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Original article

Foraging behaviour of *Scymnus coccivora* Ayyar against cotton mealybug *Phenacoccus solenopsis* Tinsley

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ABSTRACT

Predation is one of the significant biotic mortality factors reducing the insect pest population as functional response and the numerical response of the predator are the key factor regulating the population dynamics of predator prey species. This study is aimed to evaluate the functional response of all the developmental stages of *Scymnus coccivora* Ayyar (Coleoptera: Coccinellidae) against the different densities of cotton mealybug, *Phenacoccus solenopsis* (Tinsley) (Hemiptera: Pseudococcidae) and the numerical response of female predator. Experiments were carried out in controlled environment laboratory conditions at 25 ± 1 °C temperature, 60 ± 5% relative humidity and photoperiod of 16 h. Number of eggs consumed, number of eggs laid and the Efficiency of Conversion of Ingested food (ECI) were recorded daily. Results from the study revealed that all the developmental stages of *S. coccivora* exhibited a Type II response. Different parameters such as attack rate (a'), handling time (T_h) and the maximum rate of predation were estimated using Roger's random attack equation and Holling Disc equation in which Rogers random attack equation was found best fit. Female has shown the highest attack rate (a') followed by IVth instar grub, male, IIIrd, IInd and Ist instar grub. With low handling time, IVth instar grub has shown maximum predation rate of 76.40 per day followed by female (75.86), male (58.79), IIIrd (22.84), IInd (19.65) and Ist instar grub (15.39). The numerical response increase was curvilinearly related to different prey densities with the highest number of eggs (11.8 ± 3.44) produced at highest prey density (160). The Efficiency of Conversion of Ingested food (ECI) was highest (64.49 ± 8.03) at prey density of 10. Understanding the factors that lead to variation in functional response of predator in natural population will advance our understanding of the effects of predation on individual and the effectiveness of coccinellid predators as biocontrol agent against cotton mealybug.

1. Introduction

Insect pest management on different crops has become a matter of great concern. Most of the farmers are relying on different kinds of toxic pesticides for controlling insect pests without knowing the harmful effects of these chemicals. Although, these chemicals control insect pests but, it badly affects our ecosystem directly and indirectly. There are so many alternative ways to manage the attack of insect pests on different crops. We can employ biological control by thriving on several natural enemies *viz.*, entomopathogens, parasitoids and predators for eco-friendly insect pest management. Among biological control agents, predators play an important role in managing dreaded insect pests because of their generalist nature. The members belonging to Coccinellidae are called as ladybird beetles. The ladybird beetle family Coccinellidae comprises approximately 6000 described species in about 360 genera and 42 tribes (Hodek et al., 2012). Coccinellid beetles are important predators in agricultural crops and have been used as biological control agents against a number of sucking pests

Abbreviations: ICAR-IARI, Indian Council of Agricultural Research-Indian Agricultural Research Institute; Temp, Temperature; RH, Relative Humidity; AIC, Akakia's Information Criterion.

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viz., aphids, mealybugs, scales and whiteflies because of their wider adaptability (Hodek and Honek, 1996). Coccinellids provide an important ecosystem services as an ecological indicator and biocontrol agents of key insect pests. Coccinellid communities across the globe have experienced significant changes in recent decades leading to worldwide decline of several native species calls for sustain research in the form of augmentative biological control for their revival in crop ecosystem.

The ladybird beetle**,** *Scymnus coccivora* Ayyar (Coleoptera: Coccinellidae) is a coccidophagous predator predominantly feeding on cotton mealybug, *Phenacoccus solenopsis Tinsley* (Hemiptera: Pseudococcidae). This beetle was introduced into the Caribbean mainly to control hibiscus mealybug (*Maconellicoccus hirsutus* (Green) (Williams, 1996). This ladybird beetle is widely distributed in India, Pakistan, Sri Lanka, Thailand and Malaysia. It is being collected throughout the year all over the country. It has caused substantial control of sucking pests in general and mealybugs in particular (Mani and Krishnamoorthy, 2008).

Cotton mealybug, *P. solenopsis* widely distributed and originated in Central America (Williams and Willink, 1992; Fuchs et al., 1991) and regarded as an exotic species in South East Asia. It is a polyphagous soft bodied and sap sucking insect considered as most serious and invasive pest of cotton in Pakistan and India (Hodgson et al., 2008). It has already caused severe yield loss of cotton in Punjab, Haryana, Rajasthan, Gujarat, Madhya Pradesh, Maharashtra, Andhra Pradesh, Karnataka, and Tamil Nadu (Fand et al., 2013; Suroshe et al., 2016) states in India during 2008–09. Cotton mealybug infestation results into the lower number of cotton bolls per plant and reduce the cotton seed yield by 44% (Dhawan et al., 2007). Lots of effective pesticides are in offing against this mealybug, but their overuse for the long time might leads to insecticide resistance, pest resurgence and residues on crops. Hence, there is a strong need to explore other options in the form of coccinellid predators for the augmentative biological control of *P. solenopsis*.

Predator effectively feeds on different density of prey and also increases its mass number which is termed as foraging behavior. Functional response and numerical response are the two most important components which determine the predator–prey relationship. Functional response describes how the predation rate changes with the change in prey density. When different life stages of a predator are exposed against a different prey density, a difference in feeding rate is noticed at every level (Venkanna et al., 2021). And these differences in feeding rate describe different types of functional response. Generally, functional response is of three types (Holling, 1966; Trexler et al., 1988) *viz.*, Type I, Type II and Type III. Type I functional response shows linear curve explaining that the number of prey consumed by the predator is directly proportional to the total prey density. Type II functional response has curvilinear curve describing that, initially predation rate increases with increasing prey density, but after getting saturation, the predation rate decreased. Type III functional response shows S-shaped curve having no any relation between predation rate and prey density (Pervez and Omkar, 2005). Coccinellid predators mostly exhibit Type II functional response. Functional response studies let us know the predation rate of a predator for effective biological control of specific prey.

Numerical response is described as the reproduction rate of female predator at different prey densities (Holling, 1959). This response plays an important role to determine the effectiveness of any Coccinellid predator. Reproduction rate normally increases with the increase in predation rate. This is the reason both the responses are related to each other (Beddington et al., 1976).

Present studies were conducted to determine the effectiveness of different grub instars, male and female of *S. coccivora* against the cotton mealybug, *P. solenopsis*. This was achieved by evaluating the number of prey consumed by each life stage of *S. coccivora* against the different densities of cotton mealybug, *P. solenopsis*.

2. Materials and methods

2.1. Rearing of *P. solenopsis*

Gravid females of cotton mealybug, *P. solenopsis* were collected from the cotton fields of Indian Agricultural Research Institute, PUSA, New Delhi. All these mealybugs were kept in a jar containing sprouted potatoes in the laboratory. The mouth of a jar was covered with muslin cloth and tied with rubber band. The culture of *P. solenopsis* was maintained at 25 ± 1 °C temp, 65 ± 5% RH and a photoperiod of 16:8 (L: D) hours. This population was maintained as stock culture throughout the experimental study.

2.2. Rearing of *S. coccivora*

Male and female pairs of *S. coccivora* were collected from the cotton fields infested with cotton mealybug, *P. solenopsis* at IARI, PUSA, New Delhi. All these pairs were reared in plastic jars having sprouted potatoes infested with cotton mealybug. Blotting sheet was put at the bottom of the jar for soaking moisture and honey dew. The mouth of a jar was covered with muslin cloth and tied with rubber band. Adult mating, egg laying and emergence of first instar grub were allowed in the same jar. After molting of first instar grubs, second instar grubs were separated from that jar to avoid cannibalism. Each second instar grub was transferred with camel hair brush into the individual Petri dish (200 × 20 mm) containing cotton leaf substrate provided with sufficient mixed population of cotton mealybug as food. Fresh cotton leaves were collected from the cotton fields and the base of petiole was cut. The cut end was inserted into the Petri dish (200 × 20 mm) having the solidified agar solution (2%) to keep the leaves fresh and tender for longer time. Every day, fresh mealybugs were added in the Petri dish till the emergence of adults from the grubs. The newly emerged adults were transferred in the jars having sprouted potatoes infested with cotton mealybug. The culture of *S. coccivora* was maintained at controlled conditions as given above.

2.3. Functional response study

This study was conducted in the Biological Control Laboratory, Division of Entomology, ICAR-IARI, at controlled laboratory conditions (25 ± 1 °C temp, 60 ± 5% RH and photoperiod of 16 h). About 5 ml of agar media (2%) was poured at one side of petri dish (200 × 20 mm) by keeping petri dish in tilted position for solidification of Agar. Fresh collected cotton leaf was kept upside down in the Petri dish by inserting cut end of petiole in agar media to keep the leaf fresh. Third instar nymphs of *P. solenopsis* having different densities were gently transferred using camel hair brush on to the leaf and allowed to settle. The densities of third instar nymphs used were as *viz.*, 5, 10, 15, 20, 25, 30, and 35 for 1st instar grub; 6, 12, 15, 20, 25, 30 and 35 for 2nd instar grub; 5, 10, 15, 20, 30, 40 and 50 for 3rd instar grub; 10, 20, 40, 80, 160 and 320 for 4th instar grub, female and male. Each instar grub, male and female of *S. coccivora* was released individually on to the different densities of prey and allowed to feed for 24 h. After 24 h, the remaining number of prey population was counted. Ten replicates were maintained for each prey density and one was kept without predator as control to observe the natural mortality of cotton mealybug. To standardize the level of hunger for predator, first instar grub was released on to prey immediately after hatching; whereas, second instar was pre-starved for 6 h, third instar for 12 h and fourth instar for 18 h. For adults, 5–7 days old beetles of both sexes were selected and pre-starved for 24 h before releasing. Number of prey eaten was arrived by the deduction of the number of prey remained plus the number of control mortality from the number of prey provided. Prey density was arrived by deducting the number of control mortality from the number of prey provided.

2.3.1. Data analysis

The type of functional response was determined by using polynomial logistic regression analysis [SAS/STAT, CATMOD procedure (SAS version 9.1)]. The proportion of killed prey (Ne) in relation to initial prey density (N_0) (Trexler and Travis, 1993) was calculated and the data found was fitted to the logistic regression to get the relationship between N_a/N_0 and N_0 by applying the equation (Juliano, 2001).

$$\frac{Ne}{N0} = \exp\left(\frac{P^{0} + P^{1}N^{0} + P^{2}N_0^2}{1 + \exp(P^{0} + P^{1}N^{0} + P^{2}N_0^2)}\right)$$

where,

N_e is the number of prey eaten, N_0 is the prey density, P_1 and P_2 are the parameters to be estimated. If the linear parameter P_1 is negative, a type II functional response is considered, whereas, a positive linear parameter P_2 represents a type III functional response having density-dependent predation (Juliano, 2001). After arriving at Type-II functional response, different parameters such as attack rate (*a*') or searching efficiency, handling time (T_h) and maximum rate of predation (T/T_h) were estimated by using equations *viz.,* the Holling's disc equation (Holling, 1959) and the Rogers random equation (Rogers, 1972). These equations are given as follows:

Holling's Disc equation: $Na = \frac{a'TN0}{1+a'ThN0}$

Rogers random equation: $Na = N_0(1-e^{a(NaTh)})$

where:

Na – the number of prey eaten;

N_0 – the number of prey offered;

T – the total time available for the predator;

a′ – the searching efficiency and

Th – is the handling time.

Statistical analysis was performed using R software (R-Core Team, 2018) by using Functional Response Analysis in R (FRAIR) package (Pritchard et al., 2017) for the estimation of all the parameters of functional responses. A nonlinear regression was used for the estimation of predator handling time and searching efficiency. The regression analysis was performed for both Holling's Disc equation and Rogers random attack equation for type-II functional response analysis. Between these two models, the best fit and preference was determined by Akakia's Information Criterion (AICs). As these models use maximum likelihood method, the model is considered better fit if its respective AIC values are smaller than that of other model.

2.4. Numerical response study

Mated female beetles (5–7 days old) were starved for 24 h prior to experimentation. These pre-starved females were released individually at different densities of third instar cotton mealybug *viz.,* 10, 20, 40, 80 and 160 on cotton leaf kept in a Petri dish (200 × 20 mm) using the same procedure as in case of functional response studies. Ten replicates (n = 10) were taken for each prey density. After 24 h, the remaining mealybugs were counted to know the consumption. The number of eggs laid by the predator was also recorded within 24 h. The numerical response was calculated by the following equation:

$$NR = \text{Number of eggs laid} X \frac{\text{Oviposition period}}{\text{Total life period}} X \text{Sex ratio}$$

The efficiency of conversion of ingested food (ECI) into egg biomass at different prey densities was recorded by applying the following equation given by Omkar and Pervez (2004):

$$ECI = \frac{\text{Number of eggs laid}}{\text{Number of prey consumed}} X100$$

3. Results

3.1. Functional response

Results of the polynomial logistic regression for all the developmental stages *viz.,* I^{st}, II^{nd}, III^{rd} and IV^{th} instar grubs, male and female of *S. coccivora* exhibited a type II functional response as the value of linear coefficient P_1 was negative (Table 1). The proportion of prey consumed (Na/N_0) by all the stages declined with an increase in the prey density (Figs. 1–6).

By using Roger's random attack equation and Holling Disc equation, the coefficient of attack rate (*a*') and handling time (T_h) were estimated for all the instar grub (I to IV), male and female of *S. coccivora*. The estimated values are shown in Tables 2a and 2b. Roger's random attack equation revealed that the estimates of attack rate (*a*') was highest for female (2.19) followed by IV^{th} instar grub (2.05), adult male (1.67), III^{rd} (1.14), II^{nd} (1.10) and I^{st} instar grub (0.93). Handling time (T_h) for the IV^{th} instar grub (0.01), was substantially lowest, followed by female (0.01), male (0.02), III^{rd} (0.04), II^{nd} (0.05) and I^{st} instar grub (0.07). The maximum rate of predation was highest for the IV^{th} instar grub (76.40) followed by female (75.86), male (58.79), III^{rd} (22.84), II^{nd} (19.65) and I^{st} instar grub (15.39). The AIC's values for I^{st}, II^{nd}, III^{rd}, IV^{th} instar grubs, male and female were 290.25, 312.07, 317.16, 592.03, 474.84 and 480.54, respectively.

Holling Disc equation showed that the attack rate (*a*') was highest for female (1.05) of *S. coccivora* followed by IV^{th} instar grub (1.02), male (0.94), III^{rd} (0.73), II^{nd} (0.71) and I^{st} instar grub (0.64). Handling time (T_h) of the female and IV^{th} instar grub was same (0.01) followed by male (0.02), III^{rd} (0.04), II^{nd} (0.04) and I^{st} instar grub (0.06). The maximum rate of predation was highest for the IV^{th} instar grub (90.72) followed by female (90.68), male (66.84), III^{rd} (27.30), II^{nd} (23.88) and I^{st} instar grub (18.00). The AIC's values for I^{st}, II^{nd}, III^{rd}, IV^{th} instar grub, male and female were 290.44, 312.12, 317.02, 579.16, 470.20 and 465.00, respectively.

Significant pairwise differences were noticed between attack rates ($D_{a'}$) estimated by Rogers random attack equation for different developmental stages of *S. coccivora* except for the first and second instar grub, first and third instar grub, first and fourth instar grub, first instar grub and adult male, second and third instar grub, second and fourth instar grub, fourth instar grub and adult female. The significant pairwise differences were also observed for the handling time (DT_h) between different developmental stages of *S. coccivora,* except first and second instar grub, first and third instar grub, first and fourth instar grub, second and third instar grub and fourth instar grub and adult female (Table 3).

3.2. Numerical response

It was observed that the oviposition by female of *S. coccivora* increased curvlinearly with increasing prey density and reached saturation at highest prey density (Fig. 7). The maximum number of eggs (11.8 ± 3.44) were laid at the prey density of 160, followed by 80 (11.5 ± 3.39), 40 (8.5 ± 2.92), 20 (5.7 ± 2.39) and 10 (4.2 ± 2. 05). But, the Efficiency of Conversion of Ingested food (E.C.I) by the female decreased with increasing prey density (Fig. 8). It was found highest (64.49 ± 8.03) at the prey density of 10, followed by 20 (52. 82 ± 7.27), 40 (40.55 ± 6.37), 80 (32.68 ± 5.72) and 160 (25.07 ± 5.

Table 1
Maximum likelihood estimates for parameters of the logistic model fit to proportion of prey consumed (N_a/N_0) versus initial prey density (N_0):

Parameters		Larva				Adult Male	Adult Female
		Instar1	Instar2	Instar3	Instar4		
	Type of Response	Type II	Type II	Type II	Type II	Type II	Type II
Constant (P_0)	**Intercept(P_0)**	2.168e−01	8.286e−01	8.868e−01	2.375e++00	1.673e + 00	2.497e + 00
	SE	6.574e−01	7.522e−01	4.677e−01	2.167e−01	1.885e−01	2.212e−01
	p−value	0.742	0.271	0.058	<2e−16 ***	<2e−16 ***	<2e−16 ***
Linear (P_1)	**Coeffecient(P_1)**	−2.542e−02	−8.101e−02	−6.726e−02	−4.274e−02	−3.561e−02	−4.527e−02
	SE	1.134e−01	1.22e−01	5.954e−02	6.090e−03	5.551e−03	6.186e−03
	p-value	0.823	0.508	0.259	2.24e−12 ***	1.41e−10 ***	2.51e−13 ***
Quadratic (P_2)	**Coeffecient(P_2)**	−8.052e−04	1.966e−03	1.057e−03	2.075e−04	1.650e−04	2.242e−04
	SE	5.818e−03	6.060e−03	2.201e−03	4.443e−05	4.146e−05	4.500e−05
	p-value	0.890	0.746	0.631	3.01e−06 ***	6.90e−05 ***	6.26e−07 ***

* Significant at P < **0.05** |** Significant at P < **0.01** |*** Significant at P < **0.001**.

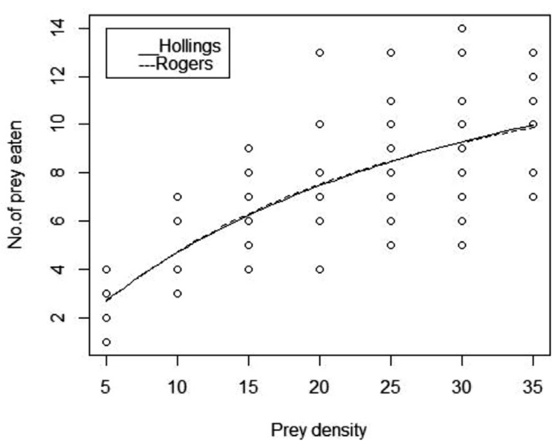

Fig. 1. Functional response of different stages of *S. coccivora* against the different prey densities.

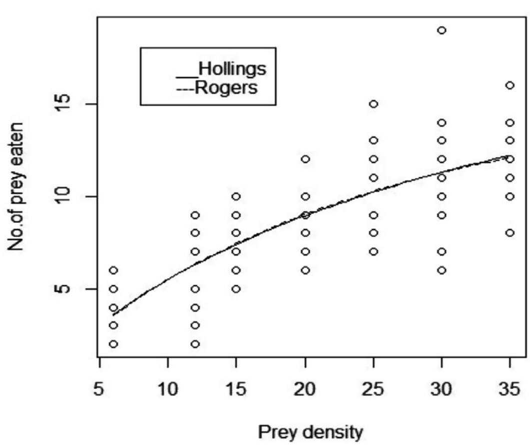

Fig. 2. Functional response of different stages of *S. coccivora* against the different prey densities.

01) (Table 4). While considering oviposition period (35 days), the total period (75 days) and sex ratio (1:1), the numerical response equation was obtained as follows:

$$NR = (-0.0007x^2 + 0.1674x + 2.67)X\frac{35}{75}X\frac{1}{2}$$

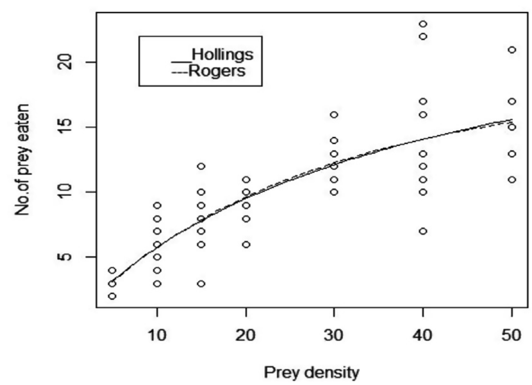

Fig. 3. Functional response of different stages of *S. coccivora* against the different prey densities.

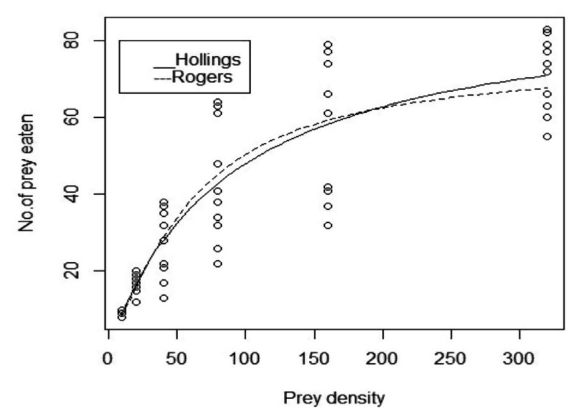

Fig. 4. Functional response of different stages of *S. coccivora* against the different prey densities.

4. Discussions

There are three types of functional response *viz.,* type I, type II and type III out of which type II is the most prevalent among coccinellid predatory beetles (Hodek, 1996). Under the present study, *S. coccivora* exhibited Type II functional response for all its developmental stages such as grubs and adults against *P. solenopsis*. Type II functional response has already been reported earlier for a variety of predators (Begon et al., 1996; Aukema and Raffa, 2004). This type of response is also reported for many coccinellids preying on different soft bodied insects, such as *Scymnus levaillanti* Mulsant on *Aphis gossypii* Glover (Uygun and Atlihan, 2000), *S. creperus* M. on *A. gossypii* (Wells et al., 2001), *Propylea dissecta* (M.), *Cheilomenes sexmaculata* (F.) and *Coccinella transversalis* F. on *A. coccivora* Koch and *Myzus persicae* (Sulzer) (Pervez and Omkar, 2005), *S. syriacus* Marsuel on *A. fabae* Scopoli (Sabaghi et al., 2011) and *S. syriacus* M. on *A. gossypii* (Sakaki and Sahragard, 2011). To the best of

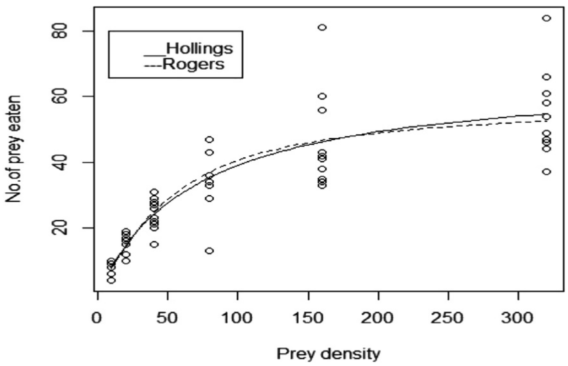

Fig. 5. Functional response of different stages of *S. coccivora* against the different prey densities.

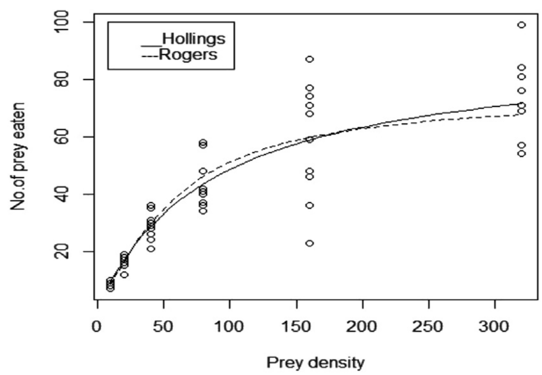

Fig. 6. Functional response of different stages of *S. coccivora* against the different prey densities.

our knowledge, the present study is the first which explain the predatory behaviour of all the stages of *S. coccivora* against third instar nymphs of *P. solenopsis*.

It was found that Roger's random attack equation was the best fit for early instar grubs (Ist and IInd) and Holling disc equation was the best fit for the other instar grubs (IIIrd and IVth) and adult stages (Tables 2a and 2b). The best fit of both the models was decided based on the AIC values, the model showing lower AIC value for a particular stage was considered the best fit.

Table 3
Pairwise difference between functional response parameters of different stages (estimated by Rogers random attack equation) with their Standard error:

Stage	D_a	D_{T_h}
1st –2nd Instar	−0.17779 (0.23092)	0.01414 (0.01335)
1st –3rd Instar	−0.20984 (0.20766)	0.02123 (0.01166)
1st –4th Instar	−1.12768(0.20080)	0.05187 (0.01053)
1st Instar -Adult Male	−0.48167(0.26898)	0.05992 (0.011117) ***
1st Instar –Adult Female	−1.26173 (0.20667) ***	0.05180 (0.1052) ***
2nd –3rd Instar	−0.03192 (0.21796)	0.00711 (0.00966)
2nd –4th Instar	−0.59351 (0.31074)	0.04922 (0.00897) ***
2nd Instar -Adult Male	−0.56909 (0.20508) **	0.03387 (0.00826) ***
2nd Instar -Adult Female	−1.08244 (0.21712) ***	0.03769 (0.00824) ***
3rd –4th Instar	−0.91807 (0.18571) ***	0.03073 (0.00508) ***
3rd Instar -Adult Male	−0.53684 (0.17854) **	0.02676 (0.00510) ***
3rd Instar -Adult Female	−1.05223 (0.19231) ***	0.03058 (0.00508) ***
4th Instar -Adult Male	0.38042 (0.17016) *	−0.00392 (0.00080) ***
4th Instar -Adult Female	−0.13384 (0.18463)	−0.00009 (0.00064)
Adult Male -Adult Female	−0.51431 (0.17731) **	0.00382 (0.00079) ***

* Significant at P < **0.05** |** Significant at P < **0.01** |*** Significant at P < **0.001**.

By using Roger's random attack equation (Table 2a) and Holling disc equation (Table 2b), different parameters like handling time (Th), attack rate (a) and maximum rate of predation (Th/T) were analysed to evaluate the predatory efficiency of *S. coccivora*. The handling time is an important parameter which indicates the predatory rate of a predator towards capturing and devouring the prey (Atlihan et al., 2010). Our finding revealed the lowest handling time (Th) for IVth instar grub followed by female, male and other grub stages. Meanwhile the attack rate (a') value of IVth instar grub estimated by both Holling and Roger's model was found lower than that of all other stages of the predator. Our findings are in line with Hodek and Honek (1996), Omkar and Kumar (2013) who reported the lowest handling time and highest attack rate for IVth instar grub of predator *Anegleis cardoni* on *A. gossypii*. It might be due to larger body size of IVth instar grub that helped them acquiring more nutrition for their subsequent pupal development. Results also revealed that IVth instar grub and adult stages of *S. coccivora* were the most voracious in nature and could consume more number of mealybugs owing to short handling time they had.

Table 2a
Coefficient of attack rate (*a'*) and handling time (T_h) [estimated by Rogers random attack equation]

Stage	Attack rate (*a'*)	Handling time (T_h)	Maximum rate of predation (T/T_h)	AICs
Instar1	0.93	0.07	15.39	290.25
Instar2	1.10	0.05	19.65	312.07
Instar3	1.14	0.04	22.84	317.16
Instar4	2.05	0.01	76.40	592.03
Adult male	1.67	0.02	58.79	474.84
Adult female	2.19	0.01	75.86	480.54

Table 2b
Coefficient of attack rate (*a'*) and handling time (T_h) [estimated by Hollings equation]

Stage	Attack rate (*a'*)	Handling time (T_h)	Maximum rate of predation (T/T_h)	AICs
Instar1	0.64	0.06	18.00	290.44
Instar2	0.71	0.04	23.88	312.12
Instar3	0.73	0.04	27.30	317.02
Instar4	1.02	0.01	90.72	579.16
Adult male	0.94	0.02	66.84	470.20
Adult female	1.05	0.01	90.68	465.00

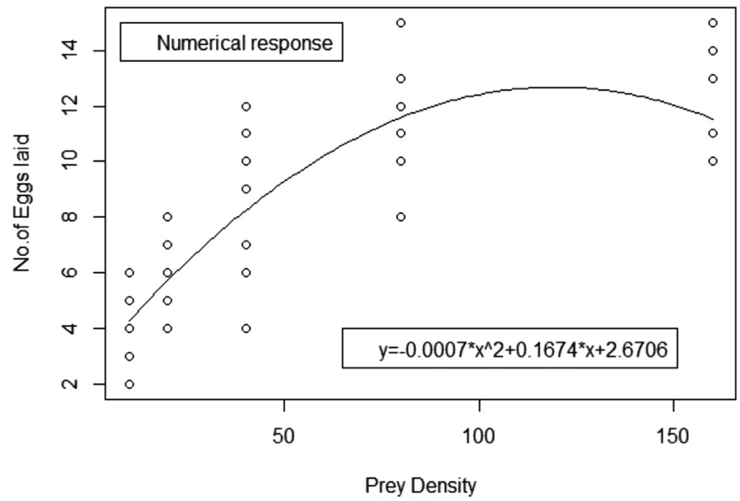

Fig. 7. Number of eggs laid by a female of *S. coccivora* at different densities of *P. solenopsis* (Numerical response).

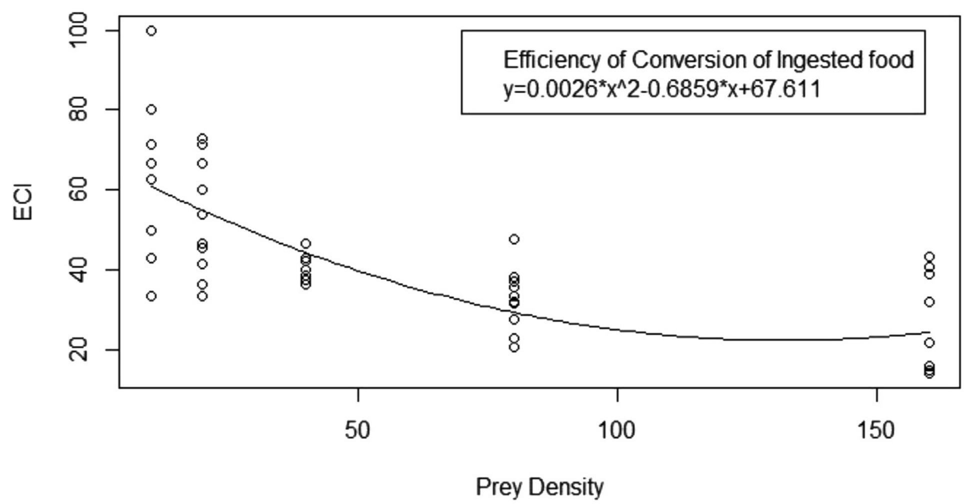

Fig. 8. Relationship between the Efficiency of Conversion of Ingested food (ECI) by *S. coccivora* and prey density.

Table 4
Mean value of prey consumption, Oviposition and E.C.I at different prey densities.

Initial Prey Density	No. of Prey Consumed (Mean ± SE)	No. of Eggs laid (Mean ± SE)	ECI (Mean ± SE)
10	6.7 ± 2.59	4.2 ± 2.05	64.49 ± 8.03
20	11.1 ± 3.33	5.7 ± 2.39	52.82 ± 7.27
40	20.9 ± 4.57	8.5 ± 2.92	40.55 ± 6.37
80	37.2 ± 6.10	11.5 ± 3.39	32.68 ± 5.72
160	56.1 ± 7.49	11.8 ± 3.44	25.07 ± 5.01

However, it was observed that IVth instar grub was more efficient than either of adults in predation on cotton mealybug. Hodek and Honek (1996) explained that IVth instar grubs possess a very determined on-site search capacity when prey is present in colonies, while adults go for prey in a more extensive manner for ensuring feeding and site for oviposition. Pair wise significant differences in functional response parameters like their attack rate and handling time for different stages of predator (Table 3) were observed which might be due to morphological and physiological changes occurred in predator during different developmental stages.

Numerical response of *S. coccivora* showed a curvilinearly rise to a plateau just like in case of functional response which indicate that both the responses could be interlinked when in operation (Fig. 7) (Omkar and Pervez, 2004). A curvilinear relationship was also reported earlier in case of cotton aphid, *A. gossypii* G. density when plotted against the number of eggs laid by coccinellid beetle, *P. dissecta* (Omkar and Pervez, 2004). The prey density-dependent productivity was observed sigmoidal in *C. lunata* F. against *A. craccivora* (Ofuya and Akingbohungbe, 1988) and curvilinear in *C. sexmaculata* against *A. craccivora* (Agarwala and Bardhanroy, 1997). A significant difference among number of eggs by *S. coccivora* at different densities of *P. solenopsis* was observed. At higher prey densities it was apparent. The values of ECI found in this study indicated that the conversion rate of prey biomass into egg biomass was higher at lower densities and was found decreasing as the prey densities goes up. It means the number of eggs laid at different prey density showed a decelerating curve just like Type II functional response. (Omkar and Pervez, 2004) also reported the decreased ECI of coccinellid predator, *P. dissecta* with increase in prey density. Hence, at low prey density the numbers of eggs laid multiplied by 100 were comparatively higher than those at higher prey density. That's why; a decelerating trend was observed when prey density increased. The decreased ECI at higher prey densities revealed that well-fed females could laid more number of eggs for investing in maintenance of different metabolic processes (Bayoumy, 2011).

5. Conclusions

Ladybird beetle, *S. coccivora* is known as a coccidophagous species and found to have more appetite for cotton mealybug, *P. solenopsis*. Considering the high attack rate and low handling time for IVth instar grub, female and males, they could be advocated for the release in augmentative biological control programme meant for mealybugs. However, more insight is needed for the better perception of predator's foraging behaviour in semi-field and field conditions.

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