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Original Article

Functional response estimations of *Chrysoperla carnea* to different densities of *Aphis craccivora* and *Gynaikothrips ficorum* nymphs

Estimativas da resposta funcional de *Chrysoperla carnea* em diferentes densidades de ninfas de *Aphis craccivora* e *Gynaikothrips ficorum*

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Abstract

The functional responses of *Chrysoperla carnea* larvae were evaluated at different seven densities of the 3rd instar nymphs of *Aphis craccivora* and *Gynaikothrips ficorum* in order to find out the relationship between predator densities and its prey by the, and also to find out their capability for biological control of aphids and thrips. Results revealed that all tested larval instars of *Ch. carnea* exhibited a type II response in relation to the prey. Moreover, the coefficients of attack rate (a) and handling time (T_h) was differed among various growing instars of predator and for the prey species. The 3rd instar larvae of *Ch. carnea* manifested the highest attacking rate (1.23 and 1.22) on the 3rd instar nymphs of *A. craccivora* and *G. ficorum*, respectively. In addition it exhibited the highest maximum predation (Na_{max}) (50.00 and 52.63) on *A. craccivora* and *G. ficorum* nymphs, respectively as compared with the other treatments. Accordingly, *Ch. carnea* could be considered as a promising bio-control agent for *A. craccivora* and *G. ficorum* management.

Keywords: *Chrysoperla carnea*, functional response, aphids, thrips, predation rate, biological control.

Resumo

As respostas funcionais de larvas de *Chrysoperla carnea* foram avaliadas em sete diferentes densidades de ninfas de 3º instar de *Aphis craccivora* e *Gynaikothrips ficorum*, a fim de descobrir a relação entre as densidades de predadores e suas presas, e sua capacidade de controle biológico de pulgões e tripes. Os resultados revelaram que todos os instares larvais testados de *Ch. carnea* apresentaram resposta de tipo II em relação à presa. Além disso, os coeficientes de taxa de ataque (a) e tempo de manejo (Th) diferiram entre os vários instares de crescimento do predador e para a espécie de presa. As larvas de 3º instar de *Ch. carnea* manifestaram a maior taxa de ataque (1,23 e 1,22) nas ninfas de 3º instar de *A. craccivora* e *G. ficorum*, respectivamente. Além disso, a maior taxa de predação máxima ($Na_{máx}$.) (50,00 e 52,63) apresentou-se em ninfas de *A. craccivora* e *G. ficorum*, respectivamente, em comparação aos demais tratamentos. Assim, é possível concluir que o *Ch. carnea* pode ser considerado um agente de biocontrole promissor para o manejo de *A. craccivora* e *G. ficorum*.

Palavras-chave: *Chrysoperla carnea*, resposta funcional, pulgões, tripes, taxa de predação, controle biológico.

1. Introduction

Predation is one of the main important factors for decreasing the insect pest populations. So that, the utilization of predators in insect pest management has got a lot of attention hoping to decrease the using of chemical pesticides (Atlihan et al., 2010). The important factor for the regulating of the population changes in predator-prey densities was predator's functional response. . It indicated the predator's efficiency against different prey densities (Murdoch and Oaten, 1975). The functional response of predator was classified to different types, Holling (1959, 1966) reported three types of functional response; I, (increasing the linear relationship), II (a decelerating curve) and III (a sigmoid relationship). The functional response curves can be detected by evaluating different parameters as well as coefficient of attack rate and handling time (time spent in attacking, killing, subduing and digesting). The coefficient of attack rate was estimated the increasing in the predation and the time needed for satiation. Pervez (2005) reported that the regression model was necessary for determining the functional response type.

Several factors were affect the functional response including the size of predator to its prey (Flinn et al., 1985),

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voracity (Rotheray, 1989), type of prey (Allahyari et al., 2004), the age of predator and the predacious stage (Farhadi et al., 2010). Moreover, Rotheray (1989) added other factors like as predator's density, time of day, capability of prey for defense and prey's density affect the efficiency and handling time of a predator. To reach successful control of many pest species, the used of predator's reaction to changes the prey density was extremely important. Additionally, Villa et al. (2016) stated that the *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae) larval stage feed on their prey species such as aphids (nymph and adults), while adults feed on nectar, pollen and honeydew. The ability of the predator to feed determined the effectiveness of biocontrol. (Sengonca et al., 2005) and the number of consumed prey/predator individuals depended on the prey density (Holling, 1959; Solomon, 1949). The variations in number of attacked prey density was called the functional response as that reported by Solomon (1949).

The thrips, *Gynaikothrips ficorum* (Marchal) (Phlaeothripidae) was a pan tropical thrips species feeding multiply in leaf–galls on leaves of *Ficus microcarpa* L. var. *nitida* (Alford, 2013), but in case of high abundance of *G. ficorum* can be fed on other hosts, particularly those of genus *Ficus*. According to Holling (1965), the functional response of *C. carnea* on *A. craccivora* constituted a critical factor to regulate the prey density. For this reason, the present study was implemented to find the type of functional response of the *C. carnea* larval instar when fed on different densities of the 3rd instar of *A. craccivora* and *G. ficorum* nymph under laboratory in order to assess the potential of *C. carnea* larvae against the two mentioned prey species.

2. Materials and Methods

2.1. Stock cultures of tested insect species

2.1.1. Aphis craccivora

First stock of *A. craccivora* individuals was provided on faba bean seedlings by Syngenta Company at Qaha district, Qalubiya Governorate. The obtained seedlings were taken to the laboratory of Insect Rearing at the Faculty of Agriculture at Moshtohor, Benha University for rearing of the aphid individuals on fresh grown faba bean seedlings. Faba bean seeds were sown at 1-2 cm depth in wet sawdust and placed in plastic trays (30 × 15 × 4 cm) or no. 10 pots. Containers were placed in cages covered by muslin screen (70 × 60 × 60 cm). Sawdust containing seeds was, daily, supplied with suitable amount of water until germination and the new seedlings become having 3 or 4 rows of leaves. Rearing of *A. craccivora* continued at 27 ± 1 °C. and 65 ± 5%RH. Old aphid infested faba bean leaves were cut and gently placed between the new seedlings to start aphid multiplying. The population of *Aphis gossypii* increased and gave the continuous needed supply of prey for feeding *C. carnea* larvae and achieving the desired experiments.

2.2. Stock cultures of Gynaikothrips ficorum

The infested *Ficus nitida* leaves with *G. ficorum* nymphs on small branches were handpicked from Ficus trees grown in the Faculty of Agriculture, Benha Univ and it were kept in small plastic containers. The 3rd instar of nymphs were selected for this experiment. For exposing the *G. ficorum* nymphs to *C. carnea* larvae, those were taken out from the folded leaves for selection of the 3rd instar nymphs which were used in this experiment.

2.3. The aphid lion, C. carnea

C. carnea were obtained from the Biological Control Research Laboratory at the Plant Protection Research Institute, Dokki, Giza. it was placed in. plastic containers (30 × 20 × 15 cm) covered by white pieces of muslin cloth. These larvae were released on *A. craccivora* infesting faba bean seedlings. Surviving of aphid individuals were daily added in each container to replace those consumed by the predaceous larvae. This process was continued until *C. carnea* cocoons formation. Using a soft brush, cocoons were separated, and placed in new plastic container covered with white pieces of muslin cloth until adults' emergence. Adults of *C. carnea* (10 males & 10 females) were placed in plastic containers of the same size as those used for *C. carnea* rearing but it was covered with a black cloth on which stalks of the deposited eggs were glued. Droplets of semi-artificial diet (2 gm. of dried active yeast + 1 gm. of honey + 1 mL. of distilled water) had been placed in the middle of the cloth cover using a sticker for adults' feeding. The pieces of black cloth were replaced daily by new ones. Eggs on cloth pieces were daily collected and placed in other plastic containers until hatching. The newly larvae were supplied with adequately numbers of *A. craccivora* individuals on fresh faba bean seedlings for feeding. So, enough quantities of the prey (aphid nymphs) and larvae of the predator (*C. carnea*) were always available for achieving the desired experiments.

3. Statistical Analysis

3.1. Functional response

The three *C. carnea* larval instars fed on 3rd instar nymphs of *A. craccivora* and *G. ficorum* were determined. The larvae were starved, individually, in vials for 24 hours before starting experiments (Nakamura, 1977). the 7th densities of *A. craccivora* and *G. ficorum* (10, 20, 40, 80, 90, 100, and 110) were experimented . The glass tubes were covered with muslin and kept under laboratory conditions (27 ± 1 °C and 65 ± 5 RH). After 24 hours, the numbers of *A. craccivora* and *G. ficorum* consumed by each of the three *C. carnea* larval instars were recorded by counting the number of remaining surviving prey nymphs in each tube. Five replicates of the experiment were performed.

Discrimination of the different types of functional response was exhibited by a particular instar of a predator to a particular prey species in order to fit the data to a particular Hollings' equation (Holling, 1959, 1966). For determining the type of functional response, a logistic regression model has been used as a tool taking into consideration the proportion of prey eaten (Na/N**0**) as a function of prey offered (N**0**) (Juliano, 2001). Therefore, data were fitted to the following polynomial function that describes the relationship between Na / N**0** and N**0** (Equation 1):

$$\frac{Na}{N_0} = \frac{\exp\left(\mathbf{P}_0 + \mathbf{P}_1 N_0 + P_2 N / + P_3 N_0^3\right.}{1 + \exp\left(P_0 + P_1 N_0 + P_2 N / + P_3 N_0^3\right.} \quad (1)$$

where: **P0** = Intercept; **P1** = Linear coefficient; **P2** = Quadratic coefficient; **P3** = Cubic coefficient; **Na** = Prey's number devoured; **N0** = Exposed prey, count.

The method of maximum likelihood has been estimated by a coefficient. If P1> 0 and P2< 0, the proportion of prey consumed is positively density dependent, thus describing a type III functional response. If P1<0, the proportion of prey consumed declines monotonically with the initial number of preys offered, thus describing a type II functional response (Juliano, 2001). The coefficients of polynomial logistic regression were also determined. After the determination of the shape of the curve, handling times and attack coefficients of a Type II response were estimated using Holling's disc equation modified after determination of the shape of the curve. The simplified Holling's equation, modified by reciprocal linear transformation (Livdahl and Stiven, 1983; Pervez, 2004a) as follows (Equation 2):

$$\text{Na} = \frac{a' \text{TNo}}{1 + a' T_h \text{ No}} \quad (2)$$

where: **Na** = Prey's number devoured; **No** = Exposed prey, count; **a'** = Rate of attack; **T_h** = Time taken for handling; **T** = Confinement time (24 hours).

4. Results

4.1. The functional response of C. carnea to aphid and thripsG. ficorum 3rd instar nymphs

The logistic regression for the three C. *carnea* larval instars had a significant linear parameter $P_1 < 0$ (Table 1) and the proportion of prey consumed by all predators declined with increasing prey density (Figures 1 and 2). Data suggested that all three of them exhibited a Type II response. According to the Holling disk equation, the functional response depending upon different factors was estimated such as (a), (T_h) and (Na_{max}) for each of the three *C. carnea* larval instars after being released on *A. craccivora* and *G. ficorum* 3rd instar nymphs.

4.2. On A. craccivora

Regarding the data in Table 1, the time taken for handling (T_h) was recorded during one day for one larva of the three larval instars of *C. carnea* predator, results revealed that the T_h was (0.063, 0.042, and 0.02 day) at the 1st, 2nd and 3rd larval instars, respectively. While, the attack rates were (1.29, 1.42 and 1.23) at the instar larvae 1st, 2nd and 3rd respectively, which indicate the ability of predator to search and predate a prey individual of the 3rd nymphal instar of *A. craccivora.* Moreover, the maximum predation rate (Na_{max}) during 24 h were 15.87, 23.81 and 50.00 nymphs for the 1st, 2nd and 3rd instars, respectively. Data confirmed the highest predation rate (a) and maximum

Table 1. Estimation values of attack rate (a), time taken for handling (T_h) and maximum predation (Na_{max}) of prey (*A. craccivora* and *G. ficorum*) eaten by different instars of *C. carnea*.

Prey	Instar of *C. carnea*	Parameter	Estimate	R^2	a	T_h	Maximum predation rate (Na_{max})
A. craccivora	1st	Constant (P_0)	4.6	0.995	1.29	0.063	15.87
		Linear (P_1)	-0.004				
		Quadratic (P_2)	0.319				
	2nd	Constant (P_0)	4.32	0.979	1.42	0.042	23.81
		Linear (P_1)	-0.007				
		Quadratic (P_2)	0.56				
	3rd	Constant (P_0)	0.106	0.995	1.23	0.02	50
		Linear (P_1)	-0.014				
		Quadratic (P_2)	1.139				
G. ficorum	1st	Constant (P_0)	5.9	0.973	1.87	0.06	16.66
		Linear (P_1)	-0.005				
		Quadratic (P_2)	0.368				
	2nd	Constant (P_0)	4.4	0.994	1.66	0.042	23.81
		Linear (P_1)	-0.008				
		Quadratic (P_2)	0.626				
	3rd	Constant (P_0)	0.189	0.993	1.22	0.019	52.63
		Linear (P_1)	-0.0137				
		Quadratic (P_2)	1.137				

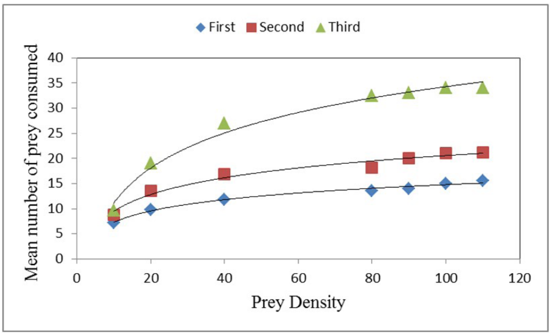

Figure 1. Functional response displayed by three larval instars of *C. carnea* to different prey densities (10, 20, 40, 80, 90,100 and 110 individuals) of 3rd nymphal instar of *A. craccivora*.

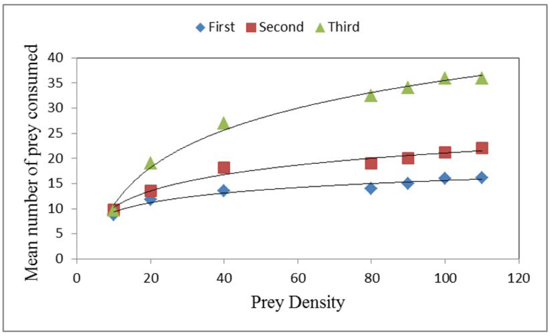

Figure 2. Functional response displayed by three larval instars of *C. carnea* to different prey densities (10, 20, 40, 80, 90,100, and 110 individuals) of the 3rd nymphal instar of *G. ficorum*.

predation (Na_{max}) during one day was stated with the 3rd larval instar of *C. carnea*.

4.3. On G. ficorum

The obtained results showed the handling (T_h) for each of the three larval instars of *C. carnea* being (0.06, 0.042 and 0.019 day) for 1st, 2nd and 3rd larval instars, respectively (Table 1) to search, predate and ingest one prey of *G. ficorum*. During one day of exposure, the attack rates (a) were (1.87, 1.66, and 1.22) at the instar larvae 1st, 2nd and 3rd, respectively. The maximum predation rate (Na_{max}) during 24 h was 16.66, 23.81 and 52.63 nymphs for each of the 3 larval instars, respectively. The maximum predation rate (a) during 24h occurred, also, by the 3rd larval instar of *C. carnea*.

Results indicated that consumption of prey individuals (aphid or thrips nymphs) weren increased by increasing the prey density (Table 2). The highest consumption rate by *C. carnea* 1st instar larva was (36.0 ± 0.89) of the 3rd instar nymphs of *G. ficorum* that occurred with the offered prey density was 110 individuals. On contrary, the lowest consumption rate was (7.2 ± 0.20) of the 1st instar nymphs of *A. craccivora* which counted with the lowest prey density (10 individuals). The three C. *carnea* larval instars manifested a type-II functional response in which consumption rate rised with prey density but gradually decelerated until a plateau is reached at which consumption rate remains constant irrespective of prey density (Figures 1 and 2).

This obtained results indicated that the time handling spent was prolonged as the offered prey density was

Table 2. Effects of prey type on functional response of *C. carnea* to *A. craccivora* and *G. ficorum* nymphs (Mean ± SE and LSD P>0.05 0.05).

Prey type	Density of prey	Mean number larval instars of *C. carnea* ± SE		
		1st larval instar	2nd larval instar	3rd larval instar
A. craccivora	10	7.2 ± 0.20^{eB}	8.8 ± 0.58^{eA}	9.6 ± 0.24^{dA}
	20	9.8 ± 0.20^{dC}	13.6 ± 0.24^{dB}	19.0 ± 0.32^{cA}
	40	11.8 ± 0.86^{cC}	16.8 ± 0.97^{cB}	32.0 ± 1.55^{bA}
	80	13.6 ± 1.21^{bcC}	18.2 ± 0.58^{bcB}	32.4 ± 0.87^{abA}
	90	14.0 ± 0.32^{abC}	20.0 ± 0.63^{abB}	33.0 ± 0.95^{abA}
	100	15.0 ± 0.95^{abC}	21.0 ± 0.63^{aB}	34.0 ± 2.28^{aA}
	110	15.6 ± 1.91^{aC}	21.2 ± 1.96^{aB}	34.0 ± 2.28^{aA}
LSD at 0.05 level			C*S	
		1.87		
G. ficorum	10	8.8 ± 0.58^{dA}	9.8 ± 0.20^{fA}	9.6 ± 0.24^{eA}
	20	11.8 ± 0.97^{cC}	13.6 ± 0.24^{eB}	19.0 ± 0.32^{dA}
	40	13.6 ± 1.21^{bC}	18.2 ± 0.58^{dB}	32.0 ± 1.55^{cA}
	80	14.0 ± 0.32^{bC}	19.0 ± 0.32^{cdB}	32.4 ± 0.87^{cA}
	90	15.0 ± 0.95^{abC}	20.0 ± 0.63^{bcB}	34.0 ± 2.28^{bA}
	100	16.0 ± 0.32^{aC}	21.2 ± 1.96^{abB}	36.0 ± 0.45^{aA}
	110	16.2 ± 0.20^{aC}	22.0 ± 0.95^{aB}	36.0 ± 0.89^{aA}
LSD at 0.05 level			C*S	
		1.55		

Means signed by the same lowercase letter was non-significant in the same column. While, means signed by the uppercase letter was non-significant in the same row at P>0.05.

increased. Thus, the amount of consumed *A. craccivora* or *G. ficorum* is limited by the time for handling the prey rather than by the availability of prey. *C. carnea* larval instars had similar attack rates on *A. craccivora* and *G. ficorum* nymphs, but the older predacious larvae (those of the third instar) had significantly the shortest handling time for consuming the prey than the earlier ones. It was noticed that the maximum attacking rate increased as the feeding predacious larvae grew older to subsequent instars.

5. Discussion

Regarding the obtained data, it was cleared that the functional response was the type II response, in which consumption rate increased by increasing the prey density, but the consumption rate gradually decelerated with prey density increasing until the consumption rate remains constant irrespective of prey density. The exposure time may had an effect on the predator/prey relationship, the number of *A. craccivora* and *G. ficorum* nymphs killed by *C. carnea* within 24 h achieved the functional response trend. In their studies, Atlýhan et al. (2004), reported that the attack rate was similar for the three *C. carnea* larval instars and the time taken for handling of the third instar was the shortest when the predacious larvae fed on nymphs of *Hyalopterus pruni.* Similarly,, previous authors found that the 3rd instar larvae of *C. carnea* were the highest active to attack *Hyalopterus pruni* (Atlýhan et al., 2004), *Myzus persicae* (Scopes, 1969), *Aphis gossypii* (Yuksel, 1992) and *Lipaphis erysimi* (Liu and Chen, 2001).

The numbers of *A. craccivora* and *G. ficorum* nymphs killed by *C. carnea* larva was increased with increasing prey density within 24 h whereas the highest consumption rate was up to 110 individuals. In agreement with the present study, the killed numbers of *H. pruni* nymphs by *C. carnea* were high value of 160 prey per day (Atlýhan et al., 2004) and 128 prey per day for *A. gossypii* individuals (Montoya-Alvarez et al., 2010).

Generally, it could be stated that the relative importance of *C. carnea* larvae as a valuable biocontrol agent against *A. craccivora* and *G. ficorum* can be changed depending on several factors as the composition of prey community and the size of prey (Guzman and Srivastava, 2019), trophic complexity (Jonsson et al., 2018) and the relative predator's feeding preference on prey or habitat complexity. Also, Guzman and Srivastava (2019) reported that the persistence of predators in the community was maximized when the minimum prey size was relatively intermediate, but as the prey diversity was increased, the minimum body size of prey may appear of broader value.

6. Conclusions

Obtained data in the present work showed the feeding potentiality of *C. carnea* larva against young prey individuals, and inversely, the ability of *A. craccivora* and *G. ficorum* nymphs as food source for this predator at the available laboratory conditions. This subsequently led to new queries about these interactions in more complex systems. Maximal values for the attack rate coefficient were obtained by the 3rd larval instar of C. *carnea*, followed by 2nd and 1st larval instars. The shortest T_h was exhibited by 3rd larval instar of *C. carnea* released on *A. craccivora* and *G. ficorum* nymphs. From the evidence of functional response curves, the coefficient of attack rates and handling time, C. *carnea* could be an efficient biocontrol agent. *C. carnea* had the potential to be successfully exploited as a biocontrol agent for the management of *G. ficorum* and *A. craccivora* infestations, however, further field-based studies are needed.

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