Predation of Indianmeal Moth Larvae by *Lyctocoris campestris* (F.) (Hemiptera: Anthocoridae) in Different Stored Commodities[1]

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ABSTRACT Predation rates for the anthocorid predator *Lyctocoris campestris* (F.) against varying densities of late-instar *Plodia interpunctella* (Hübner) were compared in whole corn, whole wheat, or rolled oat stored commodities. More prey were attacked in corn and wheat than in oats, and female predators generally fed on more larvae than did male predators. Predation increased with an increase in prey density. This relationship was best described by a Type II functional response equation. Our results suggest that commodity type affects the number of prey attacked by this predator.

Key Words Stored products, biological control, larger pirate bug

Stored commodities are attacked by a variety of arthropods including Lepidoptera, Coleoptera, and Acari (Sinha and Watters 1985). In Minnesota, stored-grain samples taken in the late 1970's during the USDA's farmer-owned grain reserve program showed 42.9% of wheat, 83.0% of corn, and 59.6% of oat samples to be infested by insects (Storey et al. 1983), and surveys conducted in the 1980's showed 85 to 100% of stored barley to be infested (Subramanyam and Harein 1989). The total annual dollar loss due to postharvest insects in farm-stored corn, wheat, oats, and barley in Minnesota was estimated at $54.9 million (Harein et al. 1984). Insect species composition in these samples generally consisted of rusty and flat grain beetles, *Cryptolestes ferrugineus* (Stephens) and *C. pusillus* (Schönherr); red flour beetle, *Tribolium castaneum* (Herbst); sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.); foreign grain beetle, *Ahasverus advena* (Waltl); hairy fungus beetle, *Typhaea stercorea* (L.), and; Indianmeal moth, *Plodia interpunctella* (Hübner). The lesser grain

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borer, *Rhyzopertha dominica* (F.), larger black flour beetle, *Cynaeus angustus* (LeConte), and rice weevil, *Sitophilus oryzae* (L.), were found occasionally infesting grain (Barak and Harein 1981, Subramanyam et al. 1989a, 1993).

Many infestations in stored commodities originate from insects that are already contained within the storage facility. Elimination of these residual populations through sanitation and aeration is an important cultural management strategy (Arthur 1994, Hagstrum and Flinn 1995). Preventive treatments with organophosphate insecticide protectants and fumigants also have been important management tactics used against stored-grain pest populations. However, regulatory, environmental, public health, and pest resistance (Subramanyam et al. 1989b, Subramanyam and Harein 1990, Subramanyam and Hagstrum 1996) concerns have emphasized the need to develop alternative pest management practices.

The application of biological control agents (predators, parasitoids, and microbials) for suppression of insect pest populations in stored commodities is one alternative being studied (Brower et al. 1996). However, stored commodity environments are usually composed of a complex pest species and many natural enemies attack only one host species. Several approaches have been suggested including early release of predators in storages (Brower and Mullen 1990), release of predators into empty storages to attack residual populations (LeCato et al. 1977, Brower and Press 1992), or a "community" approach where both parasitoids and predators are released (Keever et al. 1986, Kraszpulski and Davis 1988, Press et al. 1982).

The larger pirate bug, *Lyctocoris campestris* (F.), is a polyphagous predator found in many different natural and man-made habitats including stored commodity ecosystems (Anderson 1962, Kelton 1967). This predator was recently discovered in a flat storage of shelled corn in Wisconsin (Parajulee and Phillips 1992). Laboratory and field research described several aspects of *L. campestris* development, reproduction, functional response, and seasonal abundance (Parajulee and Phillips 1993, 1995a, Parajulee et al. 1994). However, all of these studies were conducted using corn (*Zea mays* L.) as the grain habitat. Research with a related anthocorid, *Xylocoris flavipes* (Reuter), suggested that type of grain was an important variable that affected predation rates (LeCato 1975, Press et al. 1978).

Mathematical functions have been developed to accurately assess the relationship between number of prey available and number of prey attacked (Solomon 1949, Holling 1959). This relationship is commonly called the functional response (Solomon 1949), and has been defined as a change in the number of prey attacked as prey density changes. Several types of functional response have been recorded, but the most common type associated with arthropod predators is one where there is an increase in predation under low prey densities, followed by a deceleration in predation to a plateau under high prey densities. This response is termed the Type II response and was described by the disk equation of Holling (1959):

$$N_a = a' T N / 1 + a' T_h N$$

where N_a is the number of prey attacked, a' is the instantaneous search rate, T is the total time predators and prey are exposed to each other, N is the number of prey, and T_h is the handling time per prey. Parajulee et al. (1994) compared the functional response of *L. campestris* when attacking several different stored commodity pests in arenas with and without corn.

Our experiments were designed to investigate the relationship between prey density and number of prey attacked by female or male predators under conditions consisting of different stored commodities.

Materials and Methods

Predator rearing. *Lyctocoris campestris* was reared using a modification of the technique developed by Parajulee and Phillips (1992). Three-piece stacks of 7.0-cm Whatman filter paper saturated with distilled water were placed in 0.47- or 0.95-liter jars with adult *L. campestris* to provide a substrate for oviposition. The filter paper was collected and changed three times per week. Filter paper sheets with eggs were placed in plastic Petri dishes (100 × 15 mm) and checked regularly for hatching. These papers were kept moist with distilled water to ensure proper embryo development and eclosion of nymphs. Newly-hatched nymphs were transferred to a 0.95-liter jar and provided with sawtoothed grain beetle larvae. After 3 wks, fourth- and fifth-stadia nymphs were removed and provided fourth- and fifth-instar *P. interpunctella* larvae. Adults were then placed in "mating" jars (0.95-liter) and were maintained with moth larvae.

Experimental design. Seven-day-old adult female and male predators were starved for 48 h prior to testing. The rate of predation was measured for both sexes by assigning a single predator to one of seven prey-density treatments with five replications. Each treatment contained 300 g of corn (Great River Organic Whole Corn, Winona, MN), wheat (hard red spring, Great River Organic Milling), or rolled oats (organic oats, Hamden Park Cooperative, St. Paul, MN) placed in 0.46-liter jars. These commodities were frozen and thawed prior to use to prevent arthropod contamination. Prey density was 2, 4, 8, 12, 16, 24, or 32 *P. interpunctella* larvae per jar. Larvae were placed with the commodity 2 h prior to introduction of the predator. Predators were allowed to disperse and feed for 24 h under laboratory conditions (30°C, 60% RH). The total number of prey killed or attacked was recorded. Attacked prey were identified by darkened areas on the cuticle (Parajulee and Phillips 1992).

Statistical analysis. The predatory response of female or male *L. campestris* under varying prey densities in different commodities was analyzed using several methods. First, analysis of variance (PROC GLM, least significant difference test, LSD; SAS Institute 1995) compared the factors commodity type, predator sex, prey density, and all interactions in a randomized complete block design. Separate ANOVA's on subsets of the data were performed and means were separated using the protected LSD. Second, to assess the relationship between prey density and number of prey attacked, the functional response of *L. campestris* was tested using nonlinear least squares analysis (PROC NLIN; SAS Institute 1995, Williams and Juliano 1985). The goodness-of-fit for the nonlinear response data that was fitted to the disk equation (Holling 1959) was tested using the ratio of lack-of-fit and pure error mean squares (i.e., difference in sum of squares for all replicates and that for a "means only" model) (Parajulee et al. 1994). Differences in handling times (T_h) among commodities for female or male predators were compared using nonoverlapping 95% asymptotic confidence intervals.

Results

Commodity type, predator sex, and prey density significantly influenced the attack response of *L. campestris* to late-instar Indianmeal moth larvae (Table 1). Predators attacked more prey in corn (mean ± SEM, 2.54 ± 0.21) and wheat (2.49 ± 0.24) than in oats (1.75 ± 0.18). Overall, female *L. campestris* attacked more prey than males, 2.67 ± 0.19 vs 1.85 ± 0.15, respectively. However, differences between females and males among commodities varied. Females attacked more prey than males in corn (3.0 ± 0.35 vs 2.13 ± 0.25, $P = 0.0514$) and oats (2.22 ± 0.27 vs 1.28 ± 0.21, $P = 0.0067$), but attacks were similar in wheat (females 2.82 ± 0.36, males 2.14 ± 0.31; $P = 0.0881$). As expected, higher numbers of prey were attacked with increasing prey densities. A significant interaction between commodity and prey density was due to variable increases in predation among commodities in the prey density treatments. A significant predator sex by prey density interaction was due to female predators attacking more prey in the 24-prey density treatment than in the 32-prey density treatment.

Table 1. Analysis of variance showing main effects and interactions for female and male *L. campestris* predation of Indianmeal moth larvae in different commodities with different prey densities*.

Source	df	Mean Square	F-value	$P > F$
commodity	2	14.5	11.1	0.0001
sex	1	45.2	34.7	0.0001
prey density	6	64.0	49.1	0.0001
commodity × sex	2	0.09	0.07	0.9302
commodity × prey density	12	2.5	1.9	0.0348
sex × density	6	4.3	3.3	0.0040
commodity × sex × prey density	12	1.6	1.2	0.2905

*The experimentwise ANOVA was significant (df = 41, 178; $F = 9.8$; $P < 0.0001$).

Predation by *L. campestris* on different densities of prey in different commodities yielded a curvilinear (Type II) response (Figs. 1-3). The response data for all treatments except male predators in corn showed no significant lack of fit with the disk equation (Table 2), which indicated that the data were well predicted by the disk equation. R^2 values were low due to replicate variability. Handling times did not differ significantly among treatments, although there was a trend for increased handling time for female predators in oats (Table 3).

Discussion

One objective of this research was to compare predation of *L. campestris* in different stored commodities. Results suggest that this predator had a more difficult time either finding or attacking Indianmeal moth larvae in oats than in corn or wheat. Handling time (the time needed to pursue, subdue, and consume each prey when it is initially encountered [Luck 1984]) for female *L. campestris* in oats tended to be longer than in corn or wheat, although these differences were not significant. One explanation for lower predation in oats would be small interstitial air spaces formed by compacted oat grains. Previous research with *X. flavipes* suggests that they were unable to penetrate finely

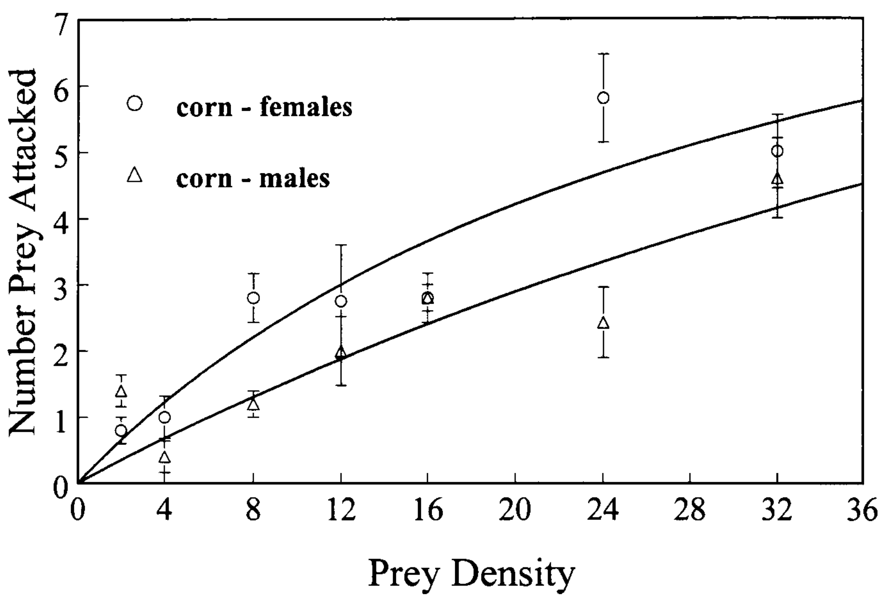

Fig. 1. Mean attack rate (number of prey attacked by *L. campestris* females and males per 24 h) (± SEM) as a function of prey density in corn. The curves show the attack rate predicted by the disk equation.

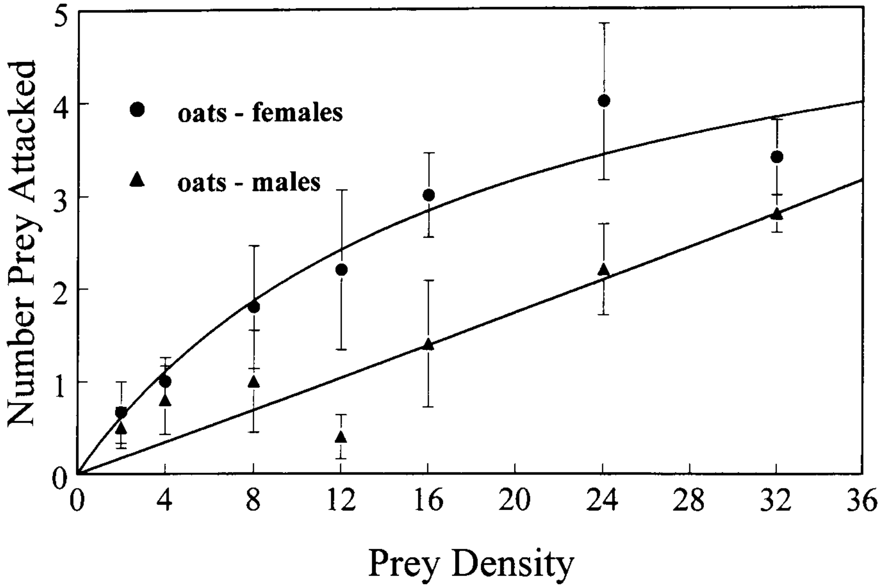

Fig. 2. Mean attack rate (number of prey attacked by *L. campestris* females and males per 24 h) (± SEM) as a function of prey density in wheat. The curves show the attack rate predicted by the disk equation.

particulated commodities and that particle size was an important factor in predation success (LeCato 1975, Press et al. 1978). *Lyctocoris campestris* is larger than *X. flavipes*, and therefore commodity size is apparently an important factor with this predator, especially in being able to penetrate the lower areas of the commodity mass to find and attack prey. Although most recently found in stored corn, *L. campestris* potentially could also be a valuable predator in stored wheat.

The other main factors that were tested in these experiments were predator sex and prey density. Overall, female *L. campestris* attacked more prey than males, although this difference was not significant in wheat. These results agree with previous research in corn (Parajulee et al. 1994). However, both sexes had similar functional responses. Therefore, it appears males can contribute to the success of a biological control program, especially since field sampling suggests a 1:1 sex ratio (Parajulee and Phillips 1995a). As the density of *L. campestris* adults increased, they were able to attack more prey, although the attack rate slowed at high prey densities. This relationship between prey density and number of prey attacked fit the Type II functional response model in all treatments except for males in corn. Our results are similar to those found in previous experiments with this predator (Parajulee et al. 1994).

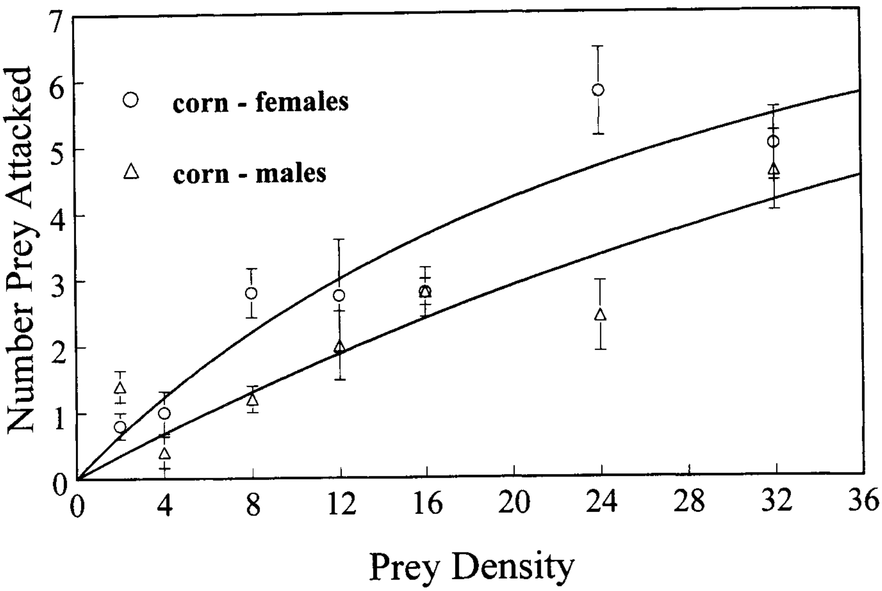

Fig. 3. Mean attack rate (number of prey attacked by *L. campestris* females and males per 24 h) (± SEM) as a function of prey density in rolled oats. The curves show the attack rate predicted by the disk equation.

The study of functional response in different types of stored commodities is a necessary beginning to developing an understanding of the predator-prey relationships in bulk grain masses. *Lyctocoris campestris* has limitations and advantages as a biological control agent that influences its use by grain pest managers in stored commodities. This predator tends to have a lower reproductive potential than other anthocorids in grain. For instance, *X. flavipes* under optimum conditions developed from egg to adult in only 16 d, while *L. campestris* took 21 to 25 d (Arbogast 1975, Parajulee and Phillips 1993). Therefore, in grain stored for extended periods, *X. flavipes* could produce more generations than *L. campestris*. Another negative aspect of the life history of *L. campestris* is that it requires a moist environment for oviposition and egg survival (Parajulee and Phillips 1992). Several grain pests can flourish under relatively dry conditions, thus the potential for *L. campestris* population growth in these areas would be suspect.

On the positive side, *L. campestris* can attack several grain pest species and can attack larger prey, such as late-instar lepidopteran larvae, than other grain predators (Parajulee and Phillips 1993). Also, adults live longer than is reported for other anthocorids (Arbogast 1975, Parajulee and Phillips 1995b). The most efficient use of this predator may be in serial augmentative releases

Table 2. Lack-of-fit test statistics for predation of Indianmeal moth larvae by female and male *L. campestris* in several grain habitats, fitted with the Type II functional response model*.

Habitat	Sex	*F*-value	df	*P*-value	R^2
corn	female	2.3	5, 27	>0.05	0.668
	male	2.7	5, 31	<0.05	0.484
wheat	female	0.88	5, 32	>0.25	0.648
	male	1.17	5, 29	>0.25	0.582
oats	female	0.4	5, 30	>0.25	0.470
	male	0.95	5, 29	>0.25	0.402

*Analyzed by a lack-of-fit test using nonlinear regression model (PROC NLIN, SAS Institute 1995). This test divided the residual sum of squares into lack-of-fit and pure error (due to replication) sum of squares components. The *F*-test compared these values and a non-significant result indicated the disk equation was valid for the data.

Table 3. Handling time (T_h) for female and male *L. campestris* in three different commodity habitats.

Habitat	Sex	*N*	T_h (SEM) (Hours)	95% Asymptotic Confidence Interval
Corn	female	34	2.28 (0.75)	0.74 – 3.81
	male	38	1.74 (1.62)	0.0 – 5.02
Wheat	female	39	1.41 (0.84)	0.0 – 3.10
	male	36	1.90 (1.44)	0.0 – 4.83
Oats	female	37	4.06 (1.27)	1.49 – 6.63
	male	36	*	0.0 – 7.67

*Unrealistic calculation of handling time due to poor predation results in this treatment.

in bulk grain or in "clean up" situations in empty grain storages (Brower and Press 1992). In both of these types of use, the reproductive capacity of the predator may not be important because releases would be made repeatedly and storage intervals would be shorter. Research conducted in large grain masses or empty commodity storages has not been completed using *L. campestris*. Future research under actual commodity storage conditions is needed to determine the potential of this predator in stored commodity ecosystems.

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