and handling time (T_h) of predators exhibiting a type I functional response to their prey, *Aphis gossypii*.

Predator species	Parameter	Value	Asymptotic SE	Asymptotic 95% CI	
				Lower	Upper
Coccinella undecimpunctata	*b*	0.0538	0.0298	-0.00869	0.1164
	T_h	0.9640	0.2998	0.3341	1.5939
Chrysoperla carnea	*b*	0.0265	0.0134	-0.00164	0.0547
	T_h	1.4119	0.2027	0.986	1.8378

Discussion

The different types of functional responses have been documented for aphidophagous species (Hodek and Honěk, 1996), however the type II response was the most common ones in aphidophagous in response to their aphid species such as *C. septempunctata* to *A. craccivora* and *M. persicae* (Bayoumy and Awadalla, 2018); *C. undecimpunctata* to *Aphis fabae* Scopoli (Moura *et al.*, 2006), *Harmonia axyridis* (Pallas) to *A. gossypii* (Lee and Kang, 2004), *Cheilomenes sexmaculata* Fabricius and *C. transversalis* Fabricius to *A. gossypii* (Pervez and Omkar, 2005), *Hippodamia variegate* (Goeze) to *A. fabae* (Farhadi *et al.*, 2010) and to *A. craccivora* and *M. persicae* (Bayoumy and Awadalla, 2018); *Nephus includens* (Kirsch) to *A. gossypii* (Bayoumy, 2011), *Stethorus gilvifrons* Mulsant to *Tetranychus urticae* (Bayoumy *et al.*, 2014) and *C. carnea* to *A. craccivora* and *M. persicae* (Bayoumy and Awadalla, 2018). Only the second instar *C. undecimpunctata* exhibited a type II functional response to *A. craccivora* in greenhouses having broad bean plants. Predators showing a type II response, their predation rates declined as the prey density increased, hence the linear term of polynomial regression should be significantly negative. Generally, this type of response explains the suitability of coccinellids for biocontrol of aphid prey (Hodek and Honěk, 1996 and Lee and Kang, 2004). The type I response reported here to the second instar *C. carnea* to either *A. craccivora* or *A. gossypii* on broad bean and squash plants, respectively. Bayoumy and Awadalla (2018) reported a type II functional response to *C. carnea* to *A. craccivora*. This difference may be due the different predator stages tested in both studies, as the third instar *C. carnea* is more voracious. The different types and

estimates of functional response among predator species may be due to the variations in their hunger levels, digestive ability, voracity, size, and walking speed (Ofuya and Akingbohungbe, 1988; Omkar and Pervez, 2004). Further, the predatory efficiency depends on several factors such as: prey density (Matter *et al.*, 2011), prey stage and species (Koch *et al.*, 2003; Sarmento *et al.*, 2007), temperature (Skirvin *et al.*, 1997), leaf morphology (Bayoumy *et al.*, 2014), parasitism (Bayoumy, 2011; Bayoumy and Michaud, 2012), and cannibalism and intraguild predation (Burgio *et al.*, 2002). Similarity, the predator species and prey density significantly affected the consumption rates in both predator species regardless the host plant species. The second instar *C. undecimpunctata* exhibited a type II functional response to *A. craccivora* on broad bean plant, whereas it exhibited a type I response to *A. gossypii* on squash plants. This is may be because the effect of host plant more than the insect species, as *C. undecimpunctata* is more generalist predator than *C. carnea*. It seems more likely that the surface structures of squash leaves mechanically impeded the movement of *C. undecimpunctata* due to the high density of trichomes (e.g., Stavrinides and Skirvin 2003) or decreased the reactive distance to prey, or both. The type of functional response may represent the success of predators in biocontrol of aphids (Hughes *et al.*, 1992; Hodek and Honěk, 1996 and Lee and Kang, 2004). Although, the type of response was generally a type I in most of cases with a constant mortality rate regardless the prey density increased or not, this type of response might be turned to type II, on long-term, as the predator develops.

By increasing the total time of exposure and prey density, the number of killed prey items (i.e., attack rates)

increases with shorter handling time with each item (Holling, 1959). One reason to explain the increase in the number of killed aphids with increasing prey density is the higher encounter rates at higher prey densities. At higher prey densities, predators are more voracious and consume more preys than levels they probably required (Hodek and Honěk, 1996 and Omkar and Pervez, 2004). Thus, the increase in predator consumption with increasing in density of prey is more likely because hungry predators engorge the first prey items they capture, but with continuous increase in prey density they obtain small amounts of nutrients from each prey they encounter (Hodek and Honěk, 1996; Omkar and Pervez, 2004).

In this study, second instar *C. undecimpunctata* showed a lower handling time and higher attack rate both *A. craccivora* and *A. gossypii* than *C. carnea*, making the former predator more suitable for biocontrol. The best indicator describe the predation potential is handling time (*Th*). This parameter explains the cumulative time spent in capturing, killing, subduing, and digesting the prey, whereas attack rate (*a*) explains the effectiveness of a predator in prey killing. Based on the entire time of predator-prey exposure and the measured handling time (*T/Th*), we can expect the maximum number of preys that could be killed within a determined period. Thus, handling time may provide an indication of the number of predators that must be released in a space and time, based on their killing capacity, to achieve a good pest control. Based on our estimation of handling time, the highest number of prey that can be consumed by a single predatory larva during a day (a theoretical construct to satiation) was more than that measured empirically by the asymptotes of fitted curves for both prey species by both predator species. This may be because the expected number of prey that might be attacked is measured based on the actual time of feeding activity, without considering non-feeding activities (i.e., walking, drinking, resting) of predator, rather than the total time of exposure.

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الاستجابه الوظيفيه لمفترس ابو العيد ١١ نقطه ومفترس اسد المن الاخضر على حشرات المن تحت ظروف البيوت المحمية

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لتأسيس استراتيجيه للمكافحه الحيويه لحشرات المن فإنه يتطلب فهم التفاعلات الحادثه بين المفترس والفريسه. واحده من أهم الطرق المفيده لفهم هذه التفاعلات هو الاستجابه الوظيفيه. في هذه الدراسه قمنا بتقييم الفاعليه الافتراسيه بما يعبر عنها بالاستجابه الوظيفيه ومقاييسها المختلفه للعمر اليرقي الثاني لمفترس أبو العيد ١١ نقطه ومفترس أسد المن الأخضر على كلا من حشرة من البقوليات وحشرة من القطن تحت ظروف البيوت المحميه وذلك على كثافات تتراوح من ١ مفترس: ٢٠ فريسه الى ١ مفترس: ١٠٠ فريسه لكل قفص. بالنسبه لمن البقوليات فإن نسب الخفض في الفرائس المستهلكه بواسطة كلا من نوعين المقترسين للكثافات المختلفه من الفرائس توافق مع النموذج الثاني والنموذج الأول من الاستجابه الوظيفيه لمفترس أبو العيد ١١ نقطه ومفترس اسد المن الأخضر على التوالي. بينما ابدي كلا المقترسين نموذج استجابه من النوع الأول لحشرة من القطن. أوضحت تقدير مقاييس الاستجابه الوظيفيه أن مفترس اسد المن الأخضر كان لمعدل الهجوم الأعلى ووقت الأداء الأقصر على حشرة من البقوليات مقارنة بمعدل الهجوم الأقل ووقت الأداء الأطول لمفترس أبو العيد ١١ نقطه. بالنسبه لحشرة من القطن فإن معدل الهجوم كان الأعلى ووقت الأداء كان الأقصر لمقترس أبو العيد ١١ نقطه مقارنة بقيم مفترس أسد المن الأخضر. من الناحية النظريه فإن أقصى عدد من الفرائس يمكن للفرد الواحد من مفترس أبو العيد ١١ نقطه ومفترس اسد المن الأخضر أن يفترسها خلال ٢٤ ساعه كانت ١٨,٣١ و ٩,٣٠ فريسه من حشرة من القطن على التوالي، بينما كانت ٢٤,٨٩ و ١٩,٩١ فريسه من حشرة من القطن على التوالي. يعكس نموذج الاستجابة الوظيفيه إمكانية استخدام المفترسات في تنظيم تعدادات المن. بالرغم من ان نموذج الاستجابه الوظيفيه كان بصفه عامه لكلا نوعي المقترسات من النوع الأول، بما يعني معدل موت ثابت بصرف النظر عن كثافة الفريسه إزدادات او لم تزد، فإن هذا النوع من الاستجابه الوظيفيه (أي النموذج الأول) يمكن ان يتحول الى النموذج الثاني على المدي الطويل عندما يحدث استقرار للمفترس في البيوت المحميه.