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Bionomics of transverse ladybird beetle, *Coccinella transversalis* on cowpea aphid, *Aphis craccivora*

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ABSTRACT

Cowpea aphid, *Aphis craccivora* Koch is one of the important pests of legumes. It is a cosmopolitan and polyphagous pest causing 30–35% damage to vegetable crops globally. Chemical control of this pest is not only expensive but also has deleterious effects on human health, environment and non-target organisms. Biological control is one of the most important components of integrated pest management to achieve eco-friendly and sustainable management of crop pests. Coccinellid predator, *Coccinella transversalis* Fab. is an efficient predator known for its appetite on cowpea aphid under vegetable ecosystem. With this background, we conducted a study on biology, morphometric and functional response of *C. transversalis* on cowpea aphid under laboratory conditions (27±1°C and 65±5% RH) at Biological Control Lab, ICAR-Indian Agricultural Research Institute, New Delhi, during 2016-17. Type of functional response was determined through polynomial logistic regression of proportion of prey consumption to the density of prey. Functional response parameters were obtained by fitting the data to the Holling's and Roger's equations. Total life span of male and female was ranged from 47-64 and 60-71 days, with a mean of 56±6.2 and 66±3.9 days, respectively. Both male and female of *C. transversalis* were found to exhibit Type II functional response. Female has showed high attack rate (1.99±0.141) compared to male (1.90±0.088) with maximum prey consumption of 84.41 and 80.51 aphids/day, respectively. Handling time obtained for males (0.0124 day) was higher than females (0.0118 day).

Keywords: *A. craccivora,* Attack rate, Cowpea, *C. transversalis,* Predator-prey interaction's

Entomophagous insects play an important role in sustainable and eco-friendly management of dreaded pests and keep their population under general equilibrium. Among them, coccinellid beetles are important predators in horticultural ecosystem and have been used as biological control agents against a number of sucking pests because of their ability to feed on a variety of pests, voracious feeding habit and rapid numerical response. The ladybird beetle family Coccinellidae comprises approximately 6000 described species under 360 genera and 42 tribes. Predation is a significant biotic mortality factor, which reduces the insect pest population and provides a support to insect pest management programs. Predators have been receiving increased attention because of the current need to reduce the exclusive use of insecticides for the pest control (Hodek *et al*. 2012). Coccinellid predator, *Coccinella transversalis* Fab. a polyphagous ladybird beetle found in cowpea ecosystem mainly feeds on *Aphis craccivora* Koch (Omkar and Srivastava 2003). The study of biology and morphometry will help us to know the weak and strong links, construction of life tables and also for efficient mass production in laboratory for release (Tank and Korat 2007). Studies on functional response would offer a good conceptual platform to understand the actions of biological control agents in augmentative releases.Therefore, biology, morphometric and functional response of transverse ladybird, *C. transversalis* were evaluated on cowpea aphid, *A. craccivora*.

MATERIALS AND METHODS

Ten pairs of *C. transversalis* were maintained separately for their biology studies. The eggs laid by each female during 24 hr were counted and kept in separate petri dish to determine the total number of eggs laid per female, incubation period and hatching percentage (%). After hatching, the young grubs were transferred individually in glass vials of 15 cm length and 3.5 cm diameter. Sufficient amount of *A. craccivora* were placed in glass vials as a prey, developmental period taken by each instar was recorded and also pre-pupal, pupal period, adult emergence percentage, pre-oviposition, oviposition and post-oviposition was recorded. In due course of time all the stages of the predator were exposed to morphometric through Nikon

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steriobinocular microscope having camera attached with the software VIMAGE 2016. Mean and Standard deviation were calculated for morphometric and biology studies of *C. transversalis* using MS office Excel.

Functional response of both the male and female *C. transversalis* was elucidated separately on *A. craccivora* with varying densities of 5, 10, 20, 40, 60, 80, 100 and 120. Individual ladybird beetles of both male and female (7-8 days old) were starved for 24 hr prior to the experiment. The different densities of aphids were gently transferred from rearing jar to the cowpea leaves placed in the petri dish (15cm) having its petiole inserted in the 2% solidified agar solution (2%) for maintaining the leaves fresh and tender, then the starved female and male beetles were introduced in to the petri dish. Experiment was carried out at Biological Control Lab, ICAR-Indian Agricultural Research Institute, New Delhi under controlled conditions of 27±1°C, 65±5% RH and a photoperiod of 16L: 8D hr in the environmental chambers during 2016 and 2017. Each experiment was replicated ten times. After 24 hr, the number of aphids eaten by females and males of predator were recorded. Initial prey density and prey eaten was corrected by deduction of control mortality as;

No. of prey eaten, No. of prey provided – (No. of prey remained + No. of control mortality); Prey density, No. of prey provided – No. of control mortality

Data analysis: The type of functional response was determined by polynomial logistic regression analysis [SAS/STAT, CATMOD procedure (SAS version 9.1)] of the proportion of killed prey (Ne) in relation to initial prey density (N*0*). The data were fitted to the logistic regression which describes the relationship between N*a*/N*0* and N*0* (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, Ne is the number of prey eaten, N_0 is 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 evident, whereas, a positive linear parameter indicates density-dependent predation and thus a Type III functional response (Juliano 2001). First the type of functional response was determined using polynomial logistic regression. When functional response Type-II was evident, both the disc equation (Holling 1959) and the random attack equation (Rogers 1972) were used to estimate handling time (T*h*) and searching efficiency or attack rate (*a'*). For the Type II response, the equations used are as follows:

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

Rogers-II random attack equation: Na = N_0 [1-exp (a' (T_h N_0 – T))]

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; T_h, is the handling time.

Statistical analysis for the estimation of parameters of functional responses was performed with the R software (R-core team 2018) using Functional Response Analysis in R (FRAIR) package (Pritchard *et al*. 2017). A nonlinear regression was used to estimate predator handling time and searching efficiency. Prior to fitting the nonlinear regression line, optimisation was done for the estimated parameters, viz. handling time and searching efficiency with putative starting values by taking time as a fixed variable. The regression analysis was subjected to both Holling's Disc equation and Rogers II-random attack equation for Type-II. The best fit and preference between these two models was determined by an Akakia's Information Criterion (AICs), as these models use maximum likelihood method, smaller the AIC, better the fit.

RESULTS AND DISCUSSION

Biology and morphometric studies of C. transversalis: The eggs laid by the female *C. transversalis* had an incubation period of 4±0.82 days and 94.8±7.9 of hatching percent (%). However, Lohar *et al*. (2012) recorded the incubation period of 3.6±2.68 days and 92.3±3.1 hatching percent (%) for *Hippodamia convergence* Guérin-Méneville, reared on *Lipahis erysimi* Kalt. Grub stage completed development through four instars taking 13–21 days with a mean development period of 17.6±2.84 days. Among all the grub stages, first instar grew fast with duration of 3.8±1.0 days followed by second, third and fourth instar with 3.9±0.7, 4.9±1.0 and 5.0±0.9 days, respectively. Pupal development got completed in 2 to 4 days with an average of 2.80 days. Present findings are in partial agreement with Lyla *et al*. (2008) who found grub stage of *C. transversalis* lasted for 10.3 days and pupal period of 2.62 days when reared on *A. craccivora*. Female has laid a total of 372.8±46.8 eggs with mean oviposition period of 29.4±3.4 days. Earliest workers (Tank and Korat 2007) also noticed mean fecundity of *Cheilomenes sexmaculata* Fabricius as 382 eggs when reared on *Aphis gossypii* Glover, However, mean oviposition period as 37.7 days for *Coccinella undecimpunctata* L. on *L. erysimi* is in partial agreement with our findings (Solangi *et al.* 2007). Female has shown higher longevity compared to male with mean durations of 40.3±3.9 and 30.3±4.1 days, respectively (Table 1). The results of present study are in line with the earlier findings of Lohar *et al*. (2012) who recorded the longevity of 36±2.1 and 29±3.8 days of both females and males respectively for *H. convergence* on *L. erysimi.*

The length and width of eggs was recorded as 1.04 and 0.33 mm, respectively. The length of fourth instar grub varied from 8.90 to 9.10 mm with a mean of 8.97±0.07, whereas the width varied from 1.63 to 1.81 mm with a mean of 1.73 ± 0.05. The length of pupa was 4.92 to 5.03 mm with an average of 4.98 ± 0.04 mm, whereas width was 2.77 to 3.16 mm with an average of 2.97 ± 0.13 mm. Female was larger with the length of 5.90 ± 0.038 mm and width of 4.21 ± 0.33 mm compared to male which has showed the length

Table 1 Biology and morphometrics of *C. transversalis* on *A. craccivora* under laboratory conditions

Stage	Range (Days)	Mean ± SD	Morphometrics of different life stages of *C. transversalis*			
			Range		Mean ± SE	
			Length (mm)	Width (mm)	Length (mm)	Width (mm)
Egg incubation period (days)	3-5	4.0 ± 0.82	0.9 - 1.11	0.30 - 0.37	1.043 ± 0.08	0.33 ± 0.021
Hatching percent (%)	79.17-100	94.8 ± 7.90				
Grub (days) I Instar	3-5	3.8 ± 1.03	2.32 - 2.55	0.35 - 0.45	2.44 ± 0.07	0.39 ± 0.030
II Instar	3-5	3.9 ± 0.74	3.35 - 3.56	0.50 - 0.82	3.464 ± 0.06	0.65 ± 0.101
III Instar	3-5	4.9 ± 0.99	5.34 - 5.50	1.35 - 1.55	5.433 ± 0.04	1.45 ± 0.059
IV Instar	4-6	5.0 ± 0.94	8.91 - 9.10	1.63 - 1.81	8.979 ± 0.07	1.73 ± 0.057
Total developmental period (days)	13-21	17.6 ± 2.84				
Pre-pupal period (days)	1-2	1.4 ± 0.52	7.13 - 7.82	1.66 - 1.79	7.53 ± 0.18	1.728 ± 0.05
Pupal period (days)	2-4	2.80 ± 0.63	4.92 - 5.03	2.77 - 3.16	4.979 ± 0.04	2.966 ± 0.12
Percent adult emergence (%)	83-100	90.6 ± 5.11				
Sex ratio (Male : Female)		1 :1.06				
Adult longevity (days) Male	24-36	30.30 ± 4.14	5.50 - 5.79	3.45 - 4.39	5.653 ± 0.14	3.897 ± 0.29
Female	35-46	40.30 ± 3.92	5.83 - 5.95	3.65 - 4.57	5.902 ± 0.03	4.21 ± 0.32
Total life span (days) Male	47-64	56.10 ± 6.21				
Female	60-71	66.10 ± 3.90				
Pre-oviposition Period (days)	3-6	4.60 ± 1.43				
Oviposition period (days)	25-35	29.40 ± 3.37				
Post-oviposition perio(days)	3-10	6.30 ± 2.54				
Fecundity (no. of eggs)	280-434	372.8 ± 46.8				

of 5.65 ± 0.14 mm and width of 3.90 ± 0.30 mm (Table 1). Present findings are in confirmation with Tank and Korat, (2007), who recorded length and width of *C. sexmaculata* as 5.20±0.13 and 4.25±0.11 mm, respectively for female, whereas 4.23 ± 0.25 and 3.84 ± 0.14 mm in case of male. Shinde *et al*. (2016) reported that the average length and width of fourth instar grub of *Cryptolemus montrouzieri* Mulsant as 7.17 ±0.20 and 1.29 ± 0.14 mm, respectively and also the measurements recorded for pupa are in line with the present findings.

Functional response of C. transversalis: The present findings showed that both male and female of the *C. transversalis* exhibited Type II functional response against *A. craccivora.* Type-II functional response is evidenced by the negative linear parameter (P_0) of logistic regression of proportion of prey consumed to the initial prey density with exhibiting decelerating curve (Fig 1, Table 2). Results showed that the males and females of *C. transversalis* had a good predation potential against the *A. craccivora.* The attack rate or searching efficiency was found more in females (1.99±0.141) than males (1.90±0.088). Our results are in agreement with Borah and Dutta (2010) who, worked out the attack rate of females (1.87±0.3) and males (1.26±0.5) of *C. transversalis* against the *A. craccivora*. As the females need to feed more, has to search more and hence, cover more distance for searching prey than males. However,

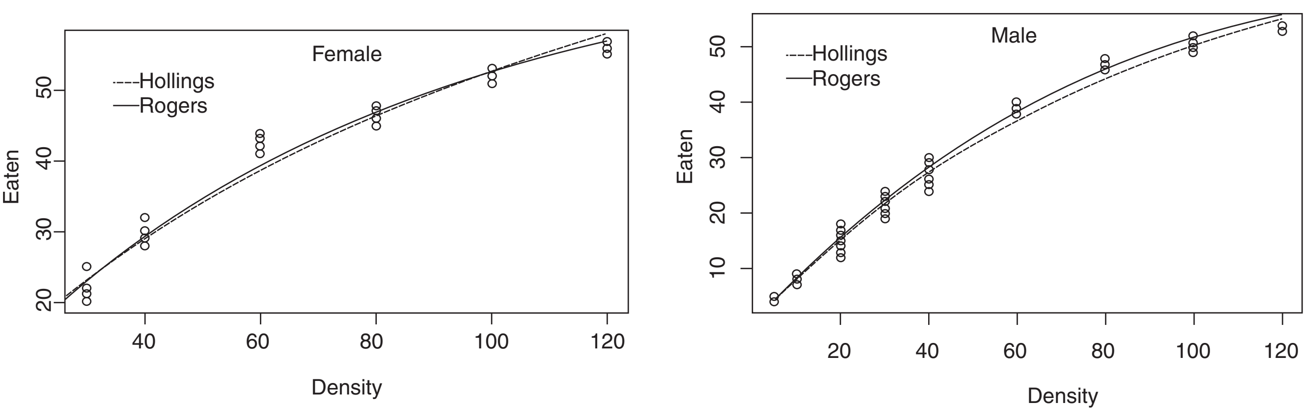

Fig 1 Functional response of *C. transversalis* female and male against the different prey densities of *A. craccivora.*

Table 2 Maximum likelihood estimates from logistic regression analysis of the proportion of prey eaten by *C. transversalis* against the different prey densities of *A. craccivora*

Sex	Parameter	Estimate	Std. error	z value	Pr (z)	Indicator	Type of functional response
Female	Intercept (P_0)	1.537e+00	2.528e-01	6.080	<1.2e-09	$P_1 < 0$	Type II
	Linear (P_1)	-1.434e-02	6.766e-03	-2.120	0.034		
	Quadratic (P_2)	2.140e-06	4.155e-05	0.052	0.959		
Male	Intercept (P_0)	1.6756416	0.1268157	0.000027	<2e-16	$P_1 < 0$	Type II
	Linear (P_1)	-0.021160	0.0039759	-5.322	1.02e-07		
	Quadratic (P_2)	0.0000466	0.0000273	1.707	0.0878		

Table 3 Estimates of co-efficient of attack rate (a) and handling time (T_h) for *C. transversalis* against *A. craccivora* (T=1day) subjected to Holling's disc equation and Rogers functional response equation

Sex	Equation	Attack rate (a) ± SE	Handling time (T_h) in Days ± SE	Maximum predation (T/T_h)	AICs
Female	Hollings	0.96 ± 0.039	0.0085 ± 0.00062	117.49	301.02
	Rogers	1.99 ± 0.141	0.0118 ± 0.00072	84.41	295.57*
Male	Hollings	0.92 ± 0.020	0.00876 ± 0.00047	114.04	456.92
	Rogers	1.90 ± 0.088	0.01242 ± 0.00059	80.51	453.65*

* Indicates best fit

handling time (T_h) obtained for males (0.0124 day) was higher than females (0.0118 day) (Table 4). Our results are partially consistence with Thompson and Goggin (2006) that higher handling time was reported in male (0.0310 day) as compared to female (0.027 day) since, females are efficient predator than males and eat preys faster than a male, that's why handling time is less for females than males and handling time (T_h) has already been reported as a good indicator of the predation rate. Female has shown high maximum predation rate (84.41/day) compared to male (80.51/day) (Table 3). These results are consistence with Parvez and Omkar (2005), who reported the Type II functional response of male and female *Propylea dissecta* Mulsant on *A. craccivora,* and with findings of Borah and Datta (2010) for *C. transversalis* on *A. craccivora* and with findings of Kumari *et al.* (2021) for *Scymnus coccivora* Ayyar against cotton mealybug, *Phenacoccus solenopsis* and with findings of Venkanna *et al.* (2021) for *C. sexmaculata* on the cotton aphid, *A. gossypii*. High predation rate of female compared to male might be due to its larger size and it also needed to store more nutrients for egg laying. Our results are in line with earlier work (Omkar and Kumar 2015) that reported the maximum rate of predation for females (86.16) than males (82.17) for *Aneglesis cardoni* Weise against the *A.gossypii*. Similar results were also reported by Kaur and Virk (2012) and Garcia *et al.* (2009) who reported that female of *C. montrouzieri* as the most efficient predator compared to males.

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