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Insect populations in grain residues associated with commercial Kansas grain elevators☆

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Abstract

Grain residues in nine commercial elevators in Kansas were sampled monthly for insects in grain residues during 1999 and 2000. Five locations per elevator were observed; the boot pit, dump pit, headhouse, rail area, and tunnel. When a grain residue was found, the quantity was estimated and a sample taken. Adult grain pest insects and beneficial insects were removed and identified. *Cryptolestes* spp. and *Sitophilus* spp. comprised about 80% of the pest insects collected. The density of *Cryptolestes* spp. appeared to rapidly increase in spring but remained low at other times of the year. The density of *Sitophilus* spp. in the residues increased consistently through the warm months, peaked immediately after the warmest month, and declined gradually as ambient temperatures cooled. Pest insects were observed in 41.7% of the 1575 samples examined, and beneficial insects were collected from 5.1% of the samples. Residue samples taken from the elevator boot pit and tunnel areas contained a greater density of pest insects (all species combined) than other locations. About 42% of the residues were estimated to be smaller than 1.5 kg, and samples from these residues contained more insects per sample than did samples from larger residues. *Anisopteromalus calandrae* comprised 88.9% of the total number of beneficial insects found. Beneficial insects were observed infrequently, and mean populations exceeded 1 insect/kg of residue in any month at only two of the nine elevators. Results from our study showed that grain residues within the elevator often contain pest insects

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and could provide food and harborage when the bins are empty, serving as sources of insect infestation for new grain.

Keywords: Sanitation; Cleaning; Elevators; Grain; Insects

1. Introduction

In the central plains region of the United States, stored-grain insects can quickly infest newly harvested grain in farm bulk bins (Hagstrum, 1987, 1989; Reed et al., 1991; Dowdy and McGaughey, 1994; Hagstrum et al., 1994; Vela-Coiffier et al., 1997; Hagstrum, 2001). A likely source of this infestation is residual grain inside the bins, which can be heavily infested with stored-grain insects (Ingemansen et al., 1986; Loschiavo and Smith, 1986; Barker and Smith, 1987, 1990). Sanitation practices such as removing grain residues from inside bins and applying bin sprays are often recommended for farm-stored hard red winter wheat in the south-central US (Reed and Pedersen, 1987; Reed and Harner, 1998; Reed et al., 1990; Cuperus et al., 1990). Nevertheless, Herron et al. (1996) found little correlation between hygiene practices and infestations inside farm bins in Australia. Furthermore, Reed et al. (1990) showed that there was no economic incentive for using insecticides as pre-binning sprays to eliminate residual populations inside empty bins, even when these sprays appeared to be effective.

Grain in commercial elevators can become infested with insects quickly, as illustrated by a study of 13 elevator sites in Kansas (Reed et al., 2001). Pitfall traps placed in wheat immediately after storage in these elevators detected insects in half the silos within two weeks. In warm climates, stored-grain insects are known to infest crops in the field (summarized by Reed et al., 2003). However, in climatic zones similar to those of the present study, sampling of new grain delivered directly from the field has given little indication of infestation (Chao et al., 1953; Hagstrum et al., 1995; Vela-Coiffier et al., 1997).

In elevators, it appears likely that a major source of the insects that infest new grain is previously infested grain present when the new crop is received. Other likely sources are infested grain residues in empty bins, spills and other related debris in and around elevators. It is also possible that trucks and railcars used to transport grain to commercial elevators may be infested. Dowdy and McGaughey (1996) surveyed four elevators in Kansas and consistently detected insects in the elevator base areas, dump pits, head houses, on the top of the elevators, silo head spaces, and outside areas. They also sampled residual material containing grain dust and did not find insects upon initial examination, but did collect some insects (primarily dermestids) after a 60-day incubation period.

In a recent survey of insects collected from grain in the bottom of elevator silos and from discharge spouts (Reed et al., 2003), *Cryptolestes* spp., *Rhyzopertha dominica* (F.), *Oryzaephilus* spp., *Tribolium* spp., and *Sitophilus* spp. weevils were observed consistently over a 2.5-year period. In the discharge spouts, *Cryptolestes* spp. comprised 65% or more of the insects collected in four of the five sampling periods (6 months each). *Rhyzopertha dominica* comprised about 10% of the population most of the time, and *Sitophilus* spp. comprised from 3.9 to 23.3% of the insects collected, depending on the sampling period. In the grain remaining inside empty bins, *Cryptolestes* spp. comprised 45%, *Sitophilus* spp. represented 32.4%, and *R. dominica* comprised 9% of the insects collected. Two of the grain elevators reported in Reed et al. (2003) were sampled in the present study. Most research on insects in grain residues found outside of storage bins has been conducted at farm sites, and there is comparatively little research in large commercial grain elevators.

Spilled grain and other residual grain materials in and around elevators but outside the storage bins may also contain resident insect populations, and represent an important source of infestation for new grain. There are few published data regarding the composition and abundance of insects in grain residues found inside elevators. The purpose of this study was to determine: (1) species composition of insects collected from grain residues in commercial elevators but outside the storage bins; and (2) distributional and seasonal density patterns of these populations.

2. Materials and methods

Nine elevators in Kansas with concrete silos were visited monthly in 1999 and 2000 to inspect for accumulations of spilled grain or grain residue, including broken grain, grain dust, and plant trash. A few visits (3% of samples) were made in January and February of 2001. Although visits were made monthly, the actual amount of grain varied depending on the time of year and frequency of grain movement through the elevator. Similar difficulties were noted in an earlier study by Reed et al. (2003). Grain residues were recorded as being in or close to one of the following locations: elevator boot, tunnel, truck dump, rail line, ground-level areas of the headhouse, or bin-deck level of the headhouse or annex (Fig. 1). The elevator boot is the enclosed base of the elevator leg, and is located in the basement or in a sub-basement pit. The tunnel houses the reclaim conveyor beneath the annex bins. The truck dump is the area above the dump pit

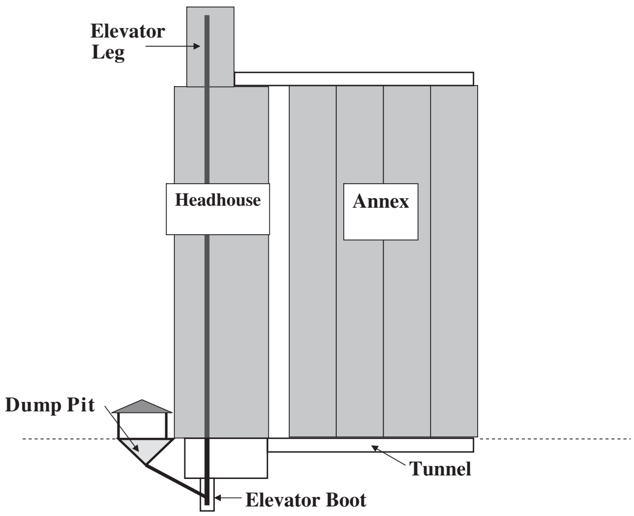

Fig. 1. Illustration of the inspection and sampling locations in grain elevators.

where grain enters the elevator from trucks. The rail load area usually is a covered part of the railroad track that passes close to the elevator. Samples collected on the rail line, including those collected in the rail load area, were designated as rail line samples. The main elevator legs are housed in the headhouse. The roof of the grain storage bins forms the floor of the bin-deck level of the headhouse and annex(es). The bin-deck level contains spouts that transport the grain from the elevator leg to the bins or to lateral conveyors.

Elevator boot areas and boot pits are often damp and the temperature in them is moderated by the subterranean location. Spills and residues in this area result from clean-out of the elevator boot (rare) or spills from worn spouts. Spills in the tunnel area are often exposed to water from leaks in the wall or floor, and the temperature in the tunnel is moderated by its subterranean location. The pit of the truck dump is nearly self-cleaning because most residues from a previous load are flushed when new grain is subsequently moved through the pit. However, spills often occur around the dump pits; these residues are exposed to ambient air. The railroad line is outside the facility and is usually covered by a roof where it passes over the dump pit. Spills on the rail line are often the result of railcar clean-out. Residues in the headhouse ground level consisted of spills from worn grain spouts. Spills on the bin-deck level may be due to worn spouts or spills from the conveyor belt. Typically, they are exposed to ambient conditions.

The amount of grain residue was recorded monthly for each elevator. Quantities of residues were estimated by the sampler as either $\leqslant 1.5$ kg, >1.5 kg $\leqslant 27$ kg (about one bushel), 1.5 kg$\leqslant$27 kg (5 bu), and >135 kg. Samples of the residues were collected as randomly as possible. When the quantity of residue was small, it was brushed into a dustpan and placed in a sample bag. When a large amount of residue or spillage was present, several kg samples were collected from different locations and placed in labeled sample bags. Samples were transported to the laboratory, where they were weighed and characterized as to grain type. Extremes of heat or cold were avoided during sample transport and the samples were stored at room temperature for a maximum of five days before analysis.

To facilitate accurate identification of insects, each sample was sieved through various wire-mesh screens to separate as much as possible the live insects from the grain and trash. Adults of *Typhaea stercorea* (L.), hairy fungus beetle; *R. dominica*; and *Ahasverus advena* (Walt.), foreign grain beetle were identified to species. Adults of the following were identified to genera because closely related species are sometimes found in stored grain: *Sitophilus*, *Cryptolestes*, *Tribolium*, and *Oryzaephilus*. Adults of the four parasitoid wasps *Habrobracon* (= *Bracon*) *hebetor* (Say), *Anisopteromalus calandrae* (Howard), *Theocolax* (= *Choetospila*) *elegans* (Westwood), and *Cephalonomia waterstoni* (Gahan) also were identified to species.

Data for the two years in which these samples were collected were combined and the Statistical Analysis System (SAS Institute, 2001) was used to analyze these data. Raw data were transformed using the square root in an attempt to normalize variances for purposes of means-testing, but non-transformed means and other statistics are reported here to facilitate intuitive interpretation. Insect density is reported as the number of live adult insects per kg of residue. The general linear models (GLM) procedure was used to determine the significance of various factors with respect to insect distribution. When a significant model effect was observed, means were separated using the Waller/Duncan k-ratio *t*-test. The correlation procedure (CORR) was used to correlate numbers of beneficial insect species with those of their primary host among the pest insect species. The frequency procedure (FREQ) was used for categorical analysis and χ^2 tests.

3. Results

In total, 46,725 pest insects and 933 beneficial insects were collected and identified from 1575 grain residue samples. The mean sample size was 559.6 ± 12.5 g (SE) of grain residue. The mean insect population density varied from 16.5 to 66.2/kg between individual grain elevators (Table 1), but means were not significantly different because variability was great. Because there was no significant relationship ($r = -0.28$, $P = 0.42$) between the storage capacity of the elevator and the insect density (all species combined), data from all elevators were combined for further analysis. The predominant insect species in all residue samples were *Sitophilus* spp. and *Cryptolestes* spp., comprising 50.3% and 30.7%, respectively, of the total number of insects collected. In the majority of the residue samples (58.3%) no pest insects were found. Of the samples in which pest insects were found, 3.2% contained $\leqslant 1$ insect/kg, 44.7% contained >1 insects $\leqslant 10$/kg, 39.6% contained >10 $\leqslant 100$ insects/kg, and 12.5% contained >100 insects/kg.

The highest density of pest insects (all species) and of *Sitophilus* spp. in particular was found in the smallest residues (<1.5 kg) compared with the other three size categories (Table 2). The density of the other insect species did not differ significantly by estimated size of the residue. Samples from residues found in or near the elevator boot pit and tunnel contained higher insect densities than did residues from the dump pit, headhouse, or rail line (Table 3). This relationship was true for each of the dominant species individually. For example, the density of both *Sitophilus* spp. and *Cryptolestes* spp. was more than four times greater in samples from or near the boot pit than in samples from the dump pit, headhouse areas or on the rail line. Density of *Tribolium* spp. in samples from the boot pits and tunnels was at least twice as great as from any of the other locations.

Samples identified as wheat were the most common type (42.8%). Other residue samples were identified as maize (17.7%), sorghum (14.0%), a mixture of wheat and sorghum (3.4%) or a mixture of maize, wheat, and sorghum (14.1%). About 8.4% were called "other" because the material consisted of uncommon mixtures of grains and dust. Mixtures of wheat and sorghum had a greater density of *Sitophilus* spp. and all species combined than did samples of either sorghum or wheat individually, and the population density of *Tribolium* spp. was lowest in residues that contained only sorghum (Table 4). The density of *Sitophilus* spp. was markedly different in residues of different grains, with an average of nearly 31/kg in wheat–sorghum mixtures but less than 7/kg in sorghum residues. The density of *Tribolium* spp. also was significantly affected by the composition of the residue. Of the species present in high numbers, only the density of *Cryptolestes* spp. was not affected by type of grain in the residue sample (Table 4). Of the insects found only in low numbers, a significantly higher density of *T. stercorea* was found in the samples classified as a mixture of wheat, maize, and sorghum than any other type of sample.

The mean density of *T. stercorea*, *R. dominica*, *A. advena*, and *Oryzaephilus* spp. in the residue samples did not exceed 2 insects/kg regardless of the time of year (Fig. 2A–D). Numbers of *T. stercorea* peaked in April and September, the beginning and the end of the warm season, and were low at other periods. Densities of *Oryzaephilus* spp. also showed two peaks, in June and October. In contrast, the greatest densities of *R. dominica* were observed in three consecutive winter months. The density of *Sitophilus* spp. was >5 insects/kg in the residue samples throughout the year except for the coldest winter months, which suggests that low temperatures

Table 1
Density of live adult pest insects per kilogram (mean ± SE) from residues collected over all sampling times, percentage of residue samples infested with pest insects, and total number of samples and adult live beetles of each species, by elevator (Elev.)

Elev.	n[a]	*Sitophilus*	*Cryptolestes*	*Tribolium*	*Typhaea stercorea*	*Rhyzopertha dominica*	*Oryzaephilus*	*Ahasverus advena*	Total	% Infested
A	64	5.94 ± 4.02	16.52 ± 9.28	1.66 ± 1.19	0.00 ± 0.00	0.27 ± 0.16	0.08 ± 0.08	0.00 ± 0.00	24.47 ± 11.68	43.8
B	94	17.05 ± 6.87	0.87 ± 0.40	0.86 ± 0.52	0.07 ± 0.07	0.32 ± 0.17	0.32 ± 0.23	0.19 ± 0.11	19.68 ± 7.09	30.8
C	124	31.28 ± 12.59	6.22 ± 1.88	2.51 ± 0.87	0.04 ± 0.03	0.09 ± 0.04	0.28 ± 0.10	0.05 ± 0.05	40.45 ± 13.86	47.6
D	152	13.45 ± 3.36	51.33 ± 33.65	0.53 ± 0.20	0.25 ± 0.09	0.50 ± 0.19	0.03 ± 0.02	0.04 ± 0.03	66.15 ± 35.71	46.7
E	192	7.91 ± 3.23	17.31 ± 8.28	2.58 ± 1.99	0.12 ± 0.08	0.97 ± 0.47	0.14 ± 0.10	0.33 ± 0.33	29.35 ± 9.85	41.7
F	174	12.04 ± 3.78	5.38 ± 2.11	2.22 ± 0.89	0.17 ± 0.09	0.09 ± 0.08	0.24 ± 0.10	0.03 ± 0.02	20.18 ± 5.74	44.8
G	186	29.15 ± 7.25	6.04 ± 1.62	14.60 ± 10.74	0.13 ± 0.10	0.04 ± 0.03	0.28 ± 0.13	0.14 ± 0.10	50.37 ± 13.85	54.8
H	311	4.79 ± 1.88	5.20 ± 1.75	4.17 ± 2.38	0.92 ± 0.64	0.08 ± 0.52	0.55 ± 0.42	0.04 ± 0.04	16.48 ± 4.99	37.3
I	278	11.29 ± 3.44	0.89 ± 0.29	3.28 ± 2.32	0.05 ± 0.03	0.17 ± 0.11	0.81 ± 0.57	0.03 ± 0.02	16.52 ± 4.33	33.8
Total	1575	21,570	16,960	6384	428	644	591	144	46,725	

[a]n = number of samples.

Table 2
Number of live adult insects[a] per kg (mean ± SE) and percentage of residue samples infested with pest insects, by estimated size of residue

Residue size (Kg)	*Sitophilus*	*Cryptolestes*	*Tribolium*	*Typhaea stercorea*	*Rhyzopertha dominica*	*Oryzaephilus*	*Ahasverus advena*	Total	% Infested
<1.5	19.36 ± 3.31a	16.46 ± 7.34a	6.40 ± 3.06a	0.30 ± 0.18a	0.39 ± 0.12a	0.46 ± 0.22a	0.15 ± 0.09a	43.52 ± 9.17a	44.0
1.5–27	9.83 ± 2.15b	3.83 ± 0.89a	3.07 ± 1.44a	0.38 ± 0.33a	0.53 ± 0.33a	0.47 ± 0.30a	0.07 ± 0.04a	18.16 ± 3.23b	40.5
27–135	10.19 ± 3.11b	9.46 ± 5.23a	0.74 ± 0.25a	0.07 ± 0.04a	0.20 ± 0.11a	0.14 ± 0.07a	0.03 ± 0.02a	20.84 ± 7.44b	39.1
>135	5.33 ± 1.79b	8.42 ± 6.23a	1.39 ± 0.69a	0.10 ± 0.06a	0.46 ± 0.30a	0.06 ± 0.04a	0.00 ± 0.00a	15.78 ± 7.28b	39.1

Data combined over all elevators and sampling visits, $n = 705$, 482, 230, and 158 for each size category, from smallest to largest.
Means within columns followed by the same letter are not significantly different ($P \geq 0.05$, Waller–Duncan k-ratio t-test, SAS Institute).
[a]ANOVA model significant with respect to total number of insects (PROC GLM, SAS Institute, $F = 6.2$, df = 3,1571, $P < 0.01$).

Table 3
Number of live adult insects[a] per kg (mean ± SE) and percentage residue samples infested with pest insects, by inspection location

Location	*Sitophilus*	*Cryptolestes*	*Tribolium*	*Typhaea stercorea*	*Rhyzopertha dominica*	*Oryzaephilus*	*Ahasverus advena*	Total	% Infested
Boot pit	40.08 ± 7.90a	9.31 ± 2.80ab	10.94 ± 5.73a	0.14 ± 0.06a	0.70 ± 0.35a	1.23 ± 0.56a	0.11 ± 0.08ab	62.54 ± 12.92a	71.1
Dump pit	8.52 ± 1.54b	6.50 ± 1.66bc	1.11 ± 0.27b	0.43 ± 0.29a	0.44 ± 0.19a	0.14 ± 0.04b	0.02 ± 0.02b	17.16 ± 2.56b	45.3
Headhouse	3.38 ± 1.44c	6.88 ± 2.74bc	1.47 ± 0.48b	0.09 ± 0.04a	0.23 ± 0.08a	0.07 ± 0.04b	0.01 ± 0.01b	12.10 ± 3.48b	29.7
Rail line	8.16 ± 2.41b	2.61 ± 1.42c	4.76 ± 4.30b	1.17 ± 1.07a	0.14 ± 0.10a	1.01 ± 0.95b	0.05 ± 0.04b	17.89 ± 5.96b	35.4
Tunnel	37.09 ± 8.49a	33.97 ± 20.94a	11.31 ± 8.20a	0.01 ± 0.01a	0.80 ± 0.65a	0.67 ± 0.54b	0.43 ± 0.27a	84.28 ± 25.24a	53.1

Data combined for all elevators and sampling visits $n = 142$, 417, 626, 147, and 243 for each location from top to bottom.
Means within columns followed by the same letter are not significantly different ($P \geqslant 0.05$, Waller–Duncan k-ratio t-test, SAS Institute).
[a]ANOVA model significant with respect to total number of insects (PROC GLM, SAS Institute, $F = 29.3$, df $= 4,1570$, $P < 0.01$).

Table 4
Number of live adult insects[a] per kg (mean ± SE) and percentage residue samples (all elevators and visits) infested by pest insect, by grain type in the residue, including wheat (W), maize (M), sorghum (S), wheat + sorghum (WS), wheat + sorghum + maize (WSM), and other (O)

Grain	n^b	*Sitophilus*	*Cryptolestes*	*Tribolium*	*Typhaea stercorea*	*Rhyzopertha dominica*	*Oryzaephilus*	*Ahasverus advena*	Total	% Infested
W	672	11.05 ± 1.93bc	16.90 ± 7.94a	2.22 ± 0.98b	0.13 ± 0.06ab	0.75 ± 0.28a	0.18 ± 0.11a	0.02 ± 0.01a	31.27 ± 8.66bc	41.4
M	281	16.79 ± 5.73bc	5.58 ± 1.96a	8.44 ± 7.06ab	0.07 ± 0.05ab	0.04 ± 0.02a	0.15 ± 0.07a	0.12 ± 0.07a	31.20 ± 9.99bc	39.2
S	221	6.71 ± 2.77c	5.83 ± 3.34a	0.65 ± 0.25b	0.02 ± 0.02b	0.15 ± 0.06a	0.82 ± 0.64a	0.01 ± 0.01a	14.12 ± 4.50c	32.1
WS	54	30.99 ± 9.40a	8.13 ± 4.14a	5.04 ± 4.39ab	0.04 ± 0.04b	0.33 ± 0.23a	0.05 ± 0.03a	0.18 ± 0.13a	44.77 ± 12.81a	46.3
WSM	222	23.80 ± 6.40b	7.39 ± 1.83a	8.91 ± 3.80ba	1.39 ± 0.90a	0.24 ± 0.11a	0.96 ± 0.60a	0.05 ± 0.04a	42.76 ± 9.86ab	50.5
Other	125	7.90 ± 3.51c	5.29 ± 2.26a	1.00 ± 0.34b	0.03 ± 0.03b	0.18 ± 0.13a	0.23 ± 0.23a	0.55 ± 0.50a	15.17 ± 5.92bc	48.8

Means within columns followed by the same letter are not significantly different ($P \geqslant 0.05$, Waller–Duncan k-ratio t-test, SAS Institute).
[a]ANOVA model significant with respect to total number of insects (PROC GLM, SAS Institute, $F = 3.6$, df $= 5,1569$, $P < 0.01$).
[b]n = number of samples.

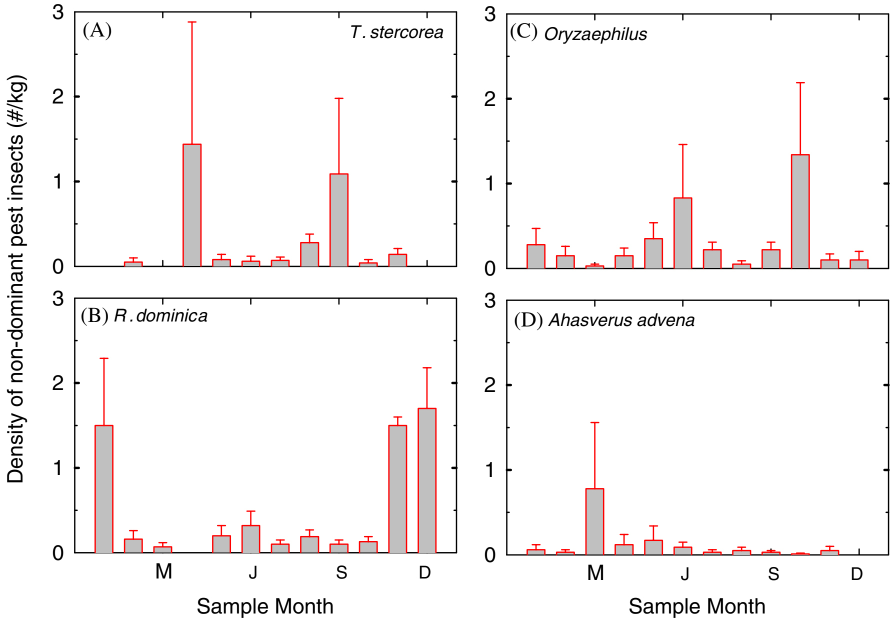

Fig. 2. (A–D) Population density trends by month (mean ± SE) for each of the four non-dominant insect species collected in grain residue samples. Data combined for all visits in 1999 and 2000.

suppressed insect populations in the residues (Fig. 3A). In contrast, *Cryptolestes* spp. density in grain residues increased markedly during the warm spring months of April, May, and June (Fig. 3B). Peak *Tribolium* spp. population density was observed in May, with considerable variability in density in other months (Fig. 3C). The pattern of insect density for all species combined reflected the temporal density distribution of *Cryptolestes* spp. which peaked during the spring and *Sitophilus* spp, which peaked in early fall (Fig. 3D).

The most abundant beneficial insect species collected in the residue samples was *A. calandrae*, a parasite of *Sitophilus* spp. *Anisopteromalus calandrae* comprised 89% of the total number of beneficial insects observed (Table 5). However, in comparison to the host density, the density of the parasitoid wasps was low, the mean density of these beneficial insects (all species) ranged from 0.06 ± 0.03 to 1.50 ± 0.72 insects per kg, and exceeded 1 per kg at only two elevators (Table 5). *Habrobracon hebetor*, a parasite of the Indianmeal moth (*Plodia interpunctella* Hübner), was found at only two elevators, and only at low densities. *Theocolax elegans*, a parasite of *Sitophilus* spp. and *R. dominica*, was found in low numbers at most of the elevators, as was *C. waterstoni*, a parasite of *Cryptolestes* spp. Beneficial insects were recovered from only 5.1% of the samples. Of the samples from which beneficial insects were recovered, 8.6% contained <1 insect/kg, 21.0% contained $\geqslant 1$ insects <2/kg, 18.5% contained $\geqslant 2$ insects <3/kg, 3.7% $\geqslant 3$ insects <4/kg, 7.4% contained $\geqslant 4$ insects <5/kg, and 40.7% contained $\geqslant 5$ insects/kg.

There were no differences in mean density for any of the beneficial insects with respect to sample size (Table 6); however, more *A. calandrae* were found in the samples from or near the boot pit and rail line compared to the other three locations (Table 7). Residues comprised of

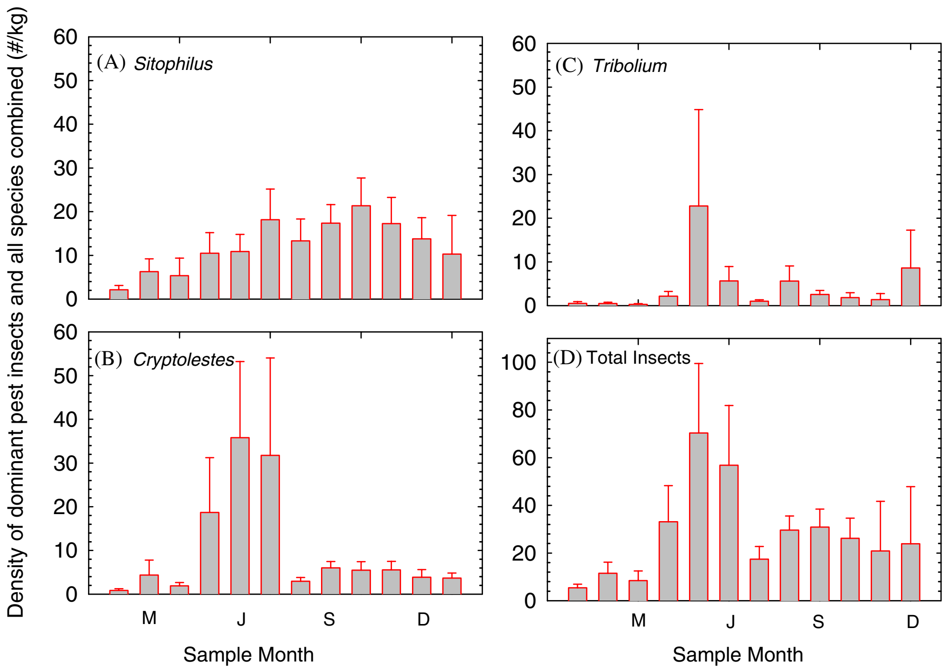

Fig. 3. (A–D) Population trends for each of the three dominant insect species in grain residue samples and all pest species combined (mean ± SE). Data combined for all visits in 1999 and 2000.

Table 5
Number of beneficial insects[a] per kilogram (mean ± SE) over all visits, percentage of residue samples in which beneficial insects were observed, and number of adult beneficial insects, by elevator (Elev.)

Elev.	n[b]	*Anisopteromalus calandrae*	*Theocolax elegans*	*Cephalonomia waterstoni*	Total	%[c]
A	64	0.13 ± 0.08	0.00 ± 0.00	0.24 ± 0.15	0.36 ± 0.18	7.2
B	94	0.80 ± 0.57	0.00 ± 0.00	0.02 ± 0.02	0.82 ± 0.58	5.3
C	124	0.66 ± 0.51	0.00 ± 0.00	0.03 ± 0.01	0.70 ± 0.51	8.9
D	152	1.30 ± 0.58	0.17 ± 0.17	0.01 ± 0.01	1.48 ± 0.64	7.2
E	192	0.05 ± 0.03	0.01 ± 0.01	0.00 ± 0.00	0.06 ± 0.03	2.1
F	174	0.07 ± 0.06	0.02 ± 0.02	0.07 ± 0.05	0.17 ± 0.12	2.9
G	186	0.06 ± 0.04	0.00 ± 0.00	0.00 ± 0.00	0.06 ± 0.04	1.6
H	311	0.10 ± 0.08	0.02 ± 0.01	0.03 ± 0.03	0.18 ± 0.10	3.5
I	278	1.45 ± 0.72	0.00 ± 0.00	0.05 ± 0.03	1.50 ± 0.72	9.4
Total	1575	830	36	57	933	

[a]Ten *Habrobracon hebetor* collected, 0.01 ± 0.01/kg and 0.03 ± 0.03/kg at elevators F and G, respectively.
[b]n = number of samples.
[c]% of samples which contained one or more of these species.

wheat contained the greatest density of *A. calandrae* and beneficial insects (all species) whereas the lowest density of *A. calandrae* and beneficial insects (all species) was found in residues of maize (Table 8).

Table 6
Number of beneficial insects[a] per kilogram (mean ± SE) over all visits and percentage residue samples in which beneficial insects were found, by estimated size of residue

Residue size (kg)	n^b	*Anisopteromalus calandrae*	*Theocolax elegans*	*Cephalonomia waterstoni*	Total	%[c]
<1.5	705	0.34 ± 0.14	0.04 ± 0.03	0.03 ± 0.02	0.41 ± 0.14	3.8
1.5–27	482	0.93 ± 0.43	0.01 ± 0.01	0.01 ± 0.01	0.95 ± 0.44	6.0
27–135	230	0.47 ± 0.25	0.00 ± 0.00	0.08 ± 0.05	0.57 ± 0.26	5.7
>135	158	0.19 ± 0.10	0.01 ± 0.01	0.08 ± 0.05	0.29 ± 0.11	7.6

[a] *H. hebetor* collected at 0.02 ± 0.02 and 0.01 ± 0.01 for 27–135 kg and >135 kg, respectively. ANOVA model not significant with respect to total number of insects (PROC GLM, SAS Institute, $F = 0.9$, df = 3,1571, $P = 0.44$).
[b] n = number of samples.
[c] % of samples which contained one or more of these species.

Table 7
Number of beneficial insects[a] per kilogram (mean ± SE) over all visits and percentage residue samples in which beneficial insects were found, by sampling location

Location	n^b	*Anisopteromalus calandrae*	*Theocolax elegans*	*Cephalonomia waterstoni*	Total	%[c]
Boot pit	142	0.87 ± 0.46a	0.02 ± 0.02a	0.08 ± 0.06a	0.97 ± 0.47ab	11.3
Dump pit	417	0.46 ± 0.21b	0.06 ± 0.06a	0.04 ± 0.03a	0.56 ± 0.24bc	5.3
Headhouse	626	0.20 ± 0.10b	0.01 ± 0.01a	0.01 ± 0.01a	0.22 ± 0.10c	2.6
Rail line	147	1.89 ± 1.30a	0.01 ± 0.01a	0.02 ± 0.02a	1.98 ± 1.30a	9.5
Tunnel	243	0.45 ± 0.24b	0.00 ± 0.00a	0.07 ± 0.04a	0.53 ± 0.24bc	5.4

Means within columns followed by the same letter are not significantly different ($P \geq 0.05$, Waller–Duncan k-ratio t-test, SAS Institute).
[a] *H. hebetor* collected at 0.04 ± 0.03 and 0.01 ± 0.01 per kg from the rail line and tunnel, respectively. ANOVA model significant with respect to total number of insects (PROC GLM, SAS Institute, $F = 4.7$, df = 4,1570, $P < 0.01$).
[b] n = number of samples.
[c] % of samples which contained one or more of these species.

A significant relationship ($P < 0.01$) between the presence or absence of the pest and beneficial insects was demonstrated by χ^2 analysis. Parasitoids were found in 10.2% of samples infested with pest insects, but in only 1.5% of samples in which no pest insects were recovered. However, correlation analysis did not show a significant relationship between the density of any pest insect and the density of the corresponding parasitoid.

4. Discussion

This study demonstrated that grain residues in commercial elevators in Kansas often contain infestations of pest insects. In the nine elevators studied, the frequency of samples infested with

Table 8
Number of beneficial insects[a] per kg (mean ± SE) over all visits and percentage of residue samples in which beneficial insects were found, by composition of the residue, either wheat (W), maize (M), sorghum (S), wheat + sorghum (WS), wheat + sorghum + maize (WSM), or other (O)

Grain	n[b]	*Habrobracon hebetor*	*Anisopteromalus calandrae*	*Theocolax elegans*	*Cephalonomia waterstoni*	Total	%[c]
W	672	0.01 ± 0.01a	1.02 ± 0.34a	0.04 ± 0.04a	0.04 ± 0.02a	1.11 ± 0.34a	6.9
M	281	0.01 ± 0.01a	0.03 ± 0.02c	0.01 ± 0.01a	0.00 ± 0.00a	0.05 ± 0.03c	1.4
S	221	0.00 ± 0.00a	0.27 ± 0.23bc	0.00 ± 0.00a	0.01 ± 0.01a	0.28 ± 0.23bc	2.3
WS	54	0.00 ± 0.00a	0.70 ± 0.44ab	0.00 ± 0.00a	0.15 ± 0.15a	0.85 ± 0.46ab	13.0
WSM	222	0.01 ± 0.01a	0.10 ± 0.04bc	0.01 ± 0.01a	0.03 ± 0.02a	0.15 ± 0.04bc	6.3
Other	125	0.01 ± 0.01a	0.10 ± 0.08bc	0.03 ± 0.03a	0.12 ± 0.08a	0.25 ± 0.17bc	4.0

Means within columns followed by the same letter are not significantly different ($P \geqslant 0.05$, Waller–Duncan k-ratio t-test, SAS Institute).

[a] *H. hebetor* collected at 0.02 ± 0.02 and 0.01 ± 0.01 for 27–135 kg and > 135 kg, respectively. ANOVA model significant with respect to total number of insects (PROC GLM, SAS Institute, $F = 3.9$, df = 4,1570, $P < 0.01$).

[b] n = number of samples.

[c] % of samples which contained one or more of these species.

pest insects ranged from about one-third to more than one-half. Furthermore, the infestation was dense in the residues, with the mean of all pest species combined over all samples being greater than 53 adult insects per kg. Only about 3% of the infested samples contained less than 1 insect/kg, and more than 50% contained > 10 insects/kg. These results are consistent with the hypothesis that grain residues were likely to be either densely infested with pest insects or not yet infested.

In our study, *Sitophilus* spp. were the most prevalent insects collected from the residue samples, comprising 46.2% of all insects collected and being found in 27.1% of all samples. Reed et al. (2003), reporting data collected in the same elevators, showed that *Sitophilus* spp. usually were a minor component of the insect population in the stored grain. Nevertheless, these species were observed often in grain left inside the bins, comprising about one-third of the pest insects and being present in 37.8% of all in-bin residues (Reed et al., 2003). These facts may indicate that residues accessible to insects in these elevators were likely to contain *Sitophilus* spp. even where the weevils comprised a minority of the insect populations in the stored grain.

Cryptolestes spp. were recovered from 23.3% of grain residues in the present study. Overall, the mean density of *Cryptolestes* spp. in samples was high (19.2/kg). However, as seen in Fig. 2, most of these insects were collected during April, May, and June. Because most bins contained no stored grain at this time of year, the insects tended to be found in the grain residues. When new wheat arrived in late June and early July, adult insects rapidly dispersed from the grain residues into the more attractive new wheat. This exodus reduced the populations in the residues. This hypothesis appears to be consistent with the results of Reed et al. (2003). They found *Cryptolestes* spp. frequently in in-bin residues and showed that these species rapidly infested the recently harvested wheat in storage.

The annual pattern of density in grain residues of both the fungivore *A. advena* and the general scavenger *Oryzaephilus* spp. appears to be related to season and harvest time. *Ahasverus advena* is often found in wheat immediately after harvest in Kansas (Dowdy and McGaughey, 1994; Reed et al., 1991), although the density in the stored grain gradually decreases in the months after harvest. The present study showed peak densities in grain residues in the elevators about a month prior to the summer harvest of wheat and immediately prior to the main fall harvest of maize and sorghum. The *Oryzaephilus* spp. density peaks occurred immediately prior to wheat harvest (June) and during the fall harvest (October).

In contrast to the erratic pattern of the other insects, the seasonal pattern of *Sitophilus* spp. density in grain residues showed a steady increase throughout the warm months, followed by a gradual decline. The greatest density occurred immediately after the warmest month and the lowest mean density corresponded with the coldest month. The general pattern of gradual build-up of *Sitophilus* spp. populations in residues is similar to that seen within stored-grain masses in elevators (Reed et al., 2003), and appears to indicate that weevils are consistent and ubiquitous residents of grain elevators. In contrast, they are seldom observed in farm-stored wheat in Kansas (Reed et al., 1991; Dowdy and McGaughey, 1994). For *Sitophilus* species, the grain elevator may provide a more constant supply of food and harborage that is more stable relative to temperature and duration than does the farm habitat.

The analysis by location within the elevator suggests that the more stable elevator environment favors *Sitophilus* spp. The density of these species was at least four times greater in samples from residues in or near the boot pit and tunnel than in samples from other locations. Weevils were found in over 70% of samples from or near the boot pit and more than half those from the tunnel, but were found in less than one-half of the samples from other locations. The boot pit and tunnel are below-ground locations that are less exposed to the variations of the ambient environment than the other locations.

In this study, the large variation in insect presence and density in grain residues complicated the analysis and interpretation of results. One important unknown was the age of the residue, i.e., how long a given residue had been in place before a sample was taken. It seems logical that residues present for a longer time would have greater insect populations if other factors were equal. The fact that residues characterized as consisting of a single grain type had fewer insects (all species combined) than residues comprised of mixtures of grains may be significant in this regard. Because only one grain is handled at a time in the elevator transport equipment, spills and other residues that contain more than one grain were by definition the result of at least two periods of grain handling. Therefore, residues comprised of mixtures of grains were likely to have remained in the same place, without clean-up, longer than residues containing only one grain.

Our study showed that beneficial insects were at least occasionally present in grain residues in grain elevators. The same species were also observed in the masses of stored grain, in grain from the discharge spouts, and in the grain residues in empty bins (Reed et al., 2003). The large number of samples taken and the large number of insects collected in this study allowed us to demonstrate through frequency analysis that the presence of beneficial insects and the presence of host species were related. The known deficiencies of the sampling method for the tiny parasitoid wasps (Reed et al., 2003) probably caused the frequency and density of the beneficial insects to be substantially underestimated.

Laboratory studies have documented that certain parasitoids observed in this study are capable of suppressing the population growth of associated host pest species (Flinn et al., 1996). Studies by Cline et al. (1985) and Press (1984) also show field suppression of *S. oryzae* by *A. calandrae*, and field suppression of *Sitophilus zeamais* (Motschulsky), the maize weevil, by *A. calandrae* (Williams and Floyd, 1971). In our study, the occurrence of beneficial insects in the residue samples was sporadic and not always correlated with occurrence of the host species. Few *C. waterstoni* were found in our study even though *Cryptolestes* spp. were abundant in the residue samples. Although the density of *A. calandrae* and that of *Sitophilus* spp. were significantly correlated in data sets from certain individual elevators in our study (statistics not shown), most were not. Furthermore, the elevators with the fewest *A. calandrae* had high populations of *Sitophilus* spp. Also, more *Sitophilus* were found in or near the elevator boot pit and dump pit compared to the other three areas, yet the greatest numbers of *A. calandrae* were found in the samples from the rail line. Thus, correlation analysis provided only weak evidence of a significant host-parasitoid relationship. This was expected because we determined the density of both host and parasitoid at a single point in time whereas, theoretically, the population density trends of the parasitoid would either increase or decrease as that of the host changed with a lag of several days or weeks. Arbogast and Mullen (1988, 1990) studied interactions of *A. calandrae* and *S. zeamais* during a 7-year period in stored maize, and also found a delayed density-dependent relationship between the parasite and the weevil host.

Our study showed that spilled grain and grain residues within the elevator environment were important sources of insect infestation. These residues could serve as harborage and dispersal sites even when bins are empty, thus playing a critical role in maintaining pest insect populations. Regular sampling and maintenance could alleviate some of the problems associated with insect infestations in commercial elevators.

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