Effects of *Xylocoris flavipes* (Hemiptera: Anthocoridae) Releases on Moth Populations in Experimental Peanut Storages[1]

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ABSTRACT A biological control test in experimental peanut storages indicated that release of large numbers of the warehouse pirate bug, *Xylocoris flavipes* (Reuter) (Hemiptera: Anthocoridae), a generalist predator of stored-product insects, has considerable potential for suppression of stored-product moth populations. Suppression of the almond moth, *Cadra cautella* (Walker), and the Indianmeal moth, *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae), was dependent on both the prey species and environmental conditions. Release of *X. flavipes* suppressed small populations of almond and Indianmeal moths by as much as 78.8% and 71.4%, respectively, before cold weather and a severe freeze eliminated the almond moth population in January. Suppression of the Indianmeal moth lasted through the 7-month test period. *X. flavipes* may be useful as one component of an integrated peanut control program based on release of biological agents

KEY WORDS Biological control, predator, peanut pests, Anthocoridae, Pyralidae, *Xylocoris flavipes*

Use of biological control for pests of stored agricultural products has received little attention until very recently (Arbogast 1984). However, increased interest in this technique has been generated by high levels of pesticide resistance in stored-product pests and new concerns about the safety of pesticides. Georgia is the leading producer of peanuts in the U.S., and this crop is an important segment of Georgia's agricultural economy. Pest control in bulk stored peanuts is a severe problem, and has become more difficult with the development of high levels of pesticide resistance, especially in the moths (Arthur et al. 1988, Zettler 1982). Biological control of the stored peanut pest complex will probably depend on an integrated approach with parasitoids used in conjunction with a more general predator. At present the best candidate for such a predator is the warehouse pirate bug, *Xylocoris flavipes* (Reuter) (Arbogast 1978).

The warehouse pirate bug is a common component of the stored grain ecosystem where it normally occurs in low numbers, but in some cases it increases to an abundance that greatly suppresses host populations (Jay et al. 1968; Arbogast 1976, 1978). This small anthocorid bug is easy to rear in large numbers on eggs of several stored-product moth species, and it attacks both eggs and small

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larvae (and to a lesser extent large larvae and pupae) of these moths (LeCato & Davis 1973, LeCato et al. 1977). *X. flavipes* has been used in conjunction with a moth larval parasite, *Bracon hebetor* Say, in a pilot test of biological control in a peanut warehouse (Keever et al. 1986). Although the results were encouraging, they were not definitive, and the effect of the predator could not be separated from that of the parasite. Therefore, in order to study the effects of a single agent (*X. flavipes*) on moth populations in simulated peanut storages, a replicated test of large scale *X. flavipes* releases was conducted in four identical metal buildings.

Materials and Methods

Experimental inshell peanut storages were established in four 25-m^3 empty metal buildings (2.5m × 5m × 2.2m) in March 1984. Untreated insect-free farmers' stock peanuts, *Arachis hypogaea* L. 'Florunner,' (Segregation - I) from the 1983 crop were removed from cold storage and introduced into each building (455 kg/building). The peanuts formed a layer about 30cm deep. Walls of the buildings were marked with tape to delineate 10 equally sized rectangles (1 × 1.25m), five on each side of the building, that met along the midline of the building to form 10 sampling quadrats (strata). Temperature and relative humidity in the buildings and in a nearby standard meteorological instrument shelter (Stevenson screen) were recorded continuously by hygrothermographs.

In March 1984, 200 eggs of the almond moth, *Cadra cautella* (Walker), from a laboratory culture, were introduced into each building twice weekly for 10 weeks to establish a mixed age population. The Indianmeal moth, *Plodia interpunctella* (Hübner), became established in all four buildings during this time period by immigration of adults from several nearby peanut storage buildings. By the fall of 1984, the four buildings were infested with mixed age populations of both moth species and by small numbers of the red flour beetle, *Tribolium castaneum* (Herbst). Early morning visual observations of adult moths resting on the walls of the buildings indicated that two of the buildings were somewhat more heavily infested than the other two. The two buildings that appeared to have the greater moth populations were designated for release of *X. flavipes* and the other two were designated as check buildings.

On 3 December 1984, the peanuts were sampled to establish pre-release baseline population counts for both moth species in each building. Ten 200g peanut samples were taken using a stratified random design with one sample taken at random from each of the 10 quadrats. A 1-liter metal scoop was used to remove a cylindrical core from the peanut layer from top to bottom, but peanuts immediately above the floor were probably under-represented in the sample. The cylindrical sample also tended to under-sample the area of peanuts alongside the building wall. Samples were placed in 1-liter jars, returned to the laboratory, and incubated at 27°C and 80±5% RH until all moths had emerged. Moths were removed, identified, counted three times a week and discarded until all emergence ceased or a second generation started to emerge. All buildings were sampled 1 day before *X. flavipes* release, 2 weeks after each release, and at monthly intervals for 6 months.

The released *X. flavipes* were from a field strain cultured for several years in the laboratory on moth eggs and young larvae of several moth species. Cultures were maintained at 27°C and 80 ± 5% RH in 38 × 25 × 17 cm plastic boxes

containing Kraft honeycomb paper to povide hiding places and reduce cannibalism. On 4 December 1984, 20 boxes containing an estimated 40,000 *X. flavipes* nymphs and adults were distributed evenly over the surface of the peanuts in each of the two buildings selected. Estimates of total numbers based on counts of 5% of the cultures selected at random. The honeycomb paper from each culture was placed on the surface of the peanuts at random and the remaining contents of the culture emptied onto the peanut surface. On 17 December, the peanuts in the four buildings were sampled as described before to provide 2-week post-release data. On 18 December 1984, a second release of an estimated 40,000 *X. flavipes* was made in each of the two treatment buildings. On 2 January 1985, 4-week post-release samples were taken in all of the buildings. A severe freeze (-17°C) occurred 21 January 1985 and no samples were taken in February. The peanuts were again sampled on the first of March, April, May, and June.

All data were transformed using the formula $\sqrt{X + 0.5}$ to eliminate zeros from the individual sample counts. Transformed test data were analyzed using the PROC GLM, ANOVA procedure (SAS Institute 1985) and data from each sampling date were analyzed separately using an ANOVA and F-test.

Results

For the first month of the test (Dec.), temperatures were unseasonably warm with weekly highs averaging 30°C and lows averaging 5°C. In contrast, January had record cold temperatures with a hard freeze on 21 January. For the period 4 January through 30 January the daily high never exceeded 23°C (except for 24 January with 25°C) and the daily lows were seldom above freezing. The week of 20-26 January saw daily highs that averaged 14°C and daily lows that averaged -6.4°C with a record low of -17°C on 21 January. In February and March, weekly high temperatures increased from ca. 27.5°C to ca. 33°C and lows averaged -1.5°C to about 3.0°C in February and March, respectively. April weekly highs averaged 34.5°C and weekly lows were about 8.0°C. Relative humidity reached 90-100% every week of the test period and weekly lows generally averaged about 35% RH with lows of about 25% RH during cold weeks and of 40-50% RH during warm weeks.

During the course of this test, no effort was made to recover *X. flavipes* from any of the incubated samples, so as not to injure or kill developing moths. Small numbers of bug nymphs and occasional adults could be seen during visual inspections. A few flour beetles, *Tribolium* spp., were observed in the buildings but none were recovered from the incubated samples, indicating very small populations of this pest. Small numbers of Indianmeal moths and almond moths were observed on the walls of each of the buildings on 3 December 1984.

Samples of peanuts taken from each of the buildings one day before release of the *X. flavipes* revealed that small numbers of almond moths and Indianmeal moths were developing in the peanut samples. Development of moths on peanuts is slow and emergence was not completed until two months had passed. The number of almond moths recovered from the four buildings on 3 December indicated that the population size was not the same in the four buildings ($P < 0.01$, $F = 8.99$, $df = 3,27$). The two buildings with the largest populations had been used for the *X. flavipes* releases. In contrast, the smaller populations of Indianmeal

moths in the buildings did not show any significant differences between the buildings ($P > 0.05$, F = 0.05, df = 3,27).

The ANOVA and F-tests for post-*X. flavipes* release dates (17 Dec. 1984, and 2 Jan 1985) showed that the predator had a highly significant effect ($P < 0.01$, F = 15.98, df = 1,72) on almond moth population numbers (Table 1). Numbers of almond moths in the treated buildings were significantly smaller than numbers in the check buildings in contrast to pre-release samples. Undoubtedly, differences would have become much greater with the advent of warm weather had not the severe cold spell of January 1985 eliminated the almond moth population. Differences between post-release sampling dates or between replicates were not significant ($P > 0.05$) nor were any of the interactions (Table 1). Post-release differences in Indianmeal moth population abundance between treatments were also highly significant ($P < 0.01$, F = 14.47, df = 1,196) (Table 2). Differences due to sampling dates were nonsignificant ($P > 0.05$). Differences between replicates were significant at the 5% level.

Table 1. Analysis of variance of almond moth abundance in peanut warehouses treated with a predator, *Xylocoris flavipes*, 2- and 4-weeks before sampling.

Source	df	SS	MS	F	Pr > F
Treatment	1	2.734	2.734	15.98	0.0002
Reps	1	0.222	0.222	1.29	0.259
Dates	1	0.332	0.332	1.94	0.168
Trt × Rep	1	0.213	0.213	1.25	0.268
Trt × Date	1	0.238	0.238	1.29	0.242
Rep × Date	1	0.041	0.041	0.24	0.626
Trt × Rep × D	1	0.100	0.100	0.58	0.447
Error	72	12.323	0.171		
Total	79	16.203			

Table 2. Analysis of variance of Indianmeal moth abundance in peanut warehouses treated with a predator, *Xylocoris flavipes*, 2- and 4-weeks and 3 to 7 months before sampling.

Source	df	SS	MS	F	Pr > F
Treatment	1	0.894	0.894	14.47	0.0002
Reps	1	0.270	0.270	4.36	0.038
Dates	5	0.666	0.133	2.16	0.060
Trt × Rep	1	0.031	0.031	0.49	0.483
Trt × Date	5	0.565	0.141	2.29	0.061
Rep × Date	5	0.863	0.172	2.80	0.018
Trt × Rep × D	5	0.170	0.042	0.69	0.601
Error	196	12.227	0.062		
Total	219	15.685			

Two weeks after the first release of ca. 40,000 *X. flavipes* per building, almond moth populations showed nearly 3-fold decreases in abundance while the populations in check buildings showed more than 5-fold increases (Table 3). Differences in population abundance were significant ($P < 0.05$, F = 5.22, df = 1,36) for this sampling date as shown by an ANOVA. Results were more variable for the smaller Indianmeal moth populations, with one treatment population decreased and the other unchanged, while one check population increased and the other showed little change (Table 4). Differences between treated and untreated populations were not significant at the 5% level but were close to significance (F = 3.65) at this level.

Table 3. Numbers of adult almond moths emerged from 10 samples taken from small warehouses containing inshell peanuts and either treated with two releases of 40,000 *Xylocoris flavipes* or left untreated. Means for each treatment and percentage of population suppression as compared to the check warehouses are given.

Warehouse	Sampling Dates			
	3 Dec 84* (Pre-release)	17 Dec 84 (First Release + 2 weeks)	2 Jan 85 (Second Release + 2 weeks)	1 Mar - 1 June (3 Mo - 6 Mo Post-release)†
Check # 1	2	11	14	0
Check # 2	1	8	19	0
Check Mean	1.5**	9.5*	16.5**	0
X. flavipes # 1	14	5	6	0
X. flavipes # 2	3	1	1	0
Treatment Mean	8.5**	3.0*	3.5**	0
% Reduction	-	68.4	78.8	-

* Differences in means within sampling dates (columns) are significant at the $P < 0.05$ = *, $P < 0.01$ = **, as determined by an ANOVA for each date (SAS Institute, 1985).

† No moths were recovered at any sampling date.

Two weeks after the second release of 40,000 *X. flavipes,* the almond moth populations in the treatment buildings showed a slight increase, whereas the abundance of the check populations increased another 74%; and the differences between check and treatment were not highly significant ($P< 0.01$, F = 10.85, df = 1,36) (Table 3). Results with the Indianmeal moth were variable, with one treatment population showing an increase and the two check populations both showing declines; treatment differences were not significant ($P > 0.05$) (Table 4). The extremely cold January and the record freeze of 21 January voided the 1 February sampling date and after sampling was resumed on 1 March, no almond moths were found from March through June (Table 3). Apparently the cold weather had killed the almond moths present in all four test buidings. In contrast, the more cold hardy Indianmeal moth populations (Howe 1965) survived, and relatively stable populations were found in both check buildings throughout the spring (Table 4). However, the two *X. flavipes* treatment buildings had only a single Indianmeal moth recovered throughout the four month spring sampling period and

Table 4. Number of adult Indianmeal moths emerged from 10 samples taken monthly from small warehouses containing inshell peanuts and either treated with two releases of 40,000 *Xylocoris flavipes* or left untreated. Means for each treatment and percentage of population reduction as compared to the check populations are given.

Warehouse	Sampling Dates						
	3 Dec 84* (Pre-release)	17 Dec 84 (First Release + 2 weeks	2 Jan 85 (Second Release + 2 weeks	1 Mar 85 (3 Mo Post-release)	1 Apr 85 (4 Mo Post-release)	1 May 85 (5 Mo Post-release)	1 June 85 (6 Mo Post-release)
Check # 1	2	5	1	4	4	3	5
Check # 2	8	9	4	7	4	6	8
Check Mean	5.0ns	7.0ns	2.5ns	5.5**	4.0*	4.5**	6.5**
X. flavipes #1	2	2	2	0	1	0	0
X. flavipes #2	8	2	5	0	0	0	0
Treatment Mean	5.0ns	2.0ns	3.5ns	0**	0.5*	0**	0**
% Reduction	-	71.4	(Increase)	100	87.5	100	100

* Differences in means within sampling dates (columns) are significant at the $P < 0.05$ = *, $P < 0.01$ = **, as determined by an ANOVA for each date (SAS Institute, 1985).

differences between treatment and check buildings were significant ($P < 0.05$) (Table 4). Apparently the large numbers of *X. flavipes* released had in the 3 months since their release virtually eliminated the Indianmeal moth population.

The percentage of the 10 samples found to be infested showed a rather similar general trend to the figures for moth abundance. When data for the two moth species were combined, the mean percentge of the 200g peanut samples infested was 50% for the check buildings and 60% for the treatment buildings just before predator release (Table 5). One month post-release samples showed an increase in infested samples in the check buildings and a decrease in the treatment buildings. Three and 6 month samples showed about half the samples from the check buildings and none from the treatment buildings infested by Indianmeal moths.

Table 5. Average percentage of samples that were infested by *Cadra cautella* and/or *Plodia interpunctella* for all samples taken from each treatment at intervals indicated.

		Months Post-release		
Treatment	Pre-release	1	3*	6*
Check #1	40	60	30	40
Check #2	60	50	60	70
Check Mean	50	55	45	55
X. flavipes # 1	70	60	0	0
X. flavipes # 2	50	40	0	0
Treatment Mean	60	50	0	0

* Percentages are for Indianmeal moth only.

Discussion

The sampling plan used in this test was not designed to determine the absolute number of moths present for several reasons. Primary reasons were that no adult moths were present in the samples because they typically fly in the airspace or rest on the walls and ceilings of the buildings, and adults tend to escape during the sampling procedure. Moths eggs are laid loose on the surface of the peanuts and on kernels within broken hulls, and some of them probably fell out of the sample during the sampling process. Eggs and young larvae of the moths were probably not distributed randomly on the surface of the layer of peanuts but were aggregated as reported by Arbogast and Mullen (1978). An aggregated distribution of eggs was suggested by the great variablity in numbers of insects between samples. However, the accuracy of the sampling was equal for all four buildings, and the small sample size undoubtedly contributed more to sampling error than any other factor. Small numbers of moths in 200g samples indicate a pest population that with the advent of warm weather could increase to damaging proportions. The pre-release samples gave a very conservative estimate of 3185 and 683 almond moths in treatment buildings 1 and 2, respectively. Similarly, numbers of Indianmeal moths were 455 and 1820 for buildings 1 and 2, respectively. Because the reproductive capacity of moths is very great, this number of moths could produce a rapid increase in the number of larvae feeding on and damaging the peanuts under the right environmental conditions.

No special effort was made to sample the numbers of *X. flavipes* because of their small size and secretive habits. Very small numbers of this predator are usually recovered even when larger samples are taken from a greater bulk of peanuts (Keever et al. 1986, Table 3). Peanut samples were incubated until adult moths emerged, and no counts of *X. flavipes* in the samples were attempted.

The results of the sampling probably indicated real changes in the populations. Check populations were increasing rapidly until the advent of cold weather, while treated populations showed declining trends for the first month after *X. flavipes* releases. *X. flavipes* is a small predator and normally feeds most effectively on eggs and young larvae of the moths, whereas large larvae, pupae and adults are less subject to attack (LeCato & Davis 1973). Thus, no quick response in the number of adult moths was expected. However, as large larvae and pupae mature, emerge as adults, mate and lay eggs, these eggs then become prey for *X. flavipes* nymphs and adults. Thus, the moths have to pass through at least a partial generation cycle before suppression by *X. flavipes* can be expected, and this same pattern was reported for the almond moth when *X. flavipes* was released in a room (LeCato et al. 1977). This was exactly the pattern of effects found in the Indianmeal moth population in this test (Table 4).

The January freeze apparently eliminated the more abundant almond moth populations in spite of the fact that Bell and Bowley (1980) reported a facultative dispause in some almond moth populations. Mullen (unpublished data) found that almond moth larvae are killed by exposure to a temperature of -10°C for 7.8 hr, a temperature above those recorded during this test (-17°C). The Indianmeal moth population may have survived because large larvae often have a facultative diapause triggered by cold temperatures and short daylight periods (Bell 1982).

We believe this test demonstrated that large numbers of *X. flavipes* can greatly reduce a small population of moths and prevent their increase to damaging levels. The level of predator release used in this test (6667/m²) was not chosen as a practical or economically feasible level but as one that should demonstrate pest population suppression if it was going to occur. Larger volumes of peanuts with greater numbers of prey might encourage a more stable predator population and probably would increase the efficiency of the predator. The results of this experimental peanut warehouse test should stimulate continued research into the use of *X. flavipes* as one component of an integrated biological control approach to pest control in bulk stored peanuts.

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