Testing the Searching Efficiency and Handling Time of Two Biological Control Agents *Menochilus sexmaculatus* and *Coccinella septempunctata* (Coccinellidae: Coleoptera) Against Onion Thrips Using Functional Response

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Abstract

The important aspect of learning predator-prey interaction is to find the functional response. This could help to measure searching efficiency and often being interrelated with the biological control effectiveness. Therefore, the functional response studies on two native ladybird beetles, *Menochilus sexmaculatus* (Fabricus, 1781) and *Coccinella septempunctata* (Linnaeus, 1758) (Coccinellidae: Coleoptera) against *Thrips tabaci* (Lindeman, 1889) was conducted in test tubes at 26±2 °C temperature and relative humidity 65±5 %. *M. sexmaculatus* exhibits a functional response with type III in all stages. The highest theoretic maximum predation of a fourth, adult female, adult male, third, second and first larval instars of *M. sexmaculatus* was estimated as 44, 39, 32, 25, 23 and 18 against onion thrips, respectively. However, *C. septempunctata* showed functional response type II in first and second larval instars whereas type III in third, fourth and adult females and males. The highest theoretic maximum predation of a fourth, adult female, adult, male, third, second and first larval instars of *C. septempunctata* was estimated as 72, 57, 46, 46, 46 and 13 to onion trips, respectively.

Keywords: thrips, ladybird beetle, biological control, type III.

I. INTRODUCTION

Onion (*Allium cepa* L.) is the most significant horticultural and cash crop in the world. Onion is often affected by several pests and diseases. Amongst the insect pests; cutworms, head borers, leaf miners and thrips are key problems. Onion thrips, *Thrips tabaci* (Lindeman, 1889) is an utmost serious pest in the biosphere. Onion thrips are found in the most onion-growing areas and have attained economic status [1]. Thrips can result in substantial economic damage to the onion crop. It is reported that onion thrips can reduce yield by up to 60% [2]. Onion thrips can reproduce numerous nymphs within a little period. It is also reported that the onion thrips is a vector of Topo-virus and Iris yellow spot virus which affect in seedling stage [3]. Mostly, immature nymphs feed on new and fleshy leaves. Due to this extensive feeding, the nymphs suck the sap which leads to the formation of silvery spots which get enlarge with feeding intensity [4].

Predators a vital role in the most biological program to mitigate the pest population and among all, ladybird beetles are also considered good biological controlling agents [5]. As a specialist predator, the ladybird beetle can prey on a variety of hosts including; mealybugs, scale insects, thrips and aphids. There are 6000 ladybird species reported in the world and among them, 71 species are reported in Pakistan [6, 7] Ladybird beetles are considered to be good biological control agents in the urban and agricultural landscape throughout the globe [8, 9]. The family of ladybird beetles is widely distributed and comprises six subfamilies [10]. Ladybird beetles are considered to be a very good predator of soft-bodied insects, mainly aphids, scales, psyllids, white flies, thrips, mites and eventually other insects [6], [8].

II. MATERIAL AND METHODS

A. Ladybird collection

Initially, all the stages of *M. sexmaculatus and C. septempunctata* were collected from the onion field.

B. Procedure

The experiment was carried out in controlled conditions with having temperature 26±2 °C and relative humidity 65±5%. *Thrips tabaci* second instars were collected from the onion crop and densities (10, 20, 30, 40, 50 and 60 nymphs) were offered to each stage of the ladybird beetle with having ten replicates. Constantly freshly collected nymphs were given to each stage and uneaten nymphs were cast off at the end of each experiment. The experiment was done in a test tube (16×150mm). Before the start of the experiment, ladybird beetles were starved for 12 hours. Starved ladybird beetles were shifted to the test tube by using a camel fine hair brush and kept for one day.

C. Data Analysis

The types of functional response were estimated by applying logistic regression in excel (Microsoft office 365) in a relationship as a prey eaten by a predator (Ne) versus the number of prey given to a test predator (No). After the end of the analysis, if the linear coefficient value is less than zero (<0), the predator exhibits a type II functional response. Whereas the linear coefficient is greater than zero (>0) and the quadratic coefficient is less than zero (<0), the insect is revealing the functional response of type III. The study is done without the prey replacement. The parameter of attack rate (a) and handling time (T_h) was found by using the random predator equation [11].

Initially, in type I, the functional response following model was used:

$$Ne= \alpha+\beta No \quad (1)$$

Here,

- Ne: Number of prey eaten by a predator,
- No: Number of prey offered to predator
- α and β: are intercept and slope

For functional response type II following model was used

$$N_e= N_o \{1\text{-exp} [a (T_h N_e\text{-}T)]\} \qquad (2)$$

Here Ne: Number of prey eaten by a predator, No: Number of prey offered to predator and, a: attack rate, and T: overall time available. Inserting the value; a=(d-bNo)/(1+cNo) in Eq. [2] a type III model of functional response was derived [12]

$$N_e= N_o \{1\text{-exp} [(d + bNo)(T_h N_e\text{-}T)/(1+cNo)]\} \qquad (3)$$

Predator showing type III functional response, the parameter c and d was non-significantly dissimilar from 0 [i.e. 95 % confidence interval (CI) included 0]. This will reduce the model of type III functional response [13].

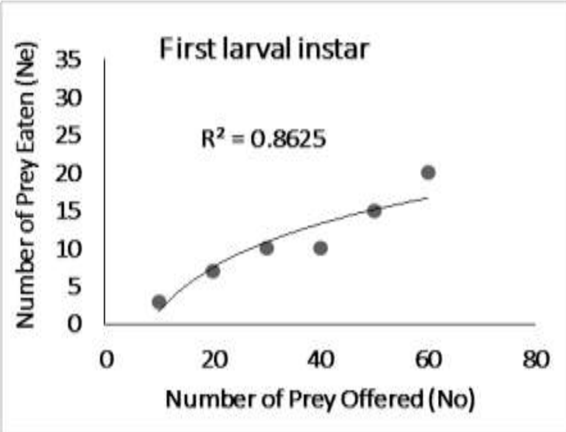
$$N_e = N_o \{1-\exp [bNo(T_h N_e-T)/]\} \quad (4)$$

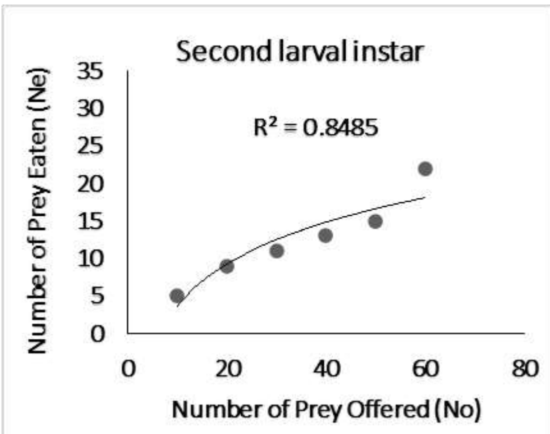
Parameters like, attack rate (a) and handling time (T_h) parameter for functional response type II or attack coefficient (b) for type III will be estimated by applying nonlinear least square regression in Microsoft office 365.

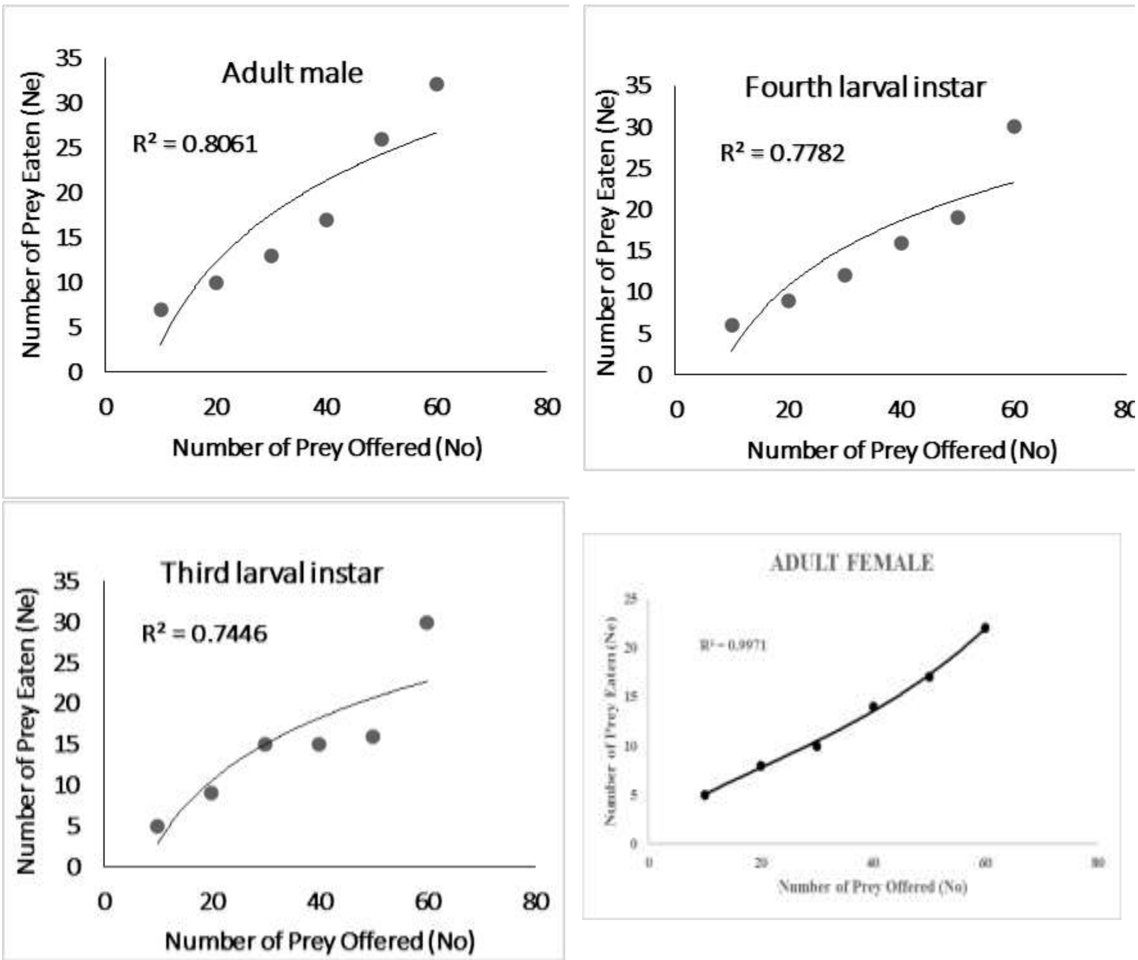
All the outcomes were statistically analyzed to one-way ANOVA and means were compared by using the Tukey test (5%) using IBM SPSS® Version 19.

III. RESULTS

Figure 1 reveals the functional response of *M. sexmaculatus* to *Thrips tabaci* and based on logistic regression (Table 1), *M. sexmaculatus* showed functional response type III in all the stages. As the prey density increases the prey consumption *of M. sexmaculatus* increases with the increase in search rate (Figure 3). In table 2, the lowest handling time (Th) was recorded in the sequence of the fourth instar (0.5454±0.22249 h) followed by adult female (0.6042±0.18665 h), adult male (0.7454±0.22249 h), third (0.9282±0.47476 h), second (1.01±0.65422 h) and first instar (1.285±0.741 h), respectively. The attack coefficient (b) 0.0227±0.00927, 0.0230±0.00927, 0.025±0.0077, 0.037±0.02, 0.042±0.027, 0.0535±0.031 was recorded for fourth instar larvae, adult female, adult male, third, second, and first instar larvae correspondingly. The highest theoretic maximum predation restricted by the upper asymptote defined by the ratio of T/T_h [12] of a fourth, adult female, adult male, third, second and first larval instars of *M. sexmaculatus* were estimated as 44, 39, 32, 25, 23 and 18 to onion thrips, respectively.







Figg. 1. Functional responses of *Menochilus sexmaculatus* against *Thrips tabaci*

TABLE1

Functional Response of *Menochilus sexmaculatus* Against *Thrips tabaci* Based on Logistic Regression Estimate Using (No/Ne)

Zigzag beetle	Cubic	Quadratic	Linear	Model
1st Instar	0.0003±0.0002	-0.026±0.02	1.0001±0.737	Type III
2nd Instar	0.0003±0.0002	-0.031±0.02	1.1398±0.599	Type III
3rd Instar	0.0004±0.00005	-0.04±0.003	1.5312±0.2958	Type III
4th Instar	0.29580±0.00026	-0.01±0.027	0.4453±0.84783	Type III
Adult male	0.0001±0.00013	-0.011±0.01	0.6679±0.45743	Type III
Adult female	0.0011±0.000	-0.01±0.014	0.670±0.460	Type III

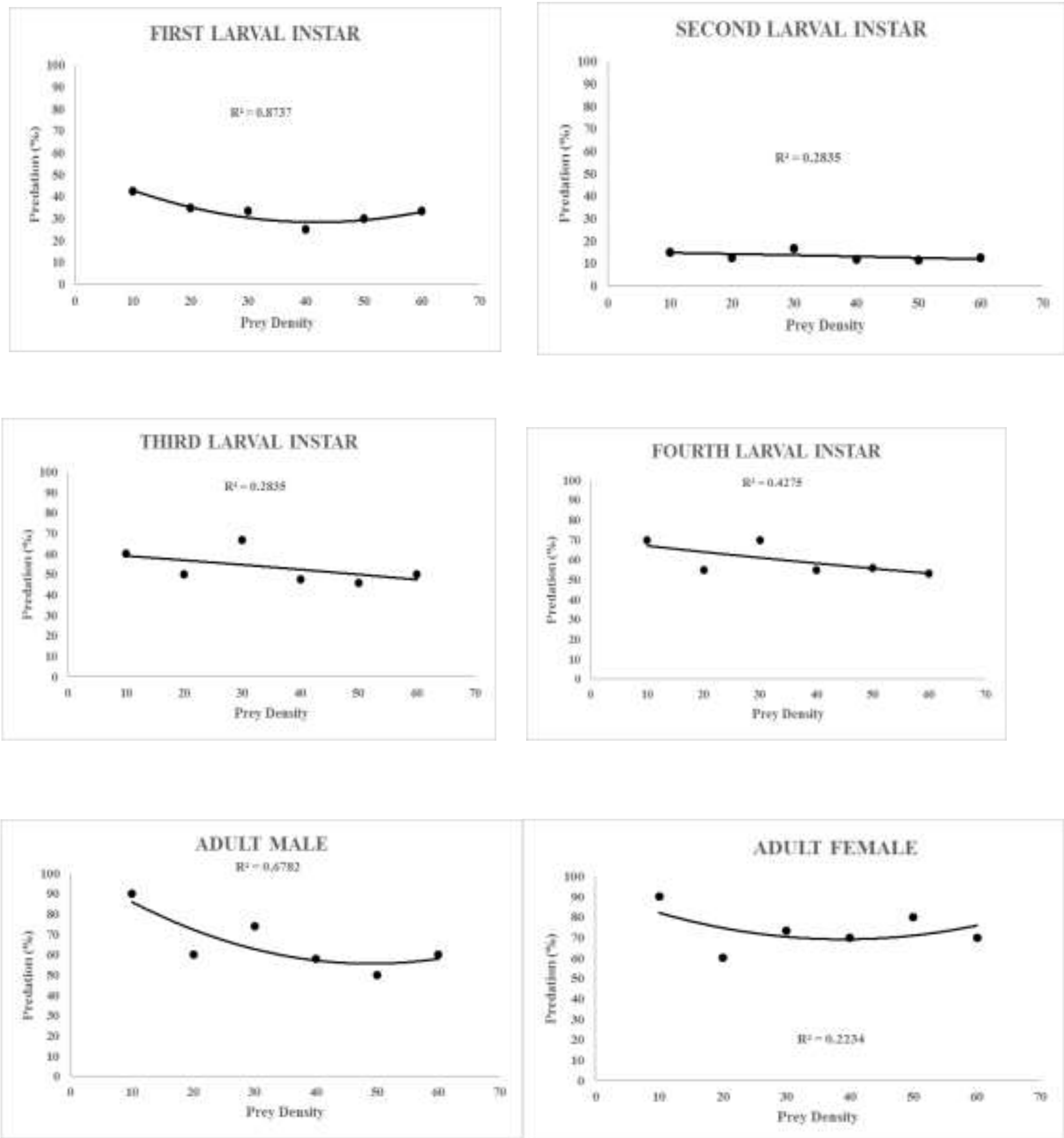


Fig. 3. Predation Percent of *Menochilus sexmaculatus* (adult male and female) against *Thrips tabaci*

TABLE 2

Parameters for the Functional Response of *Coccinella septempunctata* to *Thrips tabaci*

1st Instar		2nd Instar		3rd Instar		4th Instar		Adult Male		Adult Female	
a (h^{-1})	Th (h)	a (h^{-1})	Th (h)	b	Th (h)	b	Th (h)	b	Th (h)	b	Th (h)
0.023 ± 0.007a (0.01-0.05)	1.8444 ± 1.461A (0.09-1.44)	0.025 ± 0.008a (0.01-0.05)	0.52 ± 0.278B (0.00-1.17)	0.076 ± 0.060b (0.0029-0.257)	0.519 ± 0.313C (0.07-6.19)	0.0138 ± 0.159d (0.006-0.0337)	0.333 ± 0.159F (0.15-0.81)	0.0210 ± 0.0058c (0.011-0.036)	0.518 ± 0.14D (0.25-0.86)	0.0215 ± 0.0058c (0.010-0.034)	0.420 ± 0.14E (0.25-0.86)

Figures after similar letters inside a column are not significantly dissimilar from each other at the 5% Tukey test.

Figure 2 reveals the functional response of *Coccinella septempunctata* to *Thrips tabaci* and based on logistic regression (Table 3) *C. septempunctata* showed functional response type II in first and second larval instars whereas type III in third, fourth, and adult female and male.

As the prey density increases the prey consumption of *C. septempunctata* increases (Figure 4). In table 4, the lowest handling time (Th) was recorded in the sequence of the fourth instar (0.333 ± 0.159 h) followed by adult female (0.420 ± 0.14 h), adult male (0.518±0.14 h), third (0.519 ± 0.313 h), second (0.52 ± 0.278 h) and first instar (1.8444 ± 1.461 h), respectively. The attack rate for first and second instar larvae to onion thrips was 0.023±0.007 h^{-1} and 0.025 ± 0.008 h^{-1}, whereas the attack coefficient (b) 0.0138 ± 0.159, 0.0215 ± 0.0058, 0.0210 ± 0.0058, 0.076 ± 0.060 was recorded for fourth instar larvae, adult female, adult male and third instar larvae, respectively. The highest theoretic maximum predation restricted by the upper asymptote defined by the ratio of T/T_h [12] of a fourth, adult female, adult male, third, second and first larval instars of *C. septempunctata* were estimated as 72, 57, 46, 46, 46 and 13 to onion thrips, respectively.

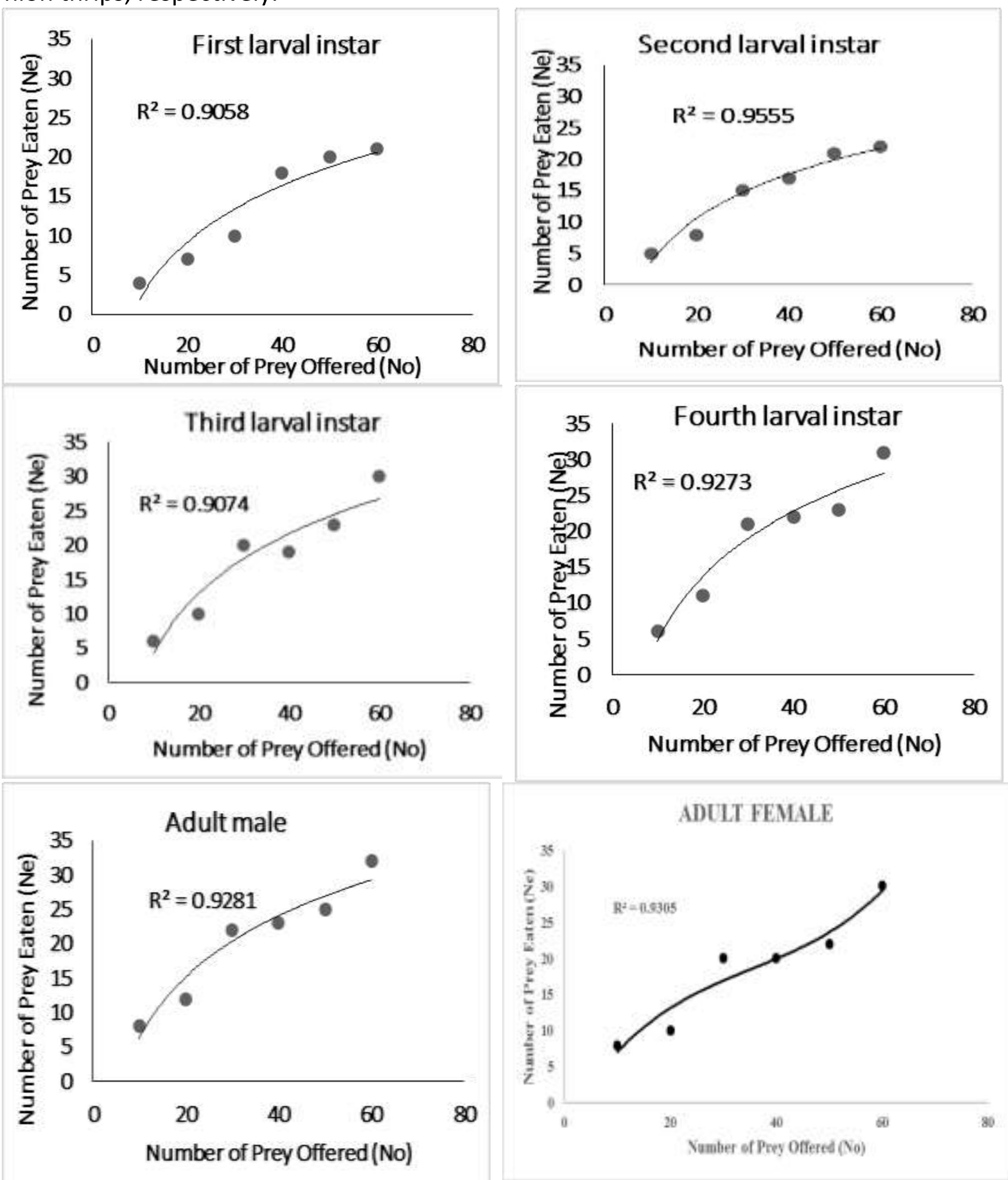


Fig. 2. Functional responses of *Coccinella septempunctata* (adult male and female) against *Thrips tabaci*

TABLE 3

Functional response of *Coccinella septempunctata* to *Thrips tabaci* based on logistic regression estimate using (No/Ne)

Seven spotted beetle	Cubic	Quadratic	Linear	Model
1st Instar	-0.0004±0.00014	0.345±0.1363	-0.5632±0.3887	Type II
2nd Instar	-0.0009±0.00071	0.0224±0.01094	-0.2284±0.33349	Type II
3rd Instar	0.0003±0.00014	-0.0337±0.01592	1.5324±0.57779	Type III
4th Instar	0.0002±0.00020	-0.0273±0.02100	1.4035±0.68593	Type III
Adult male	0.0002±0.0002	-0.0216±0.02101	1.1816±0.68652	Type III
Adult female	0.001±0.000	-0.0310±0.022	1.182±0.687	Type III

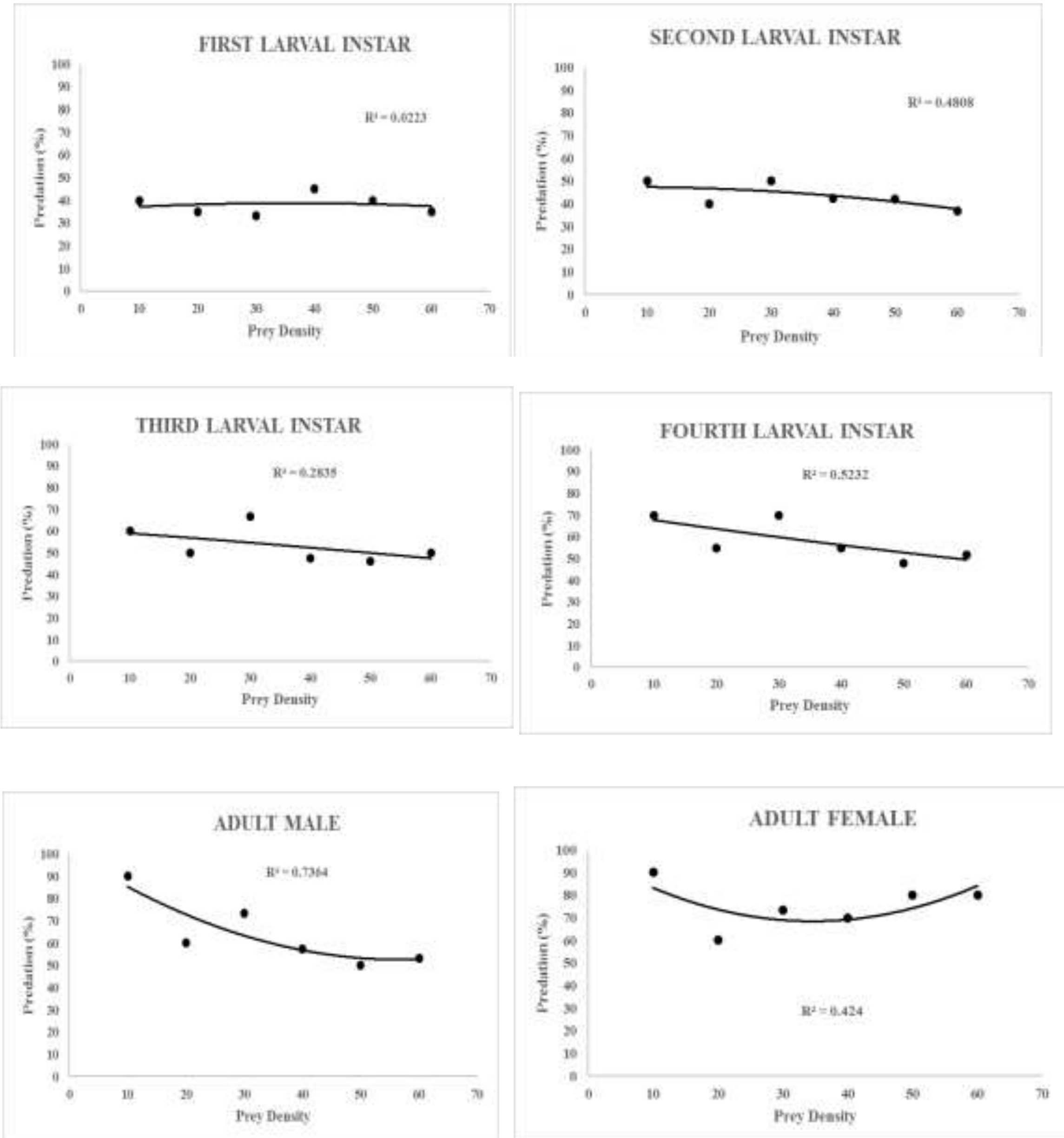


Fig. 4. Predation Percent of seven spotted ladybird beetle against *Thrips tabaci*

TABLE 4
Parameters for the functional response of *Menochilus sexmaculatus* against *Thrips tabaci*

1st Instar		2nd Instar		3rd Instar		4th Instar		Adult Male		Adult Female	
b	Th (h)	B	Th (h)	b	Th (h)	b	Th (h)	b	Th (h)	B	Th (h)
0.0535 ± 0.031a	1.285 ± 0.741A	0.042 ± 0.027b	1.01 ± 0.654228B	0.037 ± 0.020c	0.9282 ± 0.47476C	0.0227 ± 0.00927f	0.5454 ± 0.22249F	0.025 ± 0.0077d	0.7454 ± 0.222490D	0.0230 ± 0.00927e	0.6042 ± 0.18665E
(0.017-0.145)	(0.41-3.50)	(0.0020-0.121)	(0.05-2.91)	(0.002-0.085	(0.05-2.04)	(0.001-0.037)	(0.01-1.05)	(0.005-0.0395)	(0.03-1.00)	(0.0004-0.0437)	(0.12-0.95)

4 Discussions

Most of the species of ladybird beetles are studied singly in laboratory conditions and functional response type II is predominated [14]. The studies on various species of ladybird beetles showed that it exhibits a functional response of type II [15]-[17]. Though, there are also reports that ladybird beetles exhibit type III functional response [18]-[20].

Both the species of ladybird beetle foraging on thrips mostly exhibit type III functional response which may result from the predator learning that is prey switching [12]. This might also be due to less handling and processing time of prey. This will increase the killing power of the predator as either the predator processes prey more quickly or the predator will extract less content. These results are the same as Peterson et al. [21], the handling time of the adults of the ladybird *Stethorus bifidus* foraging on *Tetranychus lintearius*. The predator extracts less of the killed prey contents. The ladybird beetles feed voraciously on thrips because they are the essential host [22]-[27]. Both the species of ladybird beetle showed a significant increase in consumption of onion thrips with the increase in density. The handling time was lower for the fourth instar larvae than of female adult, male, third, second and first instar correspondingly. The results indicate mostly the stages of ladybird beetle on onion thrips reveal the functional response of type III. This finding is in the line with previous studies by Sarmento et al. [18]. The studies with type III indicate that the ladybird beetle is an efficient biological control agent [28]. As the increase in the sigmoidal curve of functional response type III, the predator is presumed to learn how to circumvent difficulties associated with prey capture [5], [29].

The highest number consumed by a fourth instar, then of adult female and male. This result coincides with the results of Kumar [5]. Thus, the fourth instar larvae are supposed to be a good biological agent. This high predation may be due to the high nutrient requirement through their following non-feeding pupal period. Finding in this study also shows that a maximum number of thrips was consumed by females followed by the male. This result can be correlated with a captured threshold as female has a bigger gut than male [30].

Predators having the lower handling time are considered to be efficient biocontrol controlling agents. The handling time is compared to prey size; the larger size makes the predator avail larger size time to consume it [31]. The females of ladybird beetles; *Cheilomenes sexmaculata*, *Propylea dissecta*, and *Coccinella transversalis* against the aphid, *Myzus persicae*. The handling time was 0.0043, 0.01 and 0.0056 h, respectively [32].

Mandour and El-Basha [33] studied the handling time of the ladybird beetle, *Cydonia vicina nilotica* on host *Aphis craccivora.* The handling time of the fourth larval instar along with an adult male and female was 0.0086, 0.0069, and 0.0115 h, respectively.

The data presented in this study show how the two ladybird beetles responded to the changes in the thrips density. Fourth instar larvae have consumed most thrips in both species. Consequently, the fourth stage is being a good potential predator against thrips.

This study on functional response in controlled laboratory conditions is always being disapproved by many researchers because the prey consumed by a predator might change in normal field conditions due to the predator and prey surroundings, for instance, meteorological conditions, intra and inter-specific competition, competition between the beneficial species, presence of alternate prey. Though, laboratory-based observations are presented as an effective approach.

5 CONFLICT OF INTEREST

The authors declare that there is no any conflict of interest regarding the publication of this article.

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