



Full Length Article

Functional Response of the Predator *Xylocoris flavipes* to three Stored Product Insect Pests

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ABSTRACT

The warehouse pirate bug, *Xylocoris flavipes* (Reuter) (Hemiptera: Anthocoridae), is a predator of many stored product insect pest. This study evaluated the functional response of *X. flavipes* with different densities of the prey species *Tribolium confusum* Duval, *Tribolium castaneum* (Herbst) and *Cryptolestes pusillus* (Schon.): empty glass jars (no wheat kernels) and glass jars filled with wheat kernels. Numbers of prey (host) attacked by predator females were greater than those attacked by predator males ($P < 0.01$) in both habitats for some of the prey life stages and species.

Key Words: Functional response; Predator; *Xylocoris flavipes*; Stored pests

INTRODUCTION

Storage losses from insect attack are often as great as sustained by the growing crops. Estimates of losses to the world's supply of stored grains from insect damage ranges from 5-10% of the world production (Burkholder, 1990). In tropical countries 20% or more may occur through the insect attack after harvest (Mondal & Port, 1995), because the climate and storage condition in the tropical countries are highly favourable for insect growth and development. In Bangladesh the annual loss amounts to over 100 crores taka (Alam, 1971).

Recently, pest management in stored commodities is facing many obstacles such as restrictions on the use of certain pesticide resistance in pest population, which pose possible health hazards and a risk of environmental contamination. Entomologists throughout the world spend a great deal of time and effort in attempt to determine the presence of beetles in stored grains, check their infestations and design better and safer methods to bring them under control. Control measures of different nature are being adopted at farm, market and public sector storage that consists of use of native or natural methods of control by plant materials and/or contact insecticides and fumigants (Maina & Lale, 2004; Hussain *et al.*, 2005).

Biological control is an over-looked component of integrated pest management of stored product pest (Flinn, 1998). Many species of insect natural enemies occurs in stored product ecosystem (Brower *et al.*, 1996) and these species represent potential biological control agents for the desired pests.

The anthocorid bug, *Xylocoris flavipes* (Reuter) is a

cosmopolitan predator of different prey (pests) of stored commodities namely *Tribolium castaneum*, *T. confusum*, *Cryptolestes pusillus*, *Rhizopertha dominica* and *Trogoderma granarium* (Ahmed, 1991). According to Arbogast (1976), *X. flavipes* predate on 13 species of insects belonging to three orders. The suppression of some pest population (prey) has been reported and advocated by several workers in their studies (Arbogast, 1976; Brower & Press, 1992).

Functional response is usually measured to provide insights into the suitability of a predator as a biological control agent (Isikber, 2005). For a predator, it is a key factor regulating population dynamics of predator-prey systems (Mandour *et al.*, 2006). Determining the effects of predations on prey populations is most commonly done through the analysis of functional and numerical responses (Huffaker & Messenger, 1976). The 'functional response' defines the rate of prey by a given number or density of predators, as a function of prey density (Holling, 1959b) and therefore, can predict the maximum number of prey attacked that can be used to help predict predator development, survival and reproduction (Oaten & Murdoch, 1975).

Early functional response research was conducted by Holling (1959a & b), who formulated the mathematical models (Type I, Type II & Type III) to describe predatory responses that were influenced by changes in predator behavior. Type I responses are mathematically simplest and are exemplified by a predator with a constant search rate over all densities and a random search pattern. The number of prey killed per predator in a Type I system would be directly proportional to prey density, thus yielding a linear response until satiation is reached (Hassell, 1978). Type II

responses incorporate predator handling time, which refers to the act of subduing, killing and eating a prey and then perhaps cleaning and resting before moving on to search for more prey. The number of prey attacked increases at a constant initial rate under the Type II model but then it increases at an ever decreasing rate as satiation is approached. Most arthropod predator possess a type II response (Holling, 1961; Royama, 1971; Oaten & Murdoch, 1975; Hassell, 1978; Luck, 1985) with some exceptions (Tostowaryk, 1972; Hassel *et al.*, 1977). The third form of functional response (Type III) is sigmoidal with a slow increasing attack rate as a predator experiences increased prey density and then decreasing as a predator approaches satiation at higher prey densities. The sigmoidal shape is thought to be the result of a change in predator search activity with changes in prey density (Holling, 1959a; Hassell, 1978).

A number of workers studied the functional response of *X. flavipes* on different stored product insect pests (Brower *et al.*, 1996; Sing, 1997). However, information on functional response accomplished in *X. flavipes* on *C. pusillus* are not available. Present study was undertaken to (i) determine levels of predation by male and female *X. flavipes* on different life stages of three species of stored product insect pests; (ii) to detect which of the aforementioned functional response models best fits the predatory behaviour of *X. flavipes* at different experimental designs; (iii) to find out the ability of *X. flavipes* to prey at various densities in both sample habits without grain and with simulated grain habitat having prey densities.

MATERIALS AND METHODS

The pests (prey) under study were collected from the Pest Control Section, BCSIR Laboratories, Rajshahi and reared at the IPM Laboratory, Institute of Biological Sciences, Rajshahi University, Bangladesh since 2003. The eggs and pupae of the red flour beetle, *T. castaneum* were maintained in the Control Temperature (CT) room at 30°C and 65±0.5% RH. Three to five day old adult *X. flavipes* were isolated from the colony and separated according to their sexes. The prey species obtained from the previously established colonies were *T. castaneum*, *T. confusum* and *C. pusillus*.

The prey species tested were *T. confusum*, *T. castaneum* and *C. pusillus*. All preys were obtained from previously established colonies and reared under standard procedures (Howe, 1991). *T. confusum* and *T. castaneum* eggs, small (1st instars) larvae, large (4th & 5th instars) larvae and pupae whereas small (1st & 2nd instars) larvae and large (4th instars) larvae of *C. pusillus* were used in the experiment. *T. confusum* and *T. castaneum* eggs were obtained by releasing 50-100 adults in glass jars (250 mL) containing flour, which is sifted daily through 70 size mesh sieves. 1st and 2nd instars larvae of all these pest species were obtained after hatching from their eggs held in petri dishes

containing a small amount of wheat flour for 3-7 days. Fourth and fifth instars larvae and pupae were collected from the petri dishes after elapsing the respective developmental dates. Larvae and pupae were collected from the petri dishes by sieving with a 70 mesh sieves and counted carefully by a fine brush.

Empty jar assay. Laboratory functional response assays were conducted in the above mentioned pest species in 250 mL glass jars with a bottom diameter of 5.5 cm. Predators were separated by sex, starved for 24 h and released singly to the glass jars containing various densities of each prey species (various stages also). The densities for the empty jar treatments were determined in preliminary assays to ensure maximum levels of predation that could be obtained.

Densities used separately in the empty jar assays for *T. confusum* and *T. castaneum* were as follows: eggs at 50, 100, 150, 200, 250 and 300; small larvae at 10, 20, 30, 40, 50 and 60 and large larvae at 2, 4, 6, 8, 10 and 12 and pupae at 1, 2, 3, 4, 5 and 6; and *C. pusillus* small larvae at 10, 20, 30, 40, 50 and 60 and large larvae at 5, 10, 15, 20, 25 and 30. The predators were removed after 24 h and the number of prey killed were determined. Five replicates of each density were deployed for sexing of the predators and 5 control jars at each density kept without predators were used to determine the level of cannibalism and natural mortality. Prey mortality in jars with predators was detected by the mean numbers of mortality in control jars.

Wheat jar assays. Five hundred mL glass jars were used and predacious activity of the prey were evaluated on *T. confusum*, *T. castaneum* and *C. pusillus*. Each jar contained 250 g of wheat having ≈9500 kernels and 15 g of flour. The prey densities in the wheat jar experiments for *T. confusum* and *T. castaneum* were supplied in each jar at the number of eggs at 50, 100, 150, 200, 250 and 300; small larvae at 10, 20, 30, 40, 50 and 60 and large larvae at 2, 4, 6, 8, 10 and 12 and pupae at 1, 2, 3, 4, 5 and 6; and in case of *C. pusillus* small larvae at 10, 20, 30, 40, 50 and 60 and large larvae at 5, 10, 15, 20, 25 and 30. All the larval stages of the preys were allowed to disperse for an hour. The host eggs were supplied in different jars in such way that they could be dispersed uniformly from top level of 2-cm depth of wheat kernel.

The male and female predators were starved for 24 h and introduced singly to the jars for 48 h. Predators were allowed to 48 h in the wheat jar treatments as opposed to the 24 h as in the empty jars, to given for acclimation to the more complex habitat. After removal of the predators, the jars containing the eggs and small larvae were kept in the Control Temperature (CT) room until the surviving prey was large enough to count them. Five replications for each prey species and density were conducted for both male and female predators and for control jars of prey without predators. Prey mortality in jars with predators were determined by the mean number of mortality in control jars.

Data analysis. Type I and II models (Holling's, 1959a & b) and type III model of Hassel *et al.* (1977) were used as:

- Type I: $N_A = aTN$,
 Type II: $N_A = aTN/(1+aT_hN)$,
 Type III: $N_A = N [1 - \exp\{-a(T-T_hNa)\}]$

In these models, N_A is the number of prey killed, N is the initial density of prey, T is the time available for searching during the experiment, a is the instantaneous rate of discovery and T_h is the amount of time the predator handles for each prey killed. The coefficients of determination (r^2 values) were calculated by SAS LIN (SAS Institute, 1996) to determine, which non-linear model best fits the experimental values. Parameters a and T_h from the functional response models were estimated using SAS LIN method (SAS Institute, 1996).

All analysis of density effects on predations and comparisons of predation relating to male and female were completed using SAS PROC MIXED method (SAS Institute, 1996).

RESULTS

Most of functional trials resulted in a strong fit close curvilinear Type II and significantly very close with Type III model, thus allowing for interpretation as either Type II or Type III. Most of the functional response trials resulted in a strong fit to a curvilinear type II response in which most predators killed majority of the prey at low prey densities and than displayed by a decrease in the rate of predation at higher prey densities.

Predatory responses of *X. flavipes* fit either a type II or type III functional response model best in all cases based on maximum values for coefficient of determination and in most of the cases, predator's killing or attack rate is increasing up to increasing a certain prey density level and then decreasing. In case of all three prey species and their life stages, generally prey density played a significant role in predation of *X. flavipes*. *X. flavipes* killed a small number of large larvae of *T. confusum* and *T. castaneum* in empty jars and less prey killed per predator can be compared to other prey species and life stages studied. It was evident from this experiment that it was really difficult for *X. flavipes* to subdue and kill large larvae of *T. confusum* and *T. castaneum* and that these prey would actively dislodge from the predators that were attempting to attack them but in wheat jars *X. flavipes* killed slightly more large larvae of *T. confusum* and *T. castaneum* than those of the empty jars.

In the present study, *X. flavipes* killed more small and large larvae of *C. pusillus* than those of *T. confusum* and *T. castaneum* in the jars filled with wheat kernels only and in the jars with hosts only. Sex of predator influenced predation in most of the cases. Significant differences in predation due to sex was predicted in some of the cases overall experiment-wide prey density trials (Table I & II) and in all the cases, female *X. flavipes* killed more prey than those of the males.

It was evident that *X. flavipes* killed nearly as many or more prey as in wheat jars compared to empty jars with

Table I. Predation of female *X. flavipes* on eggs of *T. confusum* and *T. castaneum* in empty and wheat jars, Data have been presented as the mean number of individuals killed

Density	<i>T. confusum</i>		<i>T. castaneum</i>	
	Empty jar	Wheat jar	Empty jar	Wheat jar
50	16.17 ^a ±1.21	15.19 ^a ±1.70	22.51 ^a ±1.19	21.24 ^a ±1.80
100	22.93 ^b ±1.50	19.41 ^b ±1.54	25.26 ^b ±1.71	23.37 ^{ab} ±2.41
150	32.15 ^c ±1.51	25.13 ^c ±2.29	29.13 ^c ±0.97	27.15 ^b ±3.29
200	35.39 ^{cd} ±1.65	32.34 ^d ±1.81	40.25 ^d ±1.97	37.31 ^c ±3.11
250	37.12 ^d ±1.46	34.29 ^c ±2.24	42.39 ^c ±1.68	39.36 ^d ±3.05
300	36.69 ^d ±0.92	31.99 ^d ±1.69	40.37 ^d ±3.11	37.98 ^c ±2.96

Means in a column for a given prey type followed by different letters are significantly different at P<0.01 by DMRT
 ± represent standard error of means (n=3)

Table II. Predation of female *X. flavipes* on small larvae of *C. pusillus* in empty and wheat jars. Data have been presented as the mean number of individuals killed

Density	Empty jar	Wheat jar
10	9.01 ^a ±0.29	8.17 ^a ±0.27
20	13.27 ^b ±1.21	13.83 ^b ±1.21
30	17.75 ^c ±1.81	18.29 ^c ±1.37
40	21.56 ^d ±1.86	21.36 ^d ±1.56
50	25.40 ^e ±1.47	24.25 ^c ±1.93
60	19.89 ^{cd} ±2.16	20.78 ^d ±1.83

Means in a column for a given prey type followed by different letters are significantly different at P<0.01 by DMRT
 ± represent standard error of means (n=3)

Table III. Predation of female *X. flavipes* on large larvae of *T. confusum* in empty and wheat jars, Data have been presented as the mean number of individuals killed

Density	Empty jar	Wheat jar
2	0.61 ^a ±0.16	1.01 ^a ±0.21
4	0.57 ^a ±0.17	1.60 ^c ±0.22
6	0.73 ^{ab} ±0.15	1.45 ^b ±0.16
8	1.15 ^b ±0.23	1.53 ^b ±0.22
10	1.21 ^b ±0.25	1.63 ^c ±0.16
12	1.43 ^c ±0.16	1.57 ^{bc} ±0.17

Means in a column for a given prey type followed by different letters are significantly different at P<0.01 by DMRT
 ± represent standard error of means (n=3)

similar prey densities (Table I & II). *X. flavipes* were able to locate and kill eggs and small larvae of *T. confusum* and *T. castaneum* in wheat jars at levels similar to those were killed in empty jars irrespective of the time of prey exposed. But, in the case of *T. confusum* and *T. castaneum* large larvae, *X. flavipes* were able to locate and kill more prey in wheat jars more easily exposed than those of in empty jars (Table III).

DISCUSSION

The present results fitted a sigmoidal type III response in which there is an initial slow rate of predation followed by a fairly constant rate and then a deceleration of response as in the type II model. On the other hand statistical estimates of attack rate (a) and handling time (T_h) from

Holling's and Hassell's models may have been erroneous, because of factors such as sample size and variance of data subjected to the non-linear regression (Williams & Juliano, 1985).

Jones *et al.* (2003) observed the functional responses of *Lysiphlebus testaceipes* Cresson and *Aphidius colemani* Viereck on the greenbug, *Schizaphis graminum* Rondani at four temperatures and resulted that for both *A. colemani* and *L. testaceipes*, data were fitted to type II and type III models at all temperatures, despite of stronger fits to these models (versus type I). These results comply with the present findings.

The performance of female predators often surpasses that of their male counterparts, presumably to the heavy investment of females toward production of eggs (DeBach & Smith, 1941). In the present experiment, *X. flavipes* females killed more prey than those of males in all the cases and there was no clear trend in sex differences related to presence of grain or prey type. Parajulee *et al.* (1994) observed significant effect of sex in predation in *Lyctocoris campestris* (F.). They reported more predation by the male bugs. Donnelly and Phillips (2001) stated that the female *X. flavipes* killed more prey than the males in only 30% cases.

Recently Singh and Arbogast (2008) evaluated predatory response of *X. flavipes* to bruchid pests of stored food legumes and found exhibited a type II functional response to the majority of cosmopolitan bruchid species evaluated data were fit to Hollings's disc equation. The rate of attack on adult prey was quite low but fairly consistent, with the larger-sized female predators generally more effective. The eggs and neonate larvae of *Acanthoscelidae obtectus* were the only accessible immature stages among all species examined predation on *A. obtectus* eggs and larvae was higher than on any adult bruchids. Mean predator killed of *A. obtectus* immature stages was 40 first instar larvae or 10-20 eggs per 24 h interval.

T. confusum and *T. castaneum* small larvae were used as food for rearing *X. flavipes* in our laboratory colony; so the predators may have been adapted to chemical or physical cues associated with *T. confusum* and *T. castaneum* that may have facilitated predatory behaviour in wheat. However, *X. flavipes* had no previous adaptation to *C. pusillus* host and attacked on this prey species vigorously in wheat food medium exhibiting the potential use of this predator for biological control of stored grain insect pests. Application of insect natural enemies like *X. flavipes* in biological control programmes in stored grains needs through operational studies and validations under field conditions.

In conclusion, the exposure time of prey was different in the empty and wheat jars, being higher in the filled than in the empty jars. Number of prey attacked by females was greater than that by males. *X. flavipes* consumed more small and large larvae of *C. pusillus* than *T. castaneum* and *T. confusum* in both the habitats due to their smaller sizes. The findings may be useful for modeling population dynamics

and predicting density fluctuation between the predator and the prey.

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