Seasonal Activity of Stored-Product Insects in and Around Farm-Stored Wheat

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ABSTRACT This study was conducted to examine the activity of stored-product insect pests outside farm storage facilities during the first 2 mo of storage and to relate that activity to colonization of the grain by insects. Environmental parameters describing the grain storage environment also were analyzed to help in explaining the relationship between insect densities inside and outside grain bins. The most abundant species collected were *Ahasverus advena* (Waltl), *Typhaea stercorea* (L.), *Rhyzopertha dominica* (F.), and *Cryptolestes* spp. Farms with high numbers of stored-product insects outside of storage facilities had high numbers of insects in 25-bu experimental bins, and farms on which few insects were detected outside also had fewer insects in 25-bu bins. However, this relationship was not true for commercial farm bins, possibly because of the use of insecticide on the grain or residual pest populations in farm bins. Grain moisture and test weight and the presence of livestock tended to affect insect numbers in the untreated experimental bins, but the effects were not always consistent among species. In farm bins, the use of protectants on the grain tended to obscure expected relationships to environmental parameters.

KEY WORDS migration, postharvest management, environmental parameters

AS OUR AWARENESS of problems associated with insecticide use increases, fewer materials are available for management of pest infestations in stored grain. This results in the need to develop biologically based and ecologically sound integrated management programs that exploit the unique behavior, ecology, and physiology of insect pests. Detectable levels of insects can be found in farm storage within a few weeks after bin filling (Hagstrum 1989, Subramanyam & Harein 1989, Reed et al. 1991), and these insects eventually enter the grain marketing system. Pest infestations grow rapidly and may cause substantial reductions in grain quality if left unchecked, resulting in price discounts charged at the time of sale at the elevator (Reed et al. 1989).

Stored-product insect pest management efforts in farm-stored grain usually are directed toward detecting and controlling pests inside storage facilities or within the commodity. Sampling strategies are designed to assess the first appearance and growth of infestations in the grain. However, pests are not easy to detect in grain in the early stages of infestation when densities are low (Smith 1985, Storey et al. 1982). Pests may be easier to detect outside bins before they move into the grain mass. Monitoring populations of stored-product insect pests outside storage facilities may provide an indication of the timing and extent of movement into the grain. This could provide information to managers which relates to potential pest problems (i.e., overall risk) and when direct sampling should be initiated to detect damaging levels of insects in the grain.

If a storage facility is cleaned thoroughly before filling and the grain is uninfested or treated at filling, the only source for infestation is the outside environment. Stored-grain insects have been reported in decaying wood and under tree bark; in nests of birds, mammals, and insects; and in spilled grain and animal feeds in and around farm buildings (Linsley 1944, Woodroffe 1953, Khare & Agrawal 1964). There is little evidence that stored-product insects infest ripening wheat in the field and become a source of infestation for newly harvested grain. Even if this were a common occurrence, the mortality rate is probably high for insects moving through grain harvesting machines and the grain handling system (Bailey 1962, 1969; Loschiavo 1978, Watters & Bickis 1978).

The objectives of our research were to study the activity of stored-product insect pests outside farm storage facilities during the first 2 mo of storage and to relate that activity to the first appearance of insects in the grain. Parameters describing the grain storage environment also were analyzed to assist in explaining the relationship

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Table 1. Characterization of farm bins and wheat, 1992

Farm	Livestock	Grain moisture, %	Test wt, g/L	Bin size, bu	Prefilling infestation	Bin preparation	Grain protectant[a]
H-01	No	11.2	783.1	4,000	No	Malathion	No
H-02	No	11.8	779.2	1,500	No	Malathion	No
H-05	Yes	12.0	703.2	3,500	Yes	None	No
H-06	Yes	11.9	732.9	1,500	No	Malathion	No
H-08	Yes	9.3	757.3	3,000	No	Malathion	Yes
H-09	No	13.3	763.8	6,000	Yes	Malathion	Yes
H-10	No	11.0	793.4	4,000	Yes	Reldan	Yes
L-03	Yes	13.0	748.8	5,000	Yes	Reldan	Yes
L-06	No	13.4	748.6	5,000	Yes	Reldan	Yes
L-07	Yes	13.5	730.4	4,000	No	Malathion	Yes
L-08	No	11.6	725.1	9,000	No	Malathion	Yes
L-09	Yes	12.3	678.1	1,500	No	Reldan	Yes

[a] Chlorpyrifos-methyl.

between insect densities inside and outside of grain bins.

Materials and Methods

This study was conducted during the summers of 1990 and 1992 in a total of 32 grain bins located on 16 farms in central and southeastern Kansas. New crop wheat, harvested in late June and early July, was used each year so that no residual insect infestations were present. In 1990 and 1992, 8 and 12 25-bu experimental grain bins were used, respectively. These bins had flat bottoms, were constructed of corrugated galvanized metal, and were 69 cm high by 140 cm in diameter. A 2-cm gap was provided between the lid and sidewall to allow ventilation similar to that of commercial farm bins. To remove all grain residue, the bins were steam cleaned and air dried before filling. Neither the bins nor the wheat were treated with insecticides. In 1992, 12 commercial-size farm bins measuring 1,500 to 9,000 bu also were sampled. No attempt was made to regulate how farmers prepared their bins before filling or to restrict their use of grain protectants on the wheat. In 1992, one 25-bu bin and one farm bin were located on each of the 12 farms.

The wheat was sampled weekly during the 1st mo after the bins were filled, then at 2-wk intervals for an additional month in 1990 and weekly for 2 mo in 1992. Five STORGARD WB II probe traps (Trécé, Salinas, CA) were placed in each bin, one in the center and the others midway from the center to the bin wall in each of four cardinal directions. The traps were placed about 6 cm below the surface of the wheat, as recommended by the manufacturer, to collect insects feeding within the grain mass. Traps were left in the wheat for 7 d, after which the collected adult insects were removed and counted. Probe-trap data are reported as the average number of insects collected per five traps per bin to characterize the insect populations within the grain mass.

Eight sticky traps were used to monitor adult-insect activity outside of bins on each farm. The traps were white plastic picnic plates (22.5-cm diameter) coated with Stiky Stuff sticky material (Olson Products, Medina, OH) to trap insects. The plates were mounted on wooden stakes within 0.5 m of the grain bins, with the bottom edge of the plate within 10 cm of the ground. Four traps were put around each of the 25-bu bins and farm bins in the four cardinal directions. These traps were not baited, remained sticky for at least 1 wk, and were replaced weekly, and the collected insects were counted. Because the 25-bu bin and farm bin were side-by-side on each farm, sticky traps were assumed to be monitoring the same population, and no differentiation was made in trap catch around the bins. Sticky-trap data are reported as the average number of insects collected per eight traps per farm to characterize the insect populations outside of bins.

Parameters that describe the grain storage environment in and around the farm bins were documented to examine the colonization of wheat by insects (Table 1). These parameters included the size of farm bins, the use of insecticides in the bins before wheat storage, the application of protectant (chlorpyrifos-methyl) to the wheat at bin filling, grain moisture and test weight measured in grams per liter (g/L) within 1 wk of storage, and the presence of a livestock operation on the farm.

To determine if farm bins were infested before filling, two corrugated cardboard traps were placed on the floors of the farmers' bins at 1 and 2 mo before filling. These traps were constructed as described by DeCoursey (1931), measured 10 by 15 cm, and were baited with ≈2 g of whole wheat flour. The traps were removed after 7 d exposure and torn apart, and the insects were counted. The flour from the traps was incubated for 35 d at 27°C (±1°C) and 70 % (±5%) RH to determine if insects visited the traps and deposited eggs.

Insect data were summed by each farm for each species in each sampling period for sticky traps and probe traps for each bin. Data were transformed for analysis using a $LOG_{10}(x + 1)$ transformation to normalize variance, and standard errors were calculated using Taylor's series expansion approximation (Kendall & Stuart 1963). The year-to-year variation was difficult to measure because we were unable to conduct the study on the same farms in both years. However, the variance component was partitioned to estimate the percentage of variation that could be attributed to differences in years using the VARCOMP procedure (SAS Institute 1985). Pearson correlation coefficients were calculated on transformed data using the PROC CORR procedure of SAS (SAS Institute 1985) to determine the strength and significance of the relationship between the numbers of insects collected outside and within either the 25-bu or farm bins.

The relationships between the insect data and the environmental parameters were analyzed using the PROC GLM procedure (SAS Institute 1985), and least-squares means were calculated for the sum of insects collected in the traps in each 25-bu and farm bin. Data were transformed before analysis as described. Included in this analysis were the numbers of insects collected outside of bins. Counts from outside were classified into categories based on LOG_{10} values of <0.5, 0.5–1.0, 1.0–1.5, and >1.5. This resulted in categories consisting of <3.2, 3.2–10.0, 10.1–31.7, and >31.7 insects per farm. Significant differences among categories were tested using *t*-tests (Steel & Torrie 1980).

Results and Discussion

A total of nine species of stored-product insect pests were collected each of the 2 yr of the study. The five most abundant were the externally feeding flat grain beetle, *Cryptolestes pusillus* (Schönherr), and rusty grain beetle, *C. ferrugineus* (Stephens); the internally feeding lesser grain borer, *Rhyzopertha dominica* (F.); and the two fungus feeders, the foreign grain beetle, *Ahasverus advena* (Waltl), and hairy fungus beetle, *Typhaea stercorea* (L.). Less abundant species included red flour and confused flour beetles, *Tribolium* spp.; sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.); rice weevil, *Sitophilus oryzae* (L.); and Indianmeal moth, *Plodia interpunctella* (Hübner).

Seasonal Activity. The percentage of total variance attributable to population differences from year to year was zero ($s^2 = 0.0000$) for 25-bu bins and only 23% ($s^2 = 0.1433$) for sticky traps. These were not accurate estimates of year-to-year variation because only one farm used the 1st-yr stored wheat during the 2nd yr. The farmers at the other 1st-yr locations took their wheat directly to the elevator at harvest and had no farm-stored wheat during the 2nd yr of the study. The balance of the variance component was attributed to variation among farms ($s^2 = 1.2063$ for 25-bu bins and $s^2 = 0.1072$ for sticky traps) and experimental error ($s^2 = 0.5401$ and $s^2 = 0.3713$ for 25-bu bins and sticky traps, respectively). There was no variance attributable to year-by-farm interaction for either trap type. Hagstrum et al. (1985) also reported that most variance was caused by differences among farms or among traps within bins. The total number of all species of insects collected outside averaged 10.3 per farm 1 wk after the wheat was stored and increased to a maximum of 40.6 per farm per week by the end of the sampling period (Table 2). The total of all species collected in probe traps in 25-bu bins remained about the same during the first 6 wk, then increased markedly during weeks 7 and 8 to a maximum of 243.4 per bin. For the 25-bu bins, there was a positive correlation between the number of insects collected outside of bins and in probe traps ($r = 0.57$, $P = 0.0001$, $n = 61$).

Insect populations in farm bins also were detected after 1 wk of storage at a level four times higher than that of the 25-bu bins. There was a marked increase in insect populations in farm bins during weeks 4 through 6, and maximum densities occurred after 7 wk of storage. In farm bins, the correlation between the number of insects collected outside and in probe traps was not significant ($r = 0.09$, $P = 0.57$, $n = 42$). Numbers collected in farm bins were much greater than those from 25-bu bins, possibly because the farm bins offered a greater target for migrating insects than did the 25-bu bins or possibly as the result of previous infestations in farm bins that could not occur in 25-bu bins. Additionally, the probe traps may sample a larger grain volume in the farm bins than in the 25-bu bins. The effective grain volume that a single probe trap can sample is not known (Cuperus et al. 1990). Differences in population level in the two kinds of bins could not be accounted for by grain temperature ($t = 1.21$; df = 149, 103; $P = 0.31$), grain moisture ($t = 1.95$; df = 34, 25; $P = 0.09$), or test weight ($t = 1.51$; df = 34, 25; $P = 0.29$). The correlation between the size of pest populations in the two types of bins was significant ($r = 0.26$, $P = 0.10$, $n = 42$), but the relationship was weak. It is important to point out that trapping intensity in farm bins (0.2–0.7 traps per m^2 of upper surface area) was much less than in 25-bu bins (3.3 traps per m^2).

Maximum *A. advena* populations were detected outside of bins after 2 wk of storage (Table 2), and the numbers remained below 8 beetles per farm per week for the rest of the sampling period. Within the 25-bu bins, the *A. advena* population remained relatively constant through the season with a large increase after 6 wk of storage. The positive correlation between the

Table 2. The numbers of stored-product insects ($\bar{x}$ ± SEM) collected on sticky traps outside farm-stored wheat and in pitfall traps within 25-bu bins and farm bins

Weeks storage	Outside bins	25-bu Bins	Farm bins
		All species	
1	10.3 ± 2.3	23.0 ± 9.4	93.1 ± 51.0
2	22.9 ± 12.6	37.5 ± 13.9	52.5 ± 21.8
3	14.8 ± 4.3	67.1 ± 33.5	75.2 ± 24.6
4	23.6 ± 8.5	31.0 ± 9.1	251.7 ± 83.1
5	29.2 ± 12.9	32.8 ± 8.6	314.9 ± 165.2
6	21.8 ± 10.2	46.4 ± 16.6	451.1 ± 173.1
7	29.5 ± 15.1	106.9 ± 34.7	556.6 ± 357.4
8	40.6 ± 15.0	243.4 ± 146.1	406.0 ± 206.7
		A. advena	
1	3.1 ± 1.1	2.9 ± 0.1	29.0 ± 14.1
2	14.6 ± 12.2	3.8 ± 1.3	35.2 ± 19.9
3	2.9 ± 0.8	4.3 ± 1.1	25.9 ± 13.0
4	4.5 ± 1.1	5.9 ± 1.9	119.8 ± 48.4
5	4.7 ± 1.6	6.9 ± 2.0	45.9 ± 18.9
6	3.9 ± 1.0	6.7 ± 1.4	177.8 ± 88.9
7	7.9 ± 2.4	17.0 ± 5.7	74.8 ± 21.0
8	5.7 ± 1.9	12.4 ± 3.9	89.8 ± 47.3
		T. stercorea	
1	0.6 ± 0.2	0.8 ± 0.4	20.6 ± 19.2
2	0.7 ± 0.3	3.1 ± 2.4	3.8 ± 2.6
3	3.0 ± 1.1	4.0 ± 2.2	33.8 ± 17.1
4	2.4 ± 0.6	4.8 ± 2.1	103.7 ± 52.9
5	8.0 ± 5.9	6.1 ± 3.0	116.8 ± 68.0
6	3.4 ± 1.8	4.6 ± 1.9	119.0 ± 66.7
7	14.3 ± 12.1	49.2 ± 29.7	273.0 ± 156.9
8	5.9 ± 3.1	7.4 ± 4.0	152.8 ± 88.3
		R. dominica	
1	0.4 ± 0.2	0.1 ± 0.1	0.3 ± 0.2
2	0.4 ± 0.2	0	0.6 ± 0.5
3	1.1 ± 0.7	0.2 ± 0.1	1.4 ± 1.0
4	7.2 ± 6.7	0.8 ± 0.6	3.1 ± 1.6
5	5.6 ± 4.8	2.8 ± 1.9	12.2 ± 11.0
6	8.9 ± 8.4	4.5 ± 2.8	3.0 ± 1.3
7	1.4 ± 1.2	1.0 ± 0.8	0.6 ± 0.6
8	13.4 ± 11.0	16.9 ± 11.4	1.5 ± 1.5
		Cryptolestes spp.	
1	5.1 ± 1.9	18.4 ± 9.6	43.3 ± 22.9
2	5.3 ± 2.5	27.4 ± 13.5	12.3 ± 6.7
3	4.9 ± 2.6	55.8 ± 32.7	13.4 ± 6.2
4	5.0 ± 1.9	17.7 ± 8.0	21.9 ± 11.4
5	3.7 ± 1.5	12.1 ± 4.9	102.6 ± 91.4
6	3.6 ± 1.5	23.1 ± 12.3	129.1 ± 97.9
7	2.5 ± 1.1	17.0 ± 9.9	176.2 ± 174.7
8	10.1 ± 4.7	186.4 ± 127.0	102.5 ± 96.9
		Other species[a]	
1	1.1 ± 0.4	0.8 ± 0.4	0
2	1.9 ± 0.9	3.2 ± 2.0	0.6 ± 0.4
3	2.8 ± 1.6	3.0 ± 1.4	0.7 ± 0.5
4	4.4 ± 2.8	1.9 ± 0.8	3.2 ± 2.4
5	7.3 ± 4.9	4.9 ± 2.2	7.5 ± 6.1
6	2.0 ± 0.6	7.6 ± 2.9	22.2 ± 20.8
7	3.5 ± 2.5	22.7 ± 18.3	32.0 ± 31.5
8	5.4 ± 2.6	20.3 ± 12.4	59.5 ± 59.5

[a] Other species include *Tribolium* spp., *O. surinamensis*, *S. Oryzae*, and *P. interpunctella*.

numbers of *A. advena* collected outside of bins and in 25-bu bins was significant, but the Pearson r value was low, indicating a poor relationship ($r = 0.26$, $P = 0.04$, $n = 61$). The population within farm bins peaked 6 wk after storage, with lower numbers occurring late in the sampling period. The numbers of *A. advena* collected in farm bins were not correlated with trap catch outside ($r = 0.16$, $P = 0.32$, $n = 42$) or with numbers in 25-bu bins ($r = 0.21$, $P = 0.18$, $n = 42$).

In contrast to *A. advena*, *T. stercorea* collected outside of bins demonstrated a gradual increase through the sampling period to a maximum after 7 wk of storage (Table 2). Within the 25-bu bins, populations remained relatively steady through week 6, then increased at 7 wk of storage. As with *A. advena*, the numbers of *T. stercorea* collected outside and in the 25-bu bins were positively correlated but the relationship was weak ($r = 0.26$, $P = 0.04$, $n = 61$). *T. stercorea* collected in farm bins were higher than those in 25-bu bins and increased through the sampling period to a maximum in week 7. Outside populations were significantly correlated with the numbers collected in farm bins, but this relationship also was weak though statistically significant ($r = 0.28$, $P = 0.08$, $n = 42$). The numbers of *T. stercorea* collected in the two types of bins were not significantly correlated ($r = 0.25$, $P = 0.11$, $n = 42$).

The numbers of *R. dominica* collected outside bins increased gradually during the sampling period, similar to the trend observed for *T. stercorea*, and reached a maximum by week 8 (Table 2). Populations in 25-bu bins followed a similar trend with maximum populations occurring after 8 wk of storage. The population trend through the sampling period was similar to that of *A. advena* and *T. stercorea*, but at a lower level. The numbers of *R. dominica* collected in farm bins appeared to follow a different pattern. Two farm bins were fumigated with aluminum phosphide after week 5 because the numbers of *R. dominica* collected were >100 per bin. The numbers of *R. dominica* collected from the other farm bins remained relatively constant throughout the sampling period. Despite differences in outside population and those in the two bin types, the numbers of *R. dominica* collected outside were significantly correlated with trap catch in 25-bu bins ($r = 0.74$, $P = 0.0001$, $n = 61$) and farm bins ($r = 0.52$, $P = 0.0004$, $n = 42$). However, the number of beetles collected in the two types of bins were not significantly correlated ($r = 0.12$, $P = 0.44$, $n = 42$).

The initial numbers of *Cryptolestes* spp. were larger than the other three species (Table 2). The numbers of beetles collected outside of bins remained relatively constant during the first 4 wk, declined for 3 wk, and then increased sharply to a maximum after 8 wk of storage. *Cryptolestes* spp. within 25-bu bins exhibited a small peak at 3 wk of storage, then increased dramatically on week 8. The numbers of beetles collected outside of bins and in 25-bu bins were significantly correlated ($r = 0.76$, $P = 0.0001$, $n = 61$). The numbers collected in farm bins were higher after the 1st wk of storage than in the next 3 wk and reached a maximum after 7 wk of storage. The population trends for this species were similar to *T. stercorea*. Farm bin populations of *Cryptolestes* spp. were not significantly correlated with the number of beetles outside bins ($r = -0.06$, $P = 0.69$, $n = 42$) or in 25-bu bins ($r = -0.08$, $P = 0.62$, $n = 42$).

Populations of the remaining species outside of bins (*Tribolium* spp., *O. surinamensis*, *S. oryzae*, and *P. interpunctella*) reached a maximum after 5 wk of storage (Table 2). The general trend for the combined numbers of other species collected in 25-bu bins was to increase throughout the sampling period to a maximum at 7 wk of storage. The number detected in farm bins increased throughout the sampling period to maximum levels by week 8. Numbers in 25-bu bins were significantly correlated with outside populations ($r = 0.32$, $P = 0.01$, $n = 61$) and farm bins ($r = 0.38$, $P = 0.01$, $n = 42$). Outside populations were significantly correlated with farm bin populations, but the relationship was not as strong as with 25-bu bins and outside populations ($r = 0.28$, $P = 0.07$, $n = 42$).

In 25-bu and farm bins, the general trend for insect populations, individually and combined, was initially for low numbers, then higher populations near the end of the sampling period. This trend also occurred outside the bins where the numbers of insects collected were typically much lower than those within the grain masses. It is important to note that the presence of new wheat in bins did not deplete outside populations caused by migration into bins but that the numbers of insect pests collected outside did increase as inside populations increased. This may be the normal seasonal population dynamics of outside populations or may be caused by emigration of insects from the storage facilities.

Environmental Parameters. In an effort to account for differences in insect numbers among grain bins, we examined the relationship of population size within bins to insect density outside of bins, the presence or absence of active livestock operations on farm, and grain moisture and test weight. Numerical categorizing of outside trap catch into four discrete infestation levels was done to examine how the level of infestation within a bin related to the level of pest activity outside of bins. By understanding the dynamics of stored-product insect pest activity outside of bins, we may be better able to estimate insect migration into bins and assess the risk of infestation at a particular location.

25-bu Bins. Data were categorized to determine if very high or very low outside populations were better related to inside populations than were intermediate levels. For all species combined, significantly more insects ($F = 4.44$; df = 3, 40; $P = 0.009$) were found in 25-bu bins when outside populations were >10 insects per farm than when fewer insects were detected outside (Table 3). This relationship was not significant when each species was examined individually (*A. advena*: $F = 3.89$; df = 3, 40; $P = 0.02$; *T. stercorea*: $F = 0.53$; df = 1, 42; $P = 0.47$; *R. dominica*: $F = 0.19$; df = 1, 42; $P = 0.66$; *Cryptolestes* spp.: $F = 1.97$; df = 2, 41; $P = 0.15$) (Table 3).

The mean number of all species combined in 25-bu bins was significantly greater ($F = 2.92$; df = 1, 40; $P = 0.10$) on farms that did not have active livestock operations (Table 3). Most of this difference was caused by *Cryptolestes* spp. ($F = 8.52$; df = 1, 41; $P = 0.0057$). The numbers of the other three species collected in 25-bu bins did not differ significantly because of the presence or absence of livestock (*A. advena*: $F = 0.00$: df = 1, 40; $P = 0.99$; *T. stercorea*: $F = 0.30$; df = 1, 42; $P = 0.59$; *R. dominica*: $F = 0.69$; df = 1, 42; $P = 0.41$). Perhaps farms without active livestock operations had higher insect populations because there was no animal feed present that acted as a competitive food source that may draw *Cryptolestes* spp. away from the stored wheat.

In 25-bu bins, wheat with a moisture content less than 12% had significantly more insects than bins with higher moisture grain ($F = 12.68$; df = 1, 40; $P = 0.001$) (Table 3). This relationship was true for both fungus-feeding species, *A. advena* ($F = 4.99$; df = 1, 40; $P = 0.03$) and *T. stercorea* ($F = 3.08$; df = 1, 42; $P = 0.09$), but not for *R. dominica* ($F = 2.67$; df = 1, 42; $P = 0.11$) or *Cryptolestes* spp. ($F = 0.02$; df = 1, 41; $P = 0.02$). This is contrary to the expectation that fungus-feeding insects would occur in larger numbers in wheat with a higher moisture content because fungus was expected to be more abundant in moist environments. Perhaps lower moisture caused the insects to be more active because there was less fungal growth than in higher moisture grain, and, thus, they can be caught in greater numbers in the probe traps.

The numbers of all insect species in 25-bu bins also were significantly affected by grain test weight (Table 3). A large gap in test weight occurred between 732.9 and 748.6 g/L resulting in two naturally occurring groups (Table 1). Significantly more insects were collected from 25-bu bins with test weights below 733 g/L than above 748 g/L ($F = 7.42$; df = 1, 40; $P = 0.01$). This relationship occurred for *A. advena* ($F = 2.97$; df = 1, 40; $P = 0.09$), *T. stercorea* ($F = 5.05$; df = 1, 42; $P = 0.03$), and *Cryptolestes* spp. ($F = 6.21$; df = 1, 41; $P = 0.02$) but not for *R. dominica* ($F = 0.77$; df = 1, 42; $P = 0.39$). Additional fine material in the wheat with low test weights might have been more attractive to pest species than wheat with higher test weights (Flinn et al. 1992).

Farm Bins. The relationships between the numbers of insects collected within the grain

Table 3. Least squares means ($\bar{x}$ ± SEM) of parameters that influence insect populations in 25-bu bins and farm bins

Parameter	Species				
	All species	*A. advena*	*T. stercorea*	*R. dominica*	*Cryptolestes* spp.
		25-bu Bins			
Outside Populations					
<3.2	6.0 ± 1.3a	3.3 ± 0.6a	2.3 ± 0.4	1.1 ± 0.1	2.4 ± 0.3a
3.2–10.0	10.3 ± 2.0b	8.0 ± 1.6b	3.5 ± 1.4	1.0 ± 0.1	6.3 ± 2.7b
10.1–31.6	19.7 ± 5.0c	9.7 ± 4.1b	—	—	6.1 ± 2.6b
≥31.7	29.5 ± 10.3c	6.9 ± 6.0ab	—	—	—
Livestock					
Absent	17.6 ± 3.0*	6.5 ± 1.8	3.4 ± 1.0	1.1 ± 0.1	7.8 ± 2.2**
Present	10.7 ± 2.0	6.4 ± 4.6	2.4 ± 0.7	1.0 ± 0.1	2.6 ± 0.6
Grain moisture					
<12%	20.2 ± 4.1**	8.8 ± 2.8**	3.8 ± 1.1*	1.1 ± 0.1	4.6 ± 1.2
≥12%	9.3 ± 1.5	4.8 ± 1.2	2.1 ± 0.6	1.0 ± 0.1	4.5 ± 1.0
Grain test weight					
<733 g/L	20.0 ± 3.5**	8.3 ± 2.5*	4.2 ± 1.3**	1.1 ± 0.1	6.4 ± 1.6**
>748 g/L	9.5 ± 1.8	5.0 ± 1.4	1.9 ± 0.5	1.0 ± 0.1	3.2 ± 0.8
		Farm bins			
Outside populations					
<3.2	62.2 ± 39.4	13.6 ± 6.8	8.5 ± 2.8	1.4 ± 0.2a	9.0 ± 2.6
3.2–10.0	43.1 ± 21.4	9.2 ± 4.9	16.8 ± 10.3	9.6 ± 4.9b	10.9 ± 9.9
10.1–31.6	45.9 ± 31.2	14.1 ± 12.5	—	—	1.8 ± 1.7
31.7–100	36.8 ± 33.1	18.2 ± 31.4	—	—	—
Livestock					
Absent	84.5 ± 45.2	27.4 ± 18.2*	19.2 ± 10.4	3.5 ± 1.2	3.7 ± 2.7
Present	25.2 ± 13.3	6.5 ± 4.4	7.4 ± 3.6	3.9 ± 1.1	8.5 ± 4.5
Grain moisture					
<12%	21.2 ± 15.2	8.4 ± 5.8	4.9 ± 2.6**	2.9 ± 0.9*	3.4 ± 2.4
≥12%	100.0 ± 52.7	21.4 ± 12.8	28.8 ± 14.4	4.6 ± 1.3	9.2 ± 4.9
Grain test weight					
<733 g/L	76.9 ± 44.6	2.2 ± 1.5	11.3 ± 6.3	3.7 ± 1.1	5.7 ± 4.0
>748 g/L	27.6 ± 12.6	8.1 ± 4.7	12.5 ± 5.4	3.7 ± 1.0	5.5 ± 2.9
Bin size					
<4,000 bu	43.3 ± 23.5	11.2 ± 8.2	12.3 ± 6.7	3.4 ± 1.2	2.5 ± 1.8**
≥4,000 bu	49.2 ± 24.0	16.0 ± 10.8	11.5 ± 5.5	4.0 ± 1.0	12.6 ± 6.9
Prefilling infestation					
Absent	75.7 ± 30.3	29.2 ± 18.1*	14.4 ± 6.2	4.5 ± 1.1	8.6 ± 3.9
Present	28.1 ± 17.8	6.1 ± 4.2	9.8 ± 5.7	3.0 ± 1.0	3.6 ± 2.9
Reldan protectant					
Absent	81.3 ± 42.7*	10.8 ± 7.4	34.0 ± 17.7**	3.8 ± 1.2	19.0 ± 12.7**
Present	26.1 ± 11.2	16.6 ± 9.9	4.2 ± 1.9	3.6 ± 1.0	1.6 ± 0.9

Numbers of insects in the "All species" column do not equal the sum of the individual species because of the LOG_{10} transformation. The mean values for "All species" equals $\Pi(\Sigma x_{ij})$, whereas the sum of the individual species equals $\Pi(\Pi x_{ij})$. Within species, means followed by the same letter are not significantly different (paired *t*-test, $P > 0.05$). * and **, Indicate significance at the 0.10 and 0.05 levels of probability, respectively.

mass and the environmental parameters were poor and inconsistent (Table 3). The only significant difference in the numbers of insects collected in farm bins caused by differences in the size of outside populations was for *R. dominica* ($F = 14.50$; df = 1, 33; $P = 0.0006$) with higher populations occurring inside of bins when outside populations also were higher. The numbers of insects in farm bins were not significantly different because of outside population levels for all species combined ($F = 0.10$; df = 3, 31; $P = 0.96$), *A. advena* ($F = 0.14$; df = 3, 31; $P = 0.94$), *T. stercorea* ($F = 1.03$; df = 1, 33; $P = 0.32$), or *Cryptolestes* spp. ($F = 1.64$; df = 2, 32; $P = 0.21$). These data are quite different from those from the 25-bu bins, suggesting that other factors might be influencing the relationship between outside populations and those within farm bins.

The numbers of insects in farm bins was not significantly influenced by the presence of active livestock populations for all species combined ($F = 2.23$; df = 1,31; $P = 0.15$), *T. stercorea* ($F = 1.68$; df = 1,33; $P = 0.20$), *R. dominica* ($F = 0.12$; df = 1, 33; $P = 0.73$), or *Cryptolestes* spp. ($F = 1.26$; df = 1, 32; $P = 0.27$) (Table 3). Only *A. advena* was significantly associated with livestock operations ($F = 2.69$; df = 1, 31; $P = 0.10$). More *A. advena* were collected from farm bins located on farms without livestock than farms with livestock. Madrid et al. (1990) also demonstrated that insect infestations in grain were equally likely on farms regardless of the presence of livestock.

Although more insects tended to be present in farm bins containing grain with a moisture level of 12% or higher, the difference was significant only for *T. stercorea* (F = 5.52; df = 1, 33; P = 0.02) and *R. dominica* (F = 2.94; df = 1, 33; P = 0.10). Grain moisture was not a significant factor for all species combined (F = 2.16; df = 1, 31; P = 0.15), *A. advena* (F = 1.53; df = 1, 31; P = 0.23), or *Cryptolestes* spp. (F = 1.94; df = 1, 32; P = 0.17). Grain test weight was not a factor that significantly affected farm bin populations for all species combined (F = 1.69; df = 1, 31; P = 0.20), *A. advena* (F = 1.86; df = 1, 31; P = 0.18), *T. stercorea* (F = 0.02; df = 1, 33; P = 0.88), *R. dominica* (F = 0.00; df = 1, 33; P = 0.99), and *Cryptolestes* spp. (F = 0.00; df = 1, 32; P = 0.95) (Table 3). Grain characteristics appeared to be less important in the farm bins than in the much smaller 25-bu bins.

The average size of farm bins in this study was 4,000 bu (Table 1), and the number of insects collected per bin was similar regardless of bin size. There was no significant difference because of bin size in the numbers of all species combined (F = 0.34; df = 1, 31; P = 0.56), *A. advena* (F = 0.15; df = 1, 31; P = 0.70), *T. stercorea* (F = 0.01; df = 1, 33; P = 0.93), or *R. dominica* (F = 0.30; df = 1, 33; P = 0.59) (Table 3). However, significantly more *Cryptolestes* spp. (F = 4.63; df = 1, 32; P = 0.04) were collected from the larger farm bins than from those under 4000 bu. These results are similar to those of Madrid et al. (1990) in Canada. They reported no significant difference in percent infestation by *Cryptolestes* spp., *Typhaea* sp., and *A. advena* caused by bin size but did not report the numbers of each species in each of the bin sizes.

The absence of insects in farm bins 1 to 2 mo before filling was associated with more insects in farm-bin probe traps through the sampling period, but the difference was statistically significant only for *A. advena* (F = 3.93; df = 1, 31; P = 0.06) (Table 3). There was no significant difference in the numbers of insects in farm bins because of prefilling infestations for all species combined (F = 1.51; df = 1, 31; P = 0.23), *T. stercorea* (F = 0.28; df = 1, 33; P = 0.60), *R. dominica* (F = 2.17; df = 1, 33; P = 0.15), or *Cryptolestes* spp. (F = 1.34; df = 1, 32; P = 0.26). The prefilling samples were taken on the floor of the bins, but the grain mass was sampled on the upper surface. Perhaps insects in the bottom of bins remain there after filling and do not move through the grain mass to the upper surface where they may be detected. Because no grain samples were taken from the lower areas of full bins, conclusions about prior infestation of the bins are questionable.

Farm bins containing grain treated with protectant (chlorpyrifos-methyl) had significantly fewer of all species combined (F = 2.91; df = 1, 31; P = 0.10), *T. stercorea* (F = 10.35; df = 1, 33; P = 0.003), and *Cryptolestes* spp. (F = 15.42; df = 1, 32; P = 0.0004) than those bins with untreated wheat (Table 3). However, this was not a significant factor for *A. advena* (F = 0.37; df = 1, 31; P = 0.55) or *R. dominica* (F = 0.04; df = 1, 33; P = 0.85). *R. dominica* are resistant to chlorpyrifos-methyl (Zettler & Cuperus 1990) and were not expected to be controlled.

There are a variety of parameters that influence the dynamics of insect populations inside and outside of farm-stored wheat, and these parameters are not always consistent among all pest species examined. Of the environmental parameters examined, the size of pest populations, livestock operations, and grain moisture and test weight affected the numbers of all species combined in 25-bu bins but not in farm bins. The importance of these parameters was not consistent among species. The size of farm bins and the presence of insects in bins before filling typically did not affect insect populations within the grain mass. However, the use of grain protectant at the time of bin filling did reduce the numbers of all species combined, *T. stercorea*, and *Cryptolestes* spp. but not the numbers of *A. advena* or *R. dominica*.

The difficulty of quantifying insect movement into farm bins is compounded by the use of grain protectants that in our study probably obscured the effects of outside populations on colonization of the grain. Such relationships are interpreted more easily when dealing with uninfested bins and grain not treated with protectant, as in the 25-bu bins. These data show obvious relationships between outside and inside populations in experimental bins where protectants are not used. Infestations in farm bins are difficult to predict because they are influenced by a number of factors. However, prediction may be possible if protectants are not used.

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