INTRODUCTION

Many aphid species are dangerous pests of different agricultural crops including wheat (Triticum aestivum L.), mustard (Brassica campestris L.) and other crops (Singh et al., 1988; Arora, 1999; Oerke, 2006). Research studies have indicated that biocontrol agents are effective against aphids (Tassan et al., 1979; Bugg et al., 2008). Green lacewing Chrysoperla carnea S. (Neuroptera; Chrysopidae) is a cosmopolitan polyphagous predator (Nordlund et al., 1991; Singh and Manoj, 2000; Atlhan et al., 2004) and a key predator for the management of various insect pests in agriculture system (Mulligan et al., 2010). The larval stages of C. carnea are voracious feeders and they can eat more than 487 aphids before pupation (Afzal, 1978). High searching capability of C. carnea in prey finding is a good adoption in different environments, while wide range of prey and resistance to mostly applied insecticides, makes it an important natural control agent (Sablon et al., 2013). The relationship between density of prey and consumption of predator is one of the main fundamental characteristic of predator prey interaction, this is termed as numerical and functional response (Holling, 1961). Functional response specifically is termed as a key element in regulation dynamics of a population in predator prey system. This is also described as the rate of killing of a predator to its prey at different given densities (Khan and Mir, 2008). Attack rate (a) and handling time (T_h) time spent to dominate, eat and digest prey are the important components of functional responses (Hassell et al., 1976). Therefore, the studies on functional response are important to understand the underline mechanism of predator prey interaction, to explain the practical role in coevolutionary realtionships and to contribute in bio-control (Houck and Strauss, 1985).

The objective of this study was to determine predatory potential of C. carnea on L. erysimi and D. noxia by functional response. Little work has been done on predatory efficiency of C. carnea on L. erysimi and D. noxia, as these are serious pests of wheat and mustard. There is a dire need to explore more predatory efficiency...
of \textit{C. carnea} as a bio-control tool against these aphid species through functional response estimation.

**MATERIALS AND METHODS**

The adults of \textit{C. carnea} were collected in start of January to end of February, 2019 from Bahauddin Zakariya University fields of \textit{B. campestris} \textit{L.} and \textit{T. aestivum} \textit{L.}. The adults were collected in plastic jars (15x15x25 cm) with the help of aerial net and transferred to a plastic cage (23x38x38 cm) with ventilation holes on both sides. The adults were reared and maintained under laboratory conditions (25±2°C and 65±5% R.H.) with photoperiod L12:D12 h. Artificial diet (yeast honey and distilled water with the ratio of 1:2:4 ml, respectively) was provided once a day as a food for \textit{C. carnea} adults on plastic sticks having pores. Black glossy paper was hung along sealing of cage for eggs laying. Next day eggs were removed and collected separately with the help of forceps from cage and kept in 6cm plastic petri dishes until hatching. Moist filter papers were placed at the bottom of the Petri dish to maintain humidity level.

Aphids were collected from infested fields of \textit{Triticum} \textit{aestivum} \textit{L.} and \textit{Brassica} \textit{campestris} \textit{L.} present at University.

Functional response of all larval stages of \textit{C. carnea} on \textit{L. erysimi} and \textit{D. noxia} was evaluated by providing different densities (10, 20, 30, 40, and 50) of aphids. Each starved predatory stage was transferred to 6cm plastic petri dishes having a specific density of both aphid species. Dead or alive aphids were removed from petri dishes (6cm) and provide newly collected aphids on daily basis. Second and third instars of \textit{C. Carnea} were provided with 3rd instar aphids to know the precise predatory potential. Whole experiment was consisted on 5 treatments and each treatment included 10 replications for each predatory stage. Lastly aphids consumed were counted after 24h of treatment applied.

All data were analyzed by using a statistical software R v.3.5.3 (Team, 2019). Functional response was calculated by using frair.test present in an integrated FRAIR package in statistical R software. Determining shape of functional response clearly predicts that either it is type II functional response or type III (Trexler et al., 1989). The functional response shape was determined through a logistic regression model (Juliano, 2001). Following is an equation having polynomial function (Equation 1) describes the relationship between the prey number consumed (\(N_e/N_p\)) and the prey number provided (\(N_p\)):

\[
N_e = \frac{\exp(P_0 + P_1 N_p + P_2 N_p^2 + P_3 N_p^3)}{1 + \exp(P_0 + P_1 N_p + P_2 N_p^2 + P_3 N_p^3)} \quad (1)
\]

Coefficient of above equation are \(P_0 = \) intercept \(P_1 = \) linear \(P_2 = \) quadratic and \(P_3 = \) cubic. A maximum likelihood method is used to estimate these coefficients. Confirmation of type III response obtains when \(P_1 > 0\) and \(P_3 < 0\) which shows prey consumed is positively density dependent. Whereas if \(P_1 < 0\), this shows prey consumed is negatively density dependent and it confirms a type II response (Juliano, 2001). FRAIR package include ‘frair_responses’ this function have different responses from which rogers II was used for functional response parameters calculation (Pritchard et al., 2017). Preforming above analysis resulted in type II response to our data. So further parameters of functional response were estimated through using (Equation 2) Roger’s random predator equation (Rogers, 1972):

\[
N_e = No\left(1 - \exp\left(aN_e^h(hN_e - T)\right)\right) \quad (2)
\]

Here initial prey density is \(No\) and prey number eaten is \(Ne\) where \(T\) is for experimental time (in hours or days) \(a\) is for constant capture rate of consumer per unit area or volume per unit time; time spent to consume prey is denoted by \(h\) and its unit is same as \(T\) (Jeschke et al., 2002; Sentis et al., 2013) and \(q\) is a scaling exponent that defines to which extent the functional response will change from a decelerating hyperbola (Type II: \(q = 0\)) to a sigmoidal form (Type III: \(q > 0\)). As Roger’s random predator equation has solved the issue of prey depletion so to calculate attack rate (\(a\)) and handling time (\(T_h\)) data was fitted to this equation.

**RESULTS**

Maximum likelihood estimate data by using logistic regression showed type II functional response for all the larval predatory stages of \textit{C. carnea} on both the aphid species (Table I). Results showed that consumption rate of all the larval stages of \textit{C. carnea} significantly increased by increase in prey densities. Attack rate (\(a\)) of first second and third instar recorded for \textit{L. erysimi} and \textit{D. noxia} was 0.16h, 0.43h, 1.56h, and 0.20h, 0.53h, 0.72h, respectively (Table II). Similarly, handling time (\(Th\)) recorded was 0.12h, 0.057h, 0.029h, and 0.17h, 0.050h, 0.015h, respectively (Table II). When different densities (10, 20, 30, 40, and 50) of \textit{L. erysimi} were given to 1st instar of \textit{C. carnea} the mean consumption rates were 1.8, 3.4, 5.9, 7.3, and 9, respectively, and for 2nd instar it was 4.2, 7.3, 12.1, 12.8, and 13.1, respectively, while for 3rd instar it was 9, 18.7, 22, 23.9, and 38.2. Similarly, when the same densities of \textit{D. noxia} was provided to 1st instar the mean consumption rate was 1.7 3.8, 4.1, 4.7, and 8, respectively, and for 2nd instar it was 4.8, 9.2, 14.3, 14.7, and 16.7, respectively, while for 3rd instar it was 7.3, 11.8, 20, 24.1, and 29.6, respectively.

The functional response-curves for all the instars of \textit{C. carnea} to the various prey densities are presented in Figure 1, showing increase in prey consumption by larvae with increase in aphid densities.
Feeding Potential of Green Lacewing on Two Aphid Species

Table I. Maximum likelihood estimates from logistic regression (frair) of the proportion of *L. erysimi* and *D. noxia* eaten by three predatory stages of *C. carnea*.

| Aphid species         | Predator stage | Estimate       | S.E.      | z value | Pr (>|z|)       |
|-----------------------|----------------|----------------|-----------|---------|----------------|
| *Lipaphis erysimi*    | First instar   | -0.0180471     | 0.0053457 | -3.476  | 0.0007354 *** |
|                       | Second instar  | -0.0171178     | 0.0043313 | -3.964  | 7.353e-05 *** |
|                       | Third instar   | -0.0263583     | 0.0051237 | -5.144  | 2.684e-07 *** |
| *Diuraphis noxia*     | First instar   | -0.015553      | 0.009782  | -2.601  | 0.009278 **   |
|                       | Second instar  | -0.0187132     | 0.0042358 | -4.417  | 9.967e-06 *** |
|                       | Third instar   | -0.0091162     | 0.0043117 | -2.114  | 0.03449       |

Note: Significance codes: *** 0.001 ** 0.01 * 0.05

Table II. Estimated attack rate (*a*) and handling time (*T*) of *C. carnea* different predatory stages on *L. erysimi* and *D. noxia*.

| Aphid species         | Predator stage | Coefficient | Estimate       | S.E.      | z value | Pr (z)       |
|-----------------------|----------------|-------------|----------------|-----------|---------|----------------|
| *Lipaphis erysimi*    | First instar   | a           | 0.194726      | 0.041438  | 4.699   | 2.612e-06 *** |
|                       |                | *T*         | 0.118579      | 0.035953  | 3.298   | 0.0009733 *** |
|                       | Second instar  | a           | 0.429184      | 0.066317  | 6.472   | 9.692e-11 *** |
|                       |                | *T*         | 0.056637      | 0.012983  | 4.362   | 1.287e-05 *** |
|                       | Third instar   | a           | 1.553612      | 0.0182935 | 8.493   | <2e-16 ***    |
|                       |                | *T*         | 0.0287669     | 0.0039117 | 7.354   | 1.924e-13 *** |
| *Diuraphis noxia*     | First instar   | a           | 0.155205      | 0.044099  | 3.519   | 0.0004325 *** |
|                       |                | *T*         | 0.173346      | 0.060669  | 2.857   | 0.0042734 **  |
|                       | Second instar  | a           | 0.526254      | 0.074198  | 7.092   | 1.317e-12 *** |
|                       |                | *T*         | 0.049791      | 0.010032  | 4.963   | 6.933e-07 *** |
|                       | Third instar   | a           | 0.7188259     | 0.0774432 | 9.282   | <2e-16 ***    |
|                       |                | *T*         | 0.0144063     | 0.0061845 | 3       | 0.01984       |

Note: Significance codes: *** 0.001 ** 0.01 * 0.05

**DISCUSSION**

All the larval instars of *C. carnea* have shown linear parameter (density) as negative. The prey number consumed increased by increasing prey density which predicts a type II functional response. The present results are in agreement with the studies where functional response of type II was calculated when aphids were predated by ladybird beetle (Kabissa et al., 1996; Mushtaq and Khan, 2010; Starn and Whitford, 1987; Zada et al., 2016). In our result all larval instars of *C. carnea* showed good predation potential against *L. erysimi* and *D. noxia* but third instars larvae of *C. carnea* were more predacious on these two aphid prey species. Previous studies also proved that the last larval instar of *C. carnea* have higher predation as compared to early instars (Atlıhan et al., 2004; El-Gawad et al., 2010). Higher predation of third instar larvae of *C. carnea* is a valid expression because of its large size and resulting higher rapacity. The reason of this higher predation might be due to fixed time starvation given in the begging of trial. Moreover, the age factor of larvae of *C. carnea* plays a vital role in increasing the movement speed (Zada et al., 2016).

Attack rate was observed higher of third instar of *C. carnea* on both the aphid species followed by second and first instar (Fig. 1). Less handling time was observed in respective manner as third instar having high attack rate and lesser handling time but in case of *L. erysimi* least handling time observed in first instar rather than third instar. In general handling time was more for first and second instar as compared to third instar this is because of high consumption rate of aphids this might also be because of higher levels of hunger power of digestive system and speeds of searching similar results were observed by *C. carnea* on different aphid species (Mushtaq and Khan, 2010).
CONCLUSION

Type II functional response is established in the presence of L. erysimi and D. noxia by all three larval stages of C. carnea. Third instar on both aphid species is more voracious feeder and higher attack rate with less handling time than second and first instars. The most preferable host for C. carnea larvae is L. erysimi as compared to D. noxia aphid specie. The results of this study will provide functional response information of C. carnea to scientific society in designing a bio-control tool for aphid pests.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the Department of Entomology, Central Cotton Research Institute for coordinating in the present research work and undergraduate students for helping in experiments.

Statement of conflict of interest

The authors have declared no conflict of interest.

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