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Functional response of three species of predatory pirate bugs to different densities of blossom thrips, *Frankliniella schultzei* Trybom (Thysanoptera: Thripidae)

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The functional response of three anthocorid bugs, namely *Blaptostethus pallescens* Poppius, *Cardiastethus affinis* Poppius and *Montandoniola indica* Yamada (Heteroptera: Anthocoridae) was assessed by feeding them with different densities of thrips larvae of *Frankliniella schultzei* (Trybom) in the laboratory. Predation rate of all the three species increased with

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increasing prey densities. Both *B. pallescens* and *C. affinis* exhibited type-II response and *M. indica* exhibited type-III response. Among the predators, *M. indica* proved to be effective as it showed highest predation rate, higher 1/Th, higher a/Th and lowest handling time followed by *B. pallescens*. It is evident from the present study that *M. indica* and *B. pallescens* could be used in augmentative biological control programmes for thrips.

Keywords: Anthocorid bugs, blossom thrips, functional response, predation rate.

IN an agro-ecosystem, each species interacts with many other species. Prey-predator relationship plays an important role in biological control¹. Efficiency of the predator depends on how it is able to regulate the density of its prey². Various biological and behavioural studies are required to understand biocontrol potential of a predator. Functional and numerical responses are key components in the selection of highly efficient predators for biological control programmes³. The functional response describes the rate at which a predator kills its prey at different prey densities, which shows the efficiency of a predator in regulating prey populations².

Frankliniella schultzei (Trybom) (Thysanoptera: Thripidae), is a polyphagous pest feeding on 83 species of ornamental and vegetable plants covering 55 families worldwide^{4,5}. It is also an established vector of several viral diseases, viz. tomato spotted wilt tospovirus (TSWV)^{6,7}, tomato chlorotic spot tospovirus (TCSV), groundnut ring spot tospovirus (GRSV)⁷ and tobacco streak ilarvirus (TSV)⁸. In India it has been reported to cause damage to tomato, tobacco, cotton, grain legumes, groundnut and lettuce⁹.

Anthocorids are efficient predators of thrips¹⁰⁻¹². In addition to thrips, they feed on other insects and by virtue of this habit they are categorized as a generalist predator. For instance, *Blaptostethus pallescens* Poppius has been observed as a potential predator of maize stem borer *Chilo partellus* (Swinhoe)¹³ and two-spotted spider mite *Tetranychus urticae* Koch¹⁴. *Cardiastethus affinis* Poppius was recorded as an efficient predator of *Opisina arenosella*¹⁵. It was also observed to feed on the eggs and larvae of *Corcyra cephalonica* (Stainton) and *Anadevidia* (= *Plusia*) *peponis* (Fabricious) in the laboratory¹⁵. Equally competent are members of the genus *Montandoniella*^{11,16}, of which *Montandoniella indica* Yamada has been observed to be a prominent predator of a *Liothrips karnyi* (Bagnall) infesting the foliage of black pepper in Kerala, India¹⁷. It was also found preying on *Gynaikothrips uzeli* (Zimmermann) infesting *Ficus retusa* in Karnataka, India¹⁸.

In the present study, the three above-mentioned predators have been recorded feeding on *F. schultzei* in the laboratory. Functional response is useful to determine

efficacy of predators. Though there are studies on functional response of *B. pallescens* against the eggs of *Tuta absoluta* Meyrick, there is no study on the type and magnitude of functional response of these anthocorid bugs, viz. *B. pallescens*, *C. affinis* and *M. indica* against *F. schultzei*. Therefore, the present study was conducted to determine the functional response and predation rate of the above predators to varying densities of *F. schultzei*. This information will be useful to improve our understanding of predator-prey interactions and formulating strategies for the biological control of thrips in general and *F. schultzei* in particular.

Culture of *F. schultzei* was obtained from a capsicum field, Bengaluru, India and identified by an expert at NBAIR, Bengaluru. Thrips adults were exposed to French bean pod for egg-laying. After 24 h, the beans were kept in a separate container for hatching. Once nymphs were hatched, old bean pods were replaced by new ones. The anthocorid predators *B. pallescens*, *C. affinis* and *M. indica* were reared in the laboratory on bean pods (ovipositional substrate) and provided with UV-irradiated *C. cephalonica* eggs as prey¹⁸⁻²⁰. All the cultures were maintained at $26^{\circ} \pm 2^{\circ}\text{C}$, $65\% \pm 10\%$ relative humidity with an approximate photoperiod of 12:12 (L:D). Adequate number of nymphs were raised in the laboratory.

Prior to the functional response study, adults of all the three species of anthocorid bugs were transferred from the stock culture into plastic containers (200 ml) containing tomato leaf disks artificially infested with *F. schultzei* nymphs. One complete generation of all the three predators was maintained on *F. schultzei* to acclimatize them under laboratory conditions to the target prey before initiating the experiment. Young females of each anthocorid species were exposed to different densities of *F. schultzei*. Prior to the experiment, each female was kept starved for 24 h, during which only water was provided. The experiment consisted of a tomato leaf with three leaflets placed ventral side up (avoiding the major veins) on a piece of tissue paper in a small, ventilated round plastic box (7.5 cm diameter and 2.5 cm height). Based on preliminary tests, seven densities (1, 3, 6, 9, 15, 18 and 30/leaf arena) of *F. schultzei* were presented to each female bug. Nymphs of thrips were transferred on the leaf arena gently using a fine camel brush. The plastic boxes were held in an incubator ($26^{\circ} \pm 2^{\circ}\text{C}$, $65\% \pm 10\%$ RH, 12L:12D photoperiod). The experimental units were examined after 24 h to record the number of nymphs consumed. For each prey density, five replications were maintained. The prey consumed by the anthocorid females in each replication were not replaced during the experimental period.

The data on consumption rates were analysed by general linear model, to compare the mean number of thrips consumed by each bug for each density. All these analyses were done using SAS 9.3 (ref. 21).

The shape of the curve was determined by polynomial logistic regression of the proportion of prey consumed as a function of the available prey density. The polynomial function described by Juliano²² was used

$$\frac{N_a}{N_0} = \frac{\exp(P_0 + P_1N + P_2N^2 + P_3N^3)}{(1 + \exp(P_0 + P_1N + P_2N^2 + P_3N^3))}, \quad (1)$$

where N_a is the number of prey consumed, N_0 the initial prey number available and P_0, P_1, P_2 and P_3 are the intercept, linear, quadratic and cubic coefficients respectively, which can be estimated using the maximum likelihood method²³. If $P_1 > 0$ and $P_2 < 0$, the proportion of prey consumed is positively density-dependent, thus describing a type-III functional response. If $P_1 < 0$, the proportion of prey consumed declines monotonically with the initial number of prey offered, thus describing a type-II functional response²². Once the type of functional response was identified, the next step was to estimate searching efficiency (a) and handling time (T_h). In the present analysis, Rogers' type-II random predator equation was adopted instead of Holling's disc equation in order to estimate the functional response parameters, since the latter is based on an assumption of unchanging prey density²⁴ and thus not suitable for the present experiment. On the other hand, Roger's type-II equation was preferred for modelling of type-II functional response as it does not assume constant prey density, because prey was depleted during the experiment^{22,24}. Rogers' type-II random predator model was fitted using the following equation^{25,26}

$$N_a = N_0 \{1 - \exp[a(T_h N_a - T)]\}, \quad (2)$$

where N_a is the number of prey consumed, N_0 the initial prey density, a the attack rate (h^{-1}), T_h the handling time (h) and T is the total time (24 h).

For modelling of type-III functional response with prey depletion, we have used the following equation suggested by Hassell and co-workers^{27,28}.

$$N_a = \frac{N_0 \{1 - \exp[(d + dN_0)(T_h N_e - T)]\}}{(1 + cN_0)}, \quad [3]$$

where a increases with prey density and thus cannot be assumed as a constant. In eq. (3), b, c and d are constants from the function that relate a and N_0 in type-III functional responses

$$a = \frac{d + bN_0}{1 + cN_0}, \quad (4)$$

$$a = \frac{bN_0}{1 + cN_0}. \quad (5)$$

Here d is not significantly different from 0, so it was removed.

Predator's attack rate per handling time (a/T_h)^{29,30} and the theoretical maximum number of prey killed in 1 h could be calculated as $1/T_h$ (ref. 31).

Pairwise difference between *B. pallescens* and *C. affinis* for estimated parameters has also been tested using nonlinear least squares with indicator variables and implicit function (eq. (6)) for data fitted with Rogers' random predator equation²²

$$0 = N_0 - N_0 \exp\{[a + D_a(j)]\{[T_h + D_{T_h}(j)](N_a) - T\}\}, \quad (6)$$

where j represents an indicator variable which takes values zero for the first dataset or one for the second dataset. The parameters D_a and D_{T_h} show differences in searching efficiency and handling time between the two anthocorid species respectively. Specifically, the attack rate for one species is a , and that for another species is $a + D_a$. If these parameters are significantly different from zero, then the two species differ significantly in the corresponding parameters^{22,31}.

Results showed significant difference in predation rate at varying prey densities ($F = 198.77$, $df = 6, 84$, $P < 0.001$) and for different predator species ($F = 35.76$, $df = 2, 84$, $P < 0.001$). Moreover, the interaction between densities and predator species was also found significant ($F = 6.02$, $df = 12, 84$, $P < 0.001$). Results indicated that *M. indica* was able to consume significantly more number of thrips nymphs (22.6) within 24 h than the other two predator species. Though *B. pallescens* appeared to consume more number of thrips than *C. affinis*, there was no significant difference between these two predators in terms of predation rate within most of the thrips densities (Table 1).

Based on logistic regression analyses, it was observed that *M. indica* exhibited type-III response because linear parameters were positive whereas the quadratic parameters were negative, and all these parameters were significantly different from zero (Table 2 and Figure 1). This

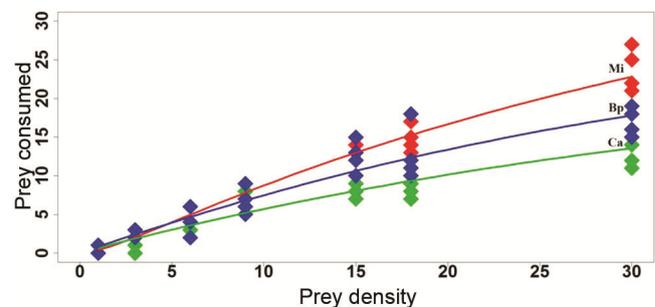


Figure 1. Functional response of anthocorids at different prey densities. Each data point represents the observed number of thrips consumed. Curve was fitted using the Roger's equation. Mi, *Montandoniola indica*; Bp, *Blaptostethus pallescens* and Ca, *Cardiastethus affinis*.

Table 1. Mean number of thrips larvae (*Frankliniella schultzei*) consumed by anthocorids

Prey density	Anthocorid predators		
	<i>Blaptostethus pallescens</i>	<i>Cardiastethus affinis</i>	<i>Montandoniola indica</i>
1	0.4 ^a ± 0.16	0.6 ^a ± 0.28	0.4 ^a ± 0.24
3	2.6 ^a ± 0.24	0.8 ^b ± 0.37	2.2 ^a ± 0.37
6	4.0 ^a ± 0.89	4.2 ^a ± 0.8	4.8 ^a ± 0.49
9	6.8 ^a ± 0.66	6.4 ^a ± 0.60	7.6 ^a ± 0.68
15	12.4 ^a ± 0.81	7.8 ^a ± 0.37	13.4 ^a ± 0.92
18	12.4 ^{ab} ± 1.43	8.8 ^b ± 0.66	15.2 ^a ± 0.80
30	16.8 ^b ± 0.73	13.6 ^b ± 0.92	22.6 ^a ± 1.58

Values bearing lowercase letter compare means among three predators within each egg density in a row. The same lowercase letters are not significantly different (one-way ANOVA, when $P < 0.05$ PROC GLM). Each value represents mean (±SE) number of thrips larvae consumed by adult females of anthocorid species at 26° ± 2°C at various prey densities for 24 h.

Table 2. Logistic model prediction on prey consumption by the anthocorid predators

Parameters		Anthocorid predators [†]		
		<i>B. pallescens</i>	<i>C. affinis</i>	<i>M. indica</i>
Type of response		II	II	III
Constant (P_0)	Intercept	1.515	0.530	0.355
	SE	0.265	0.232	0.508
	P-value	1.12e-08***	0.022*	0.484
Linear (P_1)	Intercept	-0.039	-0.024	0.183
	SE	0.011	0.010	0.066
	P-value	0.0009***	0.024*	0.005**
Quadratic (P_2)	Intercept	NA	NA	-0.005
	SE			0.001
	P-value			0.002**

*Significant at $P < 0.05$. **Significant at $P < 0.01$. ***Significant at $P < 0.001$. NA: Not applicable.

[†]Maximum likelihood estimates (±SE) for parameters of the logistic model fit to proportion of prey consumed versus initial prey density for three anthocorids at 26° ± 2°C.

indicates that the proportion of *F. schultzei* consumed by *M. indica* is positively density-dependent, which shows a type-III functional response.

The functional response parameters of *M. indica* preying *F. schultzei* over a 24 h period were estimated using eq. (3). The handling time (T_h) for *M. indica* as estimated by eq. (3) was 0.015 h (Table 3). Attack rate for type-III functional response for this anthocorid bug was also determined using nonlinear least square regression, which indicated that the parameter d was not significantly different from zero, therefore, it was removed from the model and a reduced model was used (eq. (5)). Here, attack rate increased to asymptote. The estimated attack rates of *M. indica* at densities 1, 3, 6, 9, 15, 18 and 30 were 0.37, 0.69, 0.89, 0.98, 1.06, 1.09 and 1.15 h⁻¹ respectively.

Type-II response was observed for *B. pallescens* and *C. affinis* (Table 2 and Figure 1). Logistic regression had a significant negative linear parameter ($P_1 < 0$), indicating that the proportion of prey consumption decreased as thrips density increased, which further confirms type-II

functional response for these predators. The functional response of these two predators over a 24 h period was estimated by Rogers' random predator equation (eq. (2)). Attack rate of 1.721 h⁻¹ and handling time of 0.027 h were observed for *B. pallescens*. Similarly, for *C. affinis* handling time and attack rate were 0.030 h and 1.016 h⁻¹ respectively (Table 3).

The values of a/T_h for *B. pallescens* and *C. affinis* were 63.74 and 33.86 respectively. For *M. indica*, value of a/T_h was 24.66, 46, 59.33, 65.33, 70.66, 72.66 and 76.66, at prey densities varied from 1 to 30. Theoretically, the maximum number of prey killed by *B. pallescens*, *C. affinis* and *M. indica* in 1 h was 37.03, 33.33 and 66.66 respectively. Pairwise differences between functional response parameters estimated by Rogers' random predatory equation revealed that the value of D_a obtained between *B. pallescens* and *C. affinis* was 0.70372 (0.30136)* ($P < 0.05$) and D_{T_h} was -0.00336 (0.01428).

In the present study, type-III response was observed in *M. indica*, where predation increased after density value 6, with upper processing limit of 22.6 thrips per 24 h.

Table 3. Coefficient of attack rate and handling time and other derived parameters for three anthocorid predators

Predator	Attack rate (a) (h^{-1})			95% CI		Handling time (T_h) (h)	95% CI		T/T_h	$1/T_h$
	a	b	c	Lower	Upper		Lower	Upper		
<i>B. pallescens</i>	1.721	–	–	1.206	2.44	0.027	0.006	0.038	888.80	37.03
<i>C. affinis</i>	1.016	–	–	0.702	1.598	0.030	0.004	0.055	800	33.3
<i>M. indica</i>	–*	0.532	0.431	0.205	0.915	0.015	0.002	0.031	1600	66.6

*In the best-fit type-III model, $a = bN_0/1 + cN_0$; b and c values are given in the table. N_0 is the initial prey density.

Both *B. pallescens* and *C. affinis* exhibited type-II response, where with increased density the number of thrips consumed increased at a decreasing rate with an upper plateau of 16.8 and 13.6 thrips consumed per 24 h, respectively. Type-II and type-III functional responses were reported earlier for other species of anthocorids. Several studies reported type-II functional response for anthocorids species, like *Orius albidipennis* Reuter, *O. majusculus* (Reuter), *O. laevigatus* (Fieber), *O. insidiosus* (Say), *Xylocoris flavipes* (Reuter) and *Anthocoris minki pistaciae* Wagner^{32–37}. A type-III functional response was also reported for a few anthocorid species (*B. pallescens*, *Amphiareus constrictus* (Stal), *O. niger* (Wolf.) and *O. insidiosus*) at certain temperatures^{38–40}.

Functional response parameters, viz. attack rate and handling time are used to determine the magnitude of functional responses. Handling time is the time spent pursuing, subduing and consuming each prey and that spent while preparing to search for the next prey. In the present study, handling time was less for *M. indica*, followed by *B. pallescens* and *C. affinis*. However, there was no significant difference between handling time of *B. pallescens* and *C. affinis*. In the present study, handling time for all predators ranged from 0.015 to 0.030 h. This is commensurate with the findings of Zamani *et al.*⁴¹ and Nesrin *et al.*⁴² who reported values ranging from 0.0122 to 0.0225 h and 0.005 to 0.012 h for *O. albidipennis* respectively, when fed on *Tetranychus urticae* Koch. Nevertheless, higher handling times were reported by other researchers^{37,40,43}.

Because *M. indica* showed type-III response, attack rate of this predator is a dynamic parameter which increases with increasing prey density, the attack rate was 1.15 h^{-1} at the highest density. There was significant difference in the attack rate of *B. pallescens* and *C. affinis*. Among all the predators, highest attack rate was observed for *B. pallescens*, which was considerably higher than those for *B. pallescens* to *T. absoluta* eggs⁴⁰; *O. albidipennis* to *Megaleurothrips sjostedti* Trybom³⁶ and *O. sauteri* (Poppius) to *T. urticae*⁴³. However, it was comparable with the attack rate of 1.613 and 1.267 h^{-1} for fourth instar and female *O. albidipennis* respectively, when fed on eggs of *T. urticae*⁴².

In the present study, predation rate of *M. indica* was 1.34 and 1.66 times more than *B. pallescens* and *C. affi-*

nis respectively. This may be due to its low handling time, high a/T_h and high $1/T_h$ values. Nesrin *et al.*⁴² and Zamani *et al.*⁴¹ reported the highest theoretical predation rate for *O. albidipennis* as 81.96 and 80 respectively, when fed on *T. urticae*.

M. indica and *B. pallescens* proved to be efficient predators against common blossom thrips compared to *C. affinis*. Though the present study was conducted in the laboratory in a small arena, it gives an insight into the behaviour of these anthocorids and their predation rate against common blossom thrips. There are few reports on functional response studies of these three anthocorids. Results of the present study also show that *M. indica* and *B. pallescens* might be considered for augmentative biological control against *F. schultzei*, which is a serious problem in capsicum grown in polyhouses in India. However, ecological characteristics of these predators need to be studied in natural field conditions, where predation would be affected both by biotic and abiotic factors. In field conditions, if these predators are released together there would be many factors like competition and intra-guild predation which may affect their role in the suppression of pest population. The predators may occupy different niches, show different prey preferences, host plant preference, etc. Their behaviour, prey preference, and switching to other insect pests must be studied extensively in order to understand the ecology of these predators⁴⁰. Functional response studies can improve our understanding about the behaviour of these predators, but field-based studies are warranted to understand their interaction with different prey and their persistence in the field, which would pave the way to formulate augmentative biocontrol strategies against thrips.

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