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Effect of Prey Resource on the Fitness of the Predator, *Chrysoperla carnea* (Neuroptera: Chrysopidae)

Rabia Saeed[1] and Muhammad Razaq[2*]

[1]*Entomology Department, Central Cotton Research Institute (CCRI), Old Shujaabad Road, Multan, Pakistan*
[2]*Department of Entomology, Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University, Multan,60800, Pakistan*

Abstract.- Host quality is one of the important factors affecting the life-history traits of predators. Here, we examined the development and reproductive responses of the green lacewing, *Chrysoperla carnea* (Stephens) to all life stages [1st through 5th instar nymphs (N1-N5) and adult] of the cotton jassid, *Amrasca devastans* (Dist.) (Homoptera: Cicadellidae). *C. carnea* larvae consumed more N2 than any other *A. devastans* life stage. Older life stages of the predator displayed higher rates of predation than younger ones. Larvae completed development on each of *A. devastans* life stages. However, the developmental time from egg hatch to adult eclosion was shortest on N3 and longest on the adult. *C. carnea* survival to the adult stage was the highest on N3, and lowest on adult *A. devastans*. Pupal weight (mg) and egg volume (mm^3) was lowest on adult *A. devastans.* Fecundity and egg hatching was highest when females had been reared on N3 *A. devastans*. The net replacement rate was lowest for the populations reared on N5 and adult *A. devastans*; these prey regimens also resulted in the lowest intrinsic (r_m) and finite (λ) rates of population increase. The mean relative growth rate showed significantly positive correlations with intrinsic (r_m) and finite (λ) rates of population increase, while a negative correlation was found with generation doubling time (DT). The results illustrate the potential importance of prey resources (life stage) on *C. carnea* population growth, and they indicate that *C. carnea* has considerable potential for the biological control of *A. devastans*.

Key words: *Chrysoperla carnea*, development time, intrinsic rate of population increase, *Amrasca devastans.*

INTRODUCTION

Introduction and release of predatory insects accounts for up to one third of the successful bio-control programs in the world. Among the predacious insects, the aphid lion, *Chrysoperla carnea* (Stephens) (Chrysopidae: Neuroptera) is one of the widely distributed, and most frequently used species (Athhan *et al*., 2004). It is a polyphagous carnivore present in agricultural crops, such as cotton (Mallah *et al*., 2001), brassicaceous oilseeds (Aslam and Razaq, 2007), and okra (Saeed *et al*., 2015). *C. carnea* adults feed on pollen, nectar and honeydew, while larvae are voracious predators of a wide variety of plant pests such as aphids, whiteflies, leaf miners, psyllids, thrips and caterpillars (Mansoor *et al.*, 2013; Syed *et al.*, 2005; Youksel and Gocmen, 1992). This predator's adaptation to diverse environments, broad range of prey, high ability to find prey, and high resistance to commonly applied insecticides make it a valuable biological control agent (Sablon *et al*., 2013). *C. carnea* has high reproductive rates, short developmental times, is easy to mass rear, and can be successfully used in biocontrol programmes in areas where insecticides are still a key pest management tool like in Pakistan (Mansoor *et al*., 2013).

The leaf hopper, *Amrasca devastans* (Dist.) (Homoptera: Cicadellidae) is a key pest of cotton in the Indo-Pak subcontinent (Ahmad, 1999). Besides cotton it also damages Malvaceous and Solanaceous crops. Both nymphs and adults of *A. devastans* suck the sap and inject phytotoxic saliva into the plant tissues resulting in crinkled leaves and shedding of squares and bolls; severe infestation may cause complete crop failure (Huque *et al*., 1994). Its ability to survive on a wide range of alternative hosts, short life cycle, destruction of biological control agents due to insecticides in its host crops, and development of resistance to chemicals made the management of this pest a formidable problem (Ahmad *et al*., 1999; Akbar *et al*., 2012; Saeed *et al.*, 2015). Due to harmful effects of pesticides, biological control should be considered as recourse

* Corresponding author: muhammadrazaq@bzu.edu.pk , mrazaq_2000@yahoo.com
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in integrated pest management (IPM) for managing *A. devastans*. Previous studies gave evidence that *C. carnea* use *A. devastans* as prey (Syed *et al*., 2005). Because prey quality including developmental stages can affect the survival, longevity and fecundity, and thus fitness of predators (Jokar and Zarabi, 2012; Godin and McDonough, 2002; Saeed *et al.*, 2010), the impact of *A. devastans* as prey on the biology of *C. carnea* should be evaluated before making inundative releases in the field. In this study we report for the first time the effect of *A. devastans* as prey on the development and reproduction of *C. carnea*, and we also evaluated the intrinsic (r_m) and finite (λ) rates of population increase.

MATERIALS AND METHODS

Insect rearing

A culture of *C. carnea* was obtained from the biological control laboratory of the Central Cotton Research Institute (CCRI) (Multan, Pakistan). The predator was reared using the methods of Sattar (2010). *Amrasca devastans* was reared on cotton plants, *G. hirsutum* L., in cages with dimensions of 45 × 30 × 12 cm. Stock cultures of both prey and predator were maintained at 25±2°C and 65±5% R.H. and photoperiod of 16 L:8 D. Voucher specimens for the both the predator and prey have been deposited in the laboratory of Entomology Section CCRI, Multan (Pakistan).

Predation rate

Fixed numbers of various developmental stages of prey *A. devastans* were offered to *C. carna* instars in petri dishes (5cm diameter). Treatment diets consisted of all nymphal stages *i.e.* 1st instar (N1) to 5th instar (N5) and the adult stages of *A. devastans*; each treatment had six replicates. Each *C. carnea* first instar (L1) received 20 N1, 20 N2, 20 N3, 15 N4, 10 N5 and 10 adult nymphs; each second instar (L2) received 50 N1, 50 N2, 50 N3, 30 N4, 20 N5, and 15 adult nymphs; and each third instar (L3) received, 150 N1, 150 N2, 150 N3, 50 N4, 30 N5 and 20 adult nymphs. Each petridish had a cotton leaf disc (5cm) with moistened filter paper. At the end of each 24 hour period, the numbers of prey remaining were recorded.

Survival and development of immature C. carnea

To determine effect of *A. devastans* on developmental time, *C. carnea* was first reared for a generation on *A. devastans*. The purpose was to eliminate the effect of previous host because our culture originated from a culture that had been reared on *Sitotroga cerealla* (Olivier). Subsequent treatment diets were N1, N2, N3, N4, N5 and adult life stages of *A. devastans*. A fixed quantity (n= 30 per replicate per stage) of each diet was provided to individual larvae in petri dishes (see section 2.2); there were n = 25 replicate larvae per treatment. A neonate *C. carnea* larva of F_2 generation was released into each petridish and the larval diet was replaced daily. We recorded survival and the developmental period for each instar and also the pupae.

C. carnea *reproduction*

Five pairs of adults that had been reared on each of the above treatment diets were placed in individual glass jars (16 X 23 cm) with napiliner strips for egg laying; they were fed honey solution. Numbers of eggs laid in each jar were noted daily and transferred to separate petri dishes to determine the rate of hatching. Hatching of eggs took place usually in 3-4 days. Egg volume was calculated using the formula previously employed by Ito (1997).

$$\text{Volume} = \frac{4}{3}\pi\left(\frac{l}{2}\right)\times\left(\frac{h}{2}\right)^2$$

where "*l* " and "*h*" are egg length and width respectively.

Growth rate

Twenty larvae of first instar were randomly taken from colonies fed on each treatment diet (see 2.3) and weighed, using an electric balance. These larvae were fed with their respective prey life stages until pupation, and then they were weighed again.

We used the following formula (Radford, 1967) to calculate mean relative growth rate (MRGR):

$$\text{MRGR} = [\ln W_2\ (\text{mg}) - \ln W_1\ (\text{mg})] / T$$

where W_1 is initial larva weight, W_2 is pupal weight and T is time in days, from first instar to the pupae

Intrinsic and finite rates of population increase and doubling time

The net replacement rate (R_0) was calculated by following formula previously employed by Sayyed and Wright (2001) and Saeed *et al.*, (2010):

$$R_0 = (n \times Ie \times Ia)/2$$

where n is means number of eggs per female, Ie is fraction of fertile eggs, Ia is fraction of eclosing adults and 2 is sex ratio coefficient.

The intrinsic rate of population increase (r_m) was then calculated by using net replacement rate (Birch, 1948):

$$r_m = (\ln R_0) / T$$

where ln is natural logarithm of a number, Ro is net replacement rate and T is total developmental time (egg to adult eclosion).

Further, finite rate of population increase (λ) and doubling time (DT) were calculated by using intrinsic rate of increase (Jokar and Zarabi, 2012).

$$\lambda = e^{rm}$$

where e is exponent of a given number and r_m is intrinsic rate of population increase.

$$DT = (\ln 2)/r_m)$$

where ln is natural logarithm of a number and r_m is intrinsic rate of population increase.

Statistical analysis

The data were analyzed using GenStat Statistical Package, version 15 (VSN International, Hemel Hempstead, U.K.). We compared means of variables with least significant difference test (LSD) at ($P < 0.05$).

RESULTS

Predatory potential

Chrysoperla carnea showed a significant response to the different developmental stages of prey (*A. devastans*) ($F = 6.18$; df= 5; $P = < 0.001$). Predation on adult *A. devastans* was lowest compared to other stages of prey. However, predation of N2 was the highest, followed by N3 and N1. There were significant differences among the predatory potential or consumption rate of *C. carnea* larval instars. Third instar larvae (L3) of *C. carnea* consumed the largest number of prey in all life stages when compared to L1 and L2 larvae of *C. carnea* (Table I).

Development and survival of immature stages

The developmental period of *C. carnea* from egg to pupation was significantly affected by feeding on different stages of *A. devastans* ($F = 96.20$; df= 5; $P = < 0.001$). The larvae of *C. carnea* fed on N3 prey developed faster (first instar to adult with total duration of 16.72 days), had greater pupal body weight (11.62 mg) and a higher survival rate (96%) than those on other life stages. All of these variables were negatively affected when larvae were reared on adult prey (Table II).

Chrysoperla carnea reproduction

Females of *C. carnea* whose larvae were fed on N3 prey had longer periods of oviposition and shorter pre-oviposition and post oviposition periods (Table III). However, shorter oviposition (5.0 days) with longer pre-oviposition (8.8 days) and post oviposition (7.8 days) periods were observed from those fed on adult prey. Incubation period of eggs was less whereas mean numbers of eggs (322), their viability and volume laid by females emerged from larvae fed on N3 prey were greater than those reared on other life stages (Table III).

Population growth traits

Net replacement rate or net reproductive and intrinsic rate of increase of *C. carnea* were lower when larvae were reared on adult *A. devastans*. The mean relative growth rate was higher for the larvae fed on N3 prey than those reared on other developmental stages. It was also observed that generation doubling time was highest for the population reared on adult prey (Table IV). We noted significant relationship between intrinsic rate of increase and mean relative growth rate ($t = 573$, d.f. 5, $P < 0.01$). Mean relative growth rate was positiviely correlated with intrinsic rate of increase ($r^2 = 0.99$, d.f. 5, $P < 0.01$) and finite rate of increase ($r^2 = 0.98$, d.f. 5, $P < 0.01$). While mean relative growth rate showed negative correlation with generation doubling time ($r^2 = -0.93$, d.f. 5, $P<0.01$).

Table I.- Predatory potential of *Chrysoperla carnea* immature stages on various life stages of *Amrasca devastans*

C. carnea larvae[§]	Prey stages (mean number consumed)[+]					
	N1	**N2**	**N3**	**N4**	**N5**	**Adult**
L1	11.00 c	16.17 c	13.67 c	6.67 c	3.00 c	2.17 c
L2	93.00 b	99.33 b	95.00 b	41.67 b	21.33 b	14.33 b
L3	515.00 a	581.67 a	551.00 a	132.00 a	64.00 a	36.00 a
LSD 5%	10.03	32.49	25.25	8.91	7.93	6.06
P-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Means in columns followed by the same letter are not significantly different by LSD <0.05
[§]L1, L2 and L3 represents 1st instar, 2nd instar and third instar larvae of predator *C. carnea*
[+]NI, N2, N3, N4 and N5 represent 1st instar, 2nd instar, 3rd instar, 4th instar and 5th instar nymph of prey *A. devastans*

DISCUSSION

Life history traits and feeding efficiencies of insects are considerably affected by host resource value or quality (Hagley and Barber, 1992; Uckan and Gulel, 2000; Sattar and Abro, 2009). In the present study, *C. carnea* response to prey quality varied significantly with maximum predation on N2 followed by N3 *A. devastans*. Low consumption of N4, N5 and adult prey stages might be due to the fact that they are very active and require more handling time as compared to other prey stages. Third instar larvae *carnea* have been reported to be more voracious against *Bemisia tabaci*, *Aphis gossypii*, *A. devastan* and *P. solenopsis* than other larval instars of the predator (Solangi *et al*., 2013). In another study on predatory potential of *C. carnea* against mealy bug, *Phenacoccus solenopsis*, a lower number of adults were consumed compared to younger prey stages (Huang and Enkegaard, 2010).

In the present study the consumption rate of L3 *C. carnea* was higher than that of L1 and L2; this may be due to their larger size and higher dietary requirements (Atthan *et al*., 2004; Ulhaq *et al*., 2006, Sattar *et al*., 2007). Youksel and Gocmen (1992) also showed higher aphid consumption by L3 *C. carnea* than other stages.

Developmental times and reproductive rates in insects are indicators of the quality of larval diets (Saeed *et al*., 2010). Therefore these parameters can be employed to determine suitability of prey stages in supporting predator life cycles. In the present study the developmental stages of prey had a profound impact on developmental period of *C. carnea*. Shortest larval and pupal period was found on N3 prey while longest on adult *A. devastans* indicating that larval food significantly affected the length of developmental period. This has been also recorded previously for *C. carnea* when reared on natural and artificial diets (Sattar *et al*., 2011). In addition to variations in development there were marked differences in survival of larvae fed on different stages of prey *A. devastans*. Survival rate was higher when the predator larvae fed on N3 prey than other life stages of prey.

In the current study third instar (N3) *A. devastans* was found to be better prey for *C. carnea* for several reasons. First, the developmental period was shorter compared with other developmental stages of *A. devastans*. Second, because the relationship between pupal weight and fecundity is well documented for insects (*e.g*., Barah and Sengupta, 1991; Blackmore and Lord, 2000), it was not unexpected that the higher pupal weights in *C. carnea* reared on third instar (N3) *A. devastans* will result in higher rates of oviposition. Indeed, in the present study, greater adult longevity occurred when *C. carnea* larvae were reared on N3 *A. devastans*, and this response was associated with longer oviposition period and significantly higher number of eggs laid per female.

Given our results, host quality should be expected to influence population growth traits of *C. carnea*. Intrinsic or finite rates of population increase are key measures of population growth (Varley and Gradwell, 1970). We recorded a positive correlation between intrinsic rate of increase and mean relative growth rate that reflects

Table II.- Effect of *Amrasca devastans* life stages on different life traits (± SE) of *Chrysoperla carnea.*

Prey stages[+]	Developmental period (Days) of *Chrysoperla carnea*						Pupal weight (mg)	% Survival
	First larval instar	Second larval Instar	Third larval Instar	Total larval period	Pupal period	Total developmental period		
N1	3.32 ± 0.10 a	5.08 ± 0.12 c	7.32 ± 0.13 ab	15.72 ± 0.20 b	7.28 ± 0.21 c	23.00 ± 0.26 c	7.60 ± 0.51 d	78 ± 0.50 c
N2	2.32 ± 0.10 b	4.08 ± 0.11 d	5.60 ± 0.14 d	12.00 ± 0.25 d	6.16 ± 0.25 d	18.16 ± 0.25 e	10.00 ± 0.23 b	90 ± 0.76 b
N3	1.84 ± 0.08 c	3.88 ± 0.07 d	5.40 ± 0.03 d	11.12 ± 0.12 e	5.60 ± 0.12 e	16.72 ± 0.24 f	11.62 ± 0.20 a	96 ± 0.57 a
N4	3.32 ± 0.14 a	5.20 ± 0.12 c	6.48 ± 0.16 c	15.00 ± 0.31 c	6.96 ± 0.31 c	21.96 ± 0.36 d	8.50 ± 0.29 c	82 ± 0.50 c
N5	3.44 ± 0.15 a	5.80 ± 0.20 b	7.00 ± 0.19 b	16.24 ± 0.35 b	8.72 ± 0.35 b	24.96 ± 0.36 b	6.00 ± 0.25 e	70 ± 0.58 d
Adult	3.60 ± 0.14 a	6.28 ± 0.18 a	7.48 ± 0.20 a	17.36 ± 0.23 a	9.32 ± 0.23 a	26.68 ± 0.32 a	4.10 ± 0.03 f	62± 0.29 e
LSD 5%	0.33	0.39	0.43	0.70	0.43	0.83	0.78	3.90
P-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

[+]NI, N2, N3, N4 and N5 represent 1st instar, 2nd instar, 3rd instar, 4th instar and 5th instar nymph of prey *A. devastans*
Means in columns followed by the same letter are not significantly different by LSD <0.05

Table III.- Effect of *Amrasca devastans* life stages on reproductive traits (± SE) of *Chrysoperla carnea.*

Prey stages[+]	Reproductive traits of *Chrysoperla carnea*					Fecundity	% Viability
	Pre Oviposition period (Days)	Oviposition period (Days)	Post oviposition period (Days)	Incubation period (Days)	Egg volume (mm^3)		
N1	5.00 ± 0.29 c	11.0 ± 0.50 c	5.67 ± 0.25 b	3.20 ± 0.08 c	0.16×10^{-4}c	156 ± 0.29 d	70.0 ± 0.58 d
N2	3.67 ± 0.25 d	17.3 ± 0.25 b	3.33 ± 0.10 c	2.48 ± 0.10 d	0.18×10^{-4}b	280 ± 0.50 b	86.0 ± 0.50 b
N3	2.20 ± 0.00 e	19.2 ± 0.67 a	1.60 ± 0.25 d	2.00 ± 0.02 e	0.20×10^{-4} a	322 ± 0.29 a	92.3 ± 0.25 a
N4	4.20 ± 0.29 cd	16.8 ± 0.09 b	3.80 ± 0.10 c	3.04 ± 0.04 c	0.17×10^{-4}c	207 ± 0.19 c	75.7 ± 0.51 c
N5	6.67 ± 0.51 b	9.0 ± 0.29 d	5.67 ± 0.09 b	3.52 ± 0.13 b	0.15×10^{-4} d	117 ± 0.51 e	66.0 ± 1.00 e
Adult	8.80 ± 0.09 a	5.0 ± 0.29 e	7.80 ± 0.25 a	3.96 ± 0.14 a	0.15×10^{-4} d	79 ± 0.25 f	53.0 ± 0.29 f
LSD 5%	1.08	0.88	1.05	0.27	0.008×10^{-4}	1.89	1.92
P-value	< 0.001	< 0.001	< 0.001	< 0.001	<0.001	< 0.001	< 0.001

[+]NI, N2, N3, N4 and N5 represent 1st instar, 2nd instar, 3rd instar, 4th instar and 5th instar nymph of prey *A. devastans*
Means in columns followed by the same letter are not significantly different by LSD <0.05

Table IV.- Population growth traits of *Chrysoperla carnea* on various life stages of *Amrasca devastans.*

Prey stages[+]	Growth traits of *Chrysoperla carnea*				
	Net replacement rate (R^0 per generation)	Mean relative growth rate (MRGR)	Intrinsic rate of increase (r_m)	Finite rate of increase (λ)	Doubling time (DT)
N1	85.18	0.26	0.20	1.22	3.41
N2	216.73	0.34	0.29	1.34	2.34
N3	285.79	0.44	0.34	1.40	2.04
N4	129.04	0.28	0.22	1.25	3.12
N5	54.17	0.19	0.16	1.17	4.32
Adult	26.16	0.16	0.12	1.13	5.64

[+]NI, N2, N3, N4 and N5 represent 1st instar, 2nd instar, 3rd instar, 4th instar and 5th instar nymph of prey *A. devastans*

the potential of N3 nymphs of *A. devastans* to favour *C. carnea* populations. Net reproductive rate was the highest in *C. carnea* larvae that fed on N3, which is the measure of population growth potential. A faster developmental time may also reduce the generation time (Saeed *et al*., 2010). We found a negative correlation between mean relative growth rate and generation doubling time. Therefore based upon the developmental time and other life-history responses, we can arrange the six stages of *A. devastans* in ascending order of host suitability: N3>N2>N4>N1>N5> Adult.

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