Stored-Product Insects Associated with Eight Feed Mills in the Midwestern United States

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ABSTRACT Commercial food- and pheromone-baited pitfall traps and pheromone-baited sticky traps were used during 2003 to survey stored-product insect adults in eight participating feed mills in the midwestern United States. Across the eight feed mills, 27 species of beetles (Coleoptera) and three species of moths (Lepidoptera) were captured in commercial traps. The red flour beetle, *Tribolium castaneum* (Herbst), was the most abundant insect species captured inside the eight mills. The warehouse beetle, *Trogoderma variabile* (Ballion), was the most abundant insect species outside the mill and in the mill load-out area. The Indianmeal moth, *Plodia interpunctella* (Hübner), was the most abundant moth species inside the mill and in the mill receiving area. The Simpson's index of species diversity among mills ranged from 0.39 (low diversity) to 0.81 (high diversity). The types of species found among mills were different, as indicated by a Morisita's index of <0.7, for the majority of mills. The differences in the types and numbers of insect species captured inside, outside, in receiving, and in load-out areas could be related to differences in the types of animal feeds produced and the degree of sanitation and pest management practiced.

KEY WORDS insect survey, trapping, feed mills, stored-product insects, community ecology

Commercial feed mills produce formulated feeds for a variety of livestock species such as cattle, horses, poultry, and pigs, and specialty feeds for animals such as geese, goats, moose, and bison. In the United States, there are ≈3,000 feed mills (Feedstuffs 2003). In 2002, feed mills in the United States produced ≈120.8 million tons of feed for various animal species (Feedstuffs 2003).

Feed mills are divided into various cost centers, such as receiving, material processing, mixing, pelleting, packaging, warehousing, and loading (Rempe 1994). The design and construction of feed mills is variable, because of differences in the type and quantity of feed produced and the process flow. Feed is composed of major and minor ingredients (Schoeff 1994). A large portion of the feed formulation includes cereal grains (usually ground) and by-products of cereals, legumes, and animals. Minor ingredients include vitamins, minerals, amino acids, fat, molasses, flavor enhancers and antibiotics.

Stored-product insects are often associated with feed mills because of warm temperatures in production areas and the availability of cereal ingredients in raw and processed form (Mills 1992, Mills and White 1993). In the United States, four surveys were conducted to determine stored-product insects associated with feed mills (Rilett and Weigel 1956, Triplehorn 1965, Loschiavo and Okumura 1979, Pellitteri and Boush 1983). Rilett and Weigel (1956) surveyed eight feed mills, two flour mills, and one flour and feed mill between October 1954 and March 1955 in Buffalo, NY, by collecting a 12.3-kg sample from each mill. They reported only the occurrence of insect species found in mills. In total, 2,632 insects, representing 23 species, were associated with the 11 mills. The black carpet beetle, *Attagenus piceus* (Olivier), and sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.), were found in eight of the 11 mills. Rilett and Weigel (1956) made a casual observation that mills that were cleaned of product accumulations every 2 wk had relatively fewer species (one to two species) than those that were not cleaned regularly. Triplehorn (1965) extracted insect adults from one 0.94-liter sample of grain, grain residues, and mill stock collected from each of the 118 grain elevators and feed mills in Ohio during May to September of 1961. He reported 44 species, representing 21 families in five orders. He did not separate the types of species found in grain elevators and feed mills. In addition, he reported only the percentage of facilities out of 118 that had a particular insect species. *A. piceus* was found in 104–110 facilities of the 118 during May to September; all other species were found in ≤55 facilities. Loschiavo and Okumura (1979) surveyed four feed mills in Hawaii from 15 July

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Table 1. Characteristics of the feed mills surveyed for stored-product insects during 2003

Mill ID[a]	State	No. floors	Total area (m^2)	No. visits	Sampling dates[b]	No. pitfall or sticky traps/visit[c]			
						Receiving	Mill interior	Load out	Mill exterior
1	MO	4	2,218.4	4	8 Jan., 17 Mar., 18 Aug., 13 Oct.	2	100	2	6
2	IA	2	259.0	2	31 Mar., 9 July	20	25	0	5
3	IA	4	1,657.8	4	28 Jan., 12 June, 9 July, 17 Nov.	2	100	2	6
4	IA	3	1,087.7	2	3 April, 10 July	0	50	0	0
5	OK	4	1,421.8	2	7 Jan., 17 Mar., 19 Aug., 13 Oct.	2	100	2	6
6	OK	1	2,743.9	2	26 Mar., 2 July	0	50	0	0
7	NE	1	1,752.0	2	2 April, 21 Aug.	0	50	0	0
8	KS	3	3,721.0	2	27 Mar., 3 July	13	37	0	0

[a] Mill 1 produces mash and pelleted feed for poultry animals; mill 2 produces mash and pelleted feed for poultry animals; mill 3 produces mash and pelleted feed for pigs and poultry animals; mill 4 produces mash feed for poultry animals; mill 5 produces mash and pelleted feed for poultry animals; mill 6 produces dog biscuits for companion animals; mill 7 produces liquid, mash, and pelleted feed for cattle, pigs, poultry, and horses; and mill 8 produces mash and pelleted feed for pigs.

[b] Trapping duration for all mills was 7 d, starting on the date listed.

[c] Food- and pheromone-baited pitfall traps for beetles and sticky traps for *P. interpunctella* males were paired at each location within and outside the mill.

to 31 December 1976 by examining product samples and captures in light traps and bait bags. They reported the types of species found and their incidence. Of the seven insect species (all beetles) reported, the yellow mealworm, *Alphitobius diaperinus* (Panzer); lesser grain borer, *Rhyzopertha dominica* (F.); rice weevil, *Sitophilus oryzae* (L.); and red flour beetle, *Tribolium castaneum* (Herbst), were found in all four mills. Three other species, found in three of the four feed mills, were the wardrobe beetle, *Attagenus fasciatus* (Thunberg); drugstore beetle, *Stegobium paniceum* (L.); and hairy fungus beetle, *Typhaea stercorea* (L.). Twenty feed mills in southern Wisconsin were sampled between 24 June and 12 August 1975 and 1976 by Pellitteri and Boush (1983). They collected insects captured in traps, but they did not indicate the type of traps used. They also extracted insects from spilled grain and feed, as well as hand-collected visible insects during mill visits. They collected 18,410 insects, representing 100 species in 60 families and eight orders. Of the 100 species, 19 stored-product insects constituted 83 and 92% of the total insects captured in 1975 and 1976, respectively. Of the 19 species, *Cryptolestes* spp. made up 24–29% of the total insects found, followed by the granary weevil, *Sitophilus granarius* (L.) (8–17%). The foreign grain beetle, *Ahasverus advena* (Waltl); black carpet beetle, *Attagenus megatoma* (F.); and larvae of mealworms, *Tenebrio* spp., were found in all 20 feed mills.

Each of these four surveys was limited to a single state and limited in the amount of quantitative information presented. Furthermore, the surveys were done >20 yr ago. Therefore, a survey of stored-product insects associated with feed mills was deemed necessary. With improved emphasis on sanitation and establishment of good manufacturing practices in the feed industry, especially for mills producing medicated feeds (Gill 1994), understanding the diversity of insect species present and their management is becoming critical (Pedersen 1994). Recent improvements and commercial availability of traps (Phillips et al. 2000) make it easy to sample and monitor stored-product insects associated with feed mills. Environmental (temperature, food availability, moisture, trap location, and trap design) and biological factors (age, mating status, sex, mobility, and feeding status of insects) could impact trap captures (Phillips et al. 2000). In addition, in feed-mill environments, traps and lures are competing with food odors. Despite these limitations, traps are valuable tools for monitoring stored-product insects (Arbogast et al. 2000).

We were interested in conducting a survey of stored-product insects associated with feed mills as part of a larger project designed to develop and implement a voluntary Hazard Analysis and Critical Control Points (HACCP) program in feed mills. The HACCP is a food/feed safety program that identifies and controls chemical, biological, and physical hazards from occurring in the food/feed from the farm to the table (Kvenberg et al. 2000). Management of insect and vertebrate pests is an essential prerequisite program for effective HACCP implementation (Bernard and Parkinson 1999). Identification of the types and numbers of pests present in a facility is the first step toward developing a pest management program. Therefore, during 2003 we surveyed stored-product insects associated with eight participating feed mills, spanning five states in the Midwest, by using commercial food- and pheromone-baited traps. Our objectives were to determine types and numbers of insect species found in mills and to conduct community analyses based on the trap capture data.

Materials and Methods

Feed Mill Characteristics. Eight participating feed mills (Mill ID 1–8) located in five midwestern states were surveyed for stored-product insects. The mills differed in size, number of floors, and type of feed produced (Table 1). The predominant feeds produced were for pigs, poultry, cattle, horses, and pets. Mills 1, 3, 4, 5, and 8 were concrete structures, whereas the other mills were constructed of steel. Casual observations revealed accumulation of feed debris on floors and equipment in all mills except mill 6, which had a rigorous sanitation schedule.

Insect Sampling and Counting. Mills were visited two or four times between 7 Jan and 17 Nov. 2003 to sample insects with commercial food- and pheromone-baited traps (Trécé, Adair, OK) (Table 1). The number of mill visits and the number of traps used for each of the mills were based on available resources and logistical constraints associated with travel and time.

Adult beetles were monitored by using commercial pitfall (Dome) traps (Trécé, Inc.) with food bait oil and three separate pheromone lures. Each trap was fitted with a lure for *Tribolium* spp., *Trogoderma* spp., and the cigarette beetle, *Lasioderma serricorne* (L.). Males of the Indianmeal moth, *Plodia interpunctella* (Hübner), were sampled by using (Pherocon II) sticky traps baited (Trécé, Inc.) with the moth's commercial sex pheromone. In mills 1, 3, and 5, 110 traps of each type were used for insect sampling; and in the remaining mills, 50 traps of each type were used (Table 1). Traps were placed in the receiving and load-out areas of the mills and inside and outside the mills. More than half of the traps were placed inside the mills. Traps placed outside at each mill were placed around the perimeter of the building. Pitfall and sticky traps were paired and placed throughout the mill interior in a grid fashion. The pitfall traps were placed on the floor, whereas the sticky traps for *P. interpunctella* were hung at eye level (1.8 m). The trapping duration during each visit was 7 d. After 7 d, each trap was placed in a zipper-sealed plastic bag and brought to the laboratory for separation and counting of insects. Insects were identified to species where possible, and were expressed as number of insects per trap per 7 d. Temperature and relative humidity levels inside and outside mills were measured by placing one HOBO data logger (Onset Computer Corporation, Bourne, MA) inside and placing one outside each mill site.

Trap Capture Data Analyses. The types and numbers of insects captured may be associated with the number of traps used and the number of mill visits. To determine this association, the total number of insects captured in the mill interior and the total number of species found were correlated with the number of traps used or the number of visits by using the CORR procedure (SAS Institute 1999). Across all eight mills, the relative abundance of each insect species captured in traps in each of the four mill areas, expressed as a percentage of the total, was calculated as follows: 100 × (total number of an insect species/total number of all insect species). The Simpson's index of diversity which is the probability of sampling two organisms at random that are of different species (Simpson 1949) was used to determine species diversity within each mill. The Simpson's index of diversity is calculated as follows:

$$1 - D = 1 - \Sigma(p_i)^2 \qquad [1]$$

where, $1 - D$ is the index of diversity and p_i is the proportion of individuals of a species (i is species 1 through n) relative to the total insects captured inside each mill. Values close to 0 indicate least species diversity and values close to 1 indicate high species diversity. The similarity of species composition among mills was determined by using the Morisita's index (Morisita 1959) based on captures within each mill:

$$C_\lambda = 2\Sigma X_{ij}\, X_{ik}/(\lambda_1 + \lambda_2)\, N_j\, N_k \qquad [2]$$

where C_λ is the Morsitia's index of species similarity between mill "j" and "k", and N_j and N_k are the total number of insects in mills j and k, respectively. λ_1 is calculated as follows:

$$\Sigma[X_{ij}\,(X_{ij} - 1)]/N_j(N_j - 1) \qquad [3]$$

λ_2 is calculated as follows:

$$\Sigma[X_{ik}\,(X_{ik} - 1)]/N_k\,(N_k - 1) \qquad [4]$$

The values for the Morisita's index range from 0 (no similarity) to 1 (complete similarity).

The proportion of a species (p_i in equation 1) among stores was subjected to the unweighted pair-group method, with arithmetic average cluster analysis by using the CLUSTER procedure (SAS Institute 1999). The tree diagram (clusters) showing similarity in species composition (indicated by the inverse values of distance between clusters) among stores was plotted by using the TREE procedure (SAS Institute 1999).

Differences in the mean number of insects of all species captured in traps placed inside each of the eight mills among visits or sampling occasions was compared by using one-way analysis of variance (ANOVA) and Fisher's protected least significant difference (LSD) at the $\alpha = 0.05$ level (SAS Institute 1999). Trap capture data were transformed to $\log_{10}(x + 1)$ before statistical analysis. A similar analysis was performed on trap capture data from traps placed in receiving, load-out, and the mill exterior. The receiving and load-out areas at each mills are located along the mill perimeter, so it was reasonable to examine trends in these trap captures with captures from traps placed outside the mill.

Results

The mean ambient air temperature inside the mill ranged from 6.9 to 35.1°C during the study. The outside air temperature ranged from −1.7 to 31.5°C. The standard errors for mean temperatures were <5.5%. The ambient relative humidity inside the mills ranged from 27 to 62.2%, and the outside humidity ranged from 37.9 to 73.3%. The standard errors for the mean relative humidity ranged from 0.7 to 1%. Mean temperatures across mills during January, March, April, June, July, August, October, and November visits were 12.6, 17.6, 11.4, 34.1, 29.3, 32.7, 21.3, and 21.6°C, respectively. The mill exterior temperature in January was 3.1°C and in November was 4.4°C; during the March through October visits, temperatures were 2–10°C cooler than the mill interior temperatures.

Across all eight mills, 44,397 individuals in total of 30 insect species, representing 14 families in two insect orders, were captured in the traps. The greatest number of individuals were captured in mill 1 (16,638),

Table 2. Relationship between types and numbers of insect species captured in traps inside mills as a function of number of traps used and number of mill visits

Variable	No. insects[a]	No. species[a]
No. traps	0.926 (0.0009)	0.834 (0.0100)
No. visits	0.943 (0.0004)	0.837 (0.0095)

[a] Data are presented as *r* value (*P* value). All *r* values are significant ($P < 0.05$).

followed by mill 3 (13,352), and mill 5 (8,352); all these mills were trapped on four different occasions. In mills 2, 4, 6, 7, and 8, which were visited twice, the number of insects captured was 342, 669, 48, 3,558, and 1,438, respectively. The number of species among mills ranged from seven (mill 7) to 21 (mill 3). Of the 30 insect species, only five species occurred in every mill. These species were *A. advena; T. stercorea; T. castaneum;* the warehouse beetle, *Trogoderma variabile* (Ballion); and *P. interpunctella.* Two species, *Cryptolestes* spp. and *Anthicus* spp., were captured in seven mills. *S. granarius* was trapped in six of the eight mills. The remaining species identified were found in one to five mills. Correlation analysis showed that the types and number of insect species captured in traps was influenced positively and significantly ($P < 0.05$) by the number of traps used and the number of mill visits (Table 2).

The types and numbers of insect species trapped differed among the four mill areas (Table 3). In the receiving area of mills, 19 species were found. In the mill interior, 30 insect species were found. The load-

Table 3. Taxa of insect species captured in pitfall and sticky traps at the eight feed mills

Order, family, species	Common name	Total no. insects (% of total)			
		Receiving	Mill interior	Load-out	Mill exterior
Coleoptera					
Anobiidae					
Lasioderma serricorne (F.)	Cigarette beetle	2 (0.3)	68 (0.2)	0 (0.0)	0 (0.0)
Stegobium paniceum (L.)	Drugstore beetle	6 (1.0)	539 (1.4)	11 (1.0)	6 (0.2)
Anthicidae					
Anthicus spp.		13 (2.1)	60 (0.2)	0 (0.0)	1 (0.0)
Carabidae					
Clivinia impressifrons LeConte	Slender seedcorn beetle	9 (1.5)	401 (1.0)	3 (0.3)	1 (0.0)
Stenolophus lecontei (Chaudoir)	Seedcorn beetle	0 (0.0)	21 (0.1)	0 (0.0)	0 (0.0)
Cleridae					
Necrobia rufipes (DeGeer)	Redlegged ham beetle	0 (0.0)	2 (0.0)	0 (0.0)	0 (0.0)
Curculionidae					
Sitophilus granarius (L.)	Granary weevil	2 (0.3)	31 (0.1)	2 (0.2)	0 (0.0)
Sitophilus oryzae (L.)	Rice weevil	5 (0.8)	2 (0.0)	0 (0.0)	0 (0.0)
Sitophilus zeamais (Motschulsky)	Maize weevil	0 (0.0)	115 (0.3)	2 (0.2)	1 (0.0)
Dermestidae					
Dermestes lardarius (L.)	Larder beetle	0 (0.0)	6 (0.0)	0 (0.0)	0 (0.0)
Trogoderma variabile (Ballion)		237 (38.2)	3,911 (10.0)	715 (66.9)	3,394 (89.9)
Histeridae					
Carcinops pumilio (Erichson)	Predaceous hister beetle	3 (0.5)	760 (2.0)	35 (3.3)	3 (0.1)
Laemophloeidae					
Cryptolestes spp.	Flat/rusty grain beetle	49 (7.9)	3,039 (7.8)	30 (2.8)	17 (0.5)
Mycetophagidae					
Typhaea stercorea (L.)	Hairy fungus beetle	26 (4.2)	855 (2.2)	18 (1.7)	41 (1.1)
Nitidulidae					
Carpophilus lugubris Murray	Dusky corn sap beetle	2 (0.3)	1 (0.0)	0 (0.0)	0 (0.0)
Glischrochilus quadrisignatus (Say)	Picnic Beetle	0 (0.0)	1 (0.0)	0 (0.0)	0 (0.0)
Ptinidae					
Mezium americanum (Laporte)	American spider beetle	0 (0.0)	4 (0.0)	0 (0.0)	0 (0.0)
Niptus hololeucus (Fald.)	Spider beetle	28 (4.5)	8 (0.0)	0 (0.0)	1 (0.0)
Silvanidae					
Ahasverus advena (Waltl)	Foreign grain beetle	58 (9.4)	629 (1.6)	12 (1.1)	157 (4.2)
Oryzaephilus surinamensis (L.)	Sawtoothed grain beetle	3 (0.5)	231 (0.6)	0 (0.0)	0 (0.0)
Tenebrionidae					
Alphitobius spp.		3 (0.5)	259 (0.7)	68 (6.4)	4 (0.1)
Latheticus oryzae (Waterhouse)	Longheaded flour beetle	0 (0.0)	5 (0.0)	0 (0.0)	0 (0.0)
Palorus ratzeburgi (Wissmann)	Small eyed flour beetle	0 (0.0)	3,384 (8.7)	7 (0.7)	0 (0.0)
Palorus subdepressus (Wollaston)	Depressed flour beetle	0 (0.0)	1 (0.0)	0 (0.0)	0 (0.0)
Tribolium audax (Halstead)	American black flour beetle	9 (1.5)	21 (0.1)	1 (0.1)	0 (0.0)
Tribolium castaneum (Herbst)	Red flour beetle	71 (11.5)	19,108 (49.1)	120 (11.2)	41 (1.1)
Tribolium confusum (Jacquelin du Val)	Confused flour beetle	0 (0.0)	1,331 (3.4)	10 (0.9)	3 (0.1)
Lepidoptera					
Pyralidae[a]					
Cadra cautella (Walker)	Almond moth	32 (5.2)	157 (0.4)	4 (0.4)	53 (1.4)
Plodia interpunctella (Hbner)	Indianmeal moth	62 (10.0)	3,958 (10.2)	30 (2.8)	53 (1.4)
Pyralis farinalis (L.)	Meal moth	0 (0.0)	25 (0.1)	0 (0.0)	0 (0.0)
Totals		620	38,933	1,068	3,776

[a] Captured only in the sticky traps.

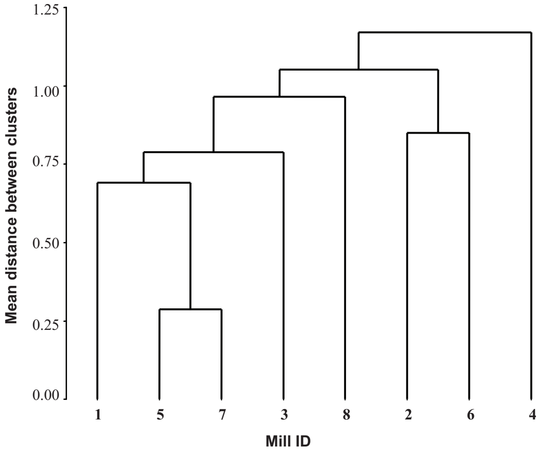

Fig. 1. Tree diagram with mean distances showing similarity of species composition among the eight feed mills.

out and mill exterior areas each had 15 insect species. The 11 insect species that were trapped in all four mill areas were *S. paniceum;* slender seedcorn beetle, *Clivinia impressifrons* (LeConte); *T. variabile;* predaceous hister beetle, *Carcinops pumilio* (Erichson); *Cryptolestes* spp.; *T. stercorea; A. advena; Alphitobius* spp.; *T. castaneum; P. interpunctella,* and the almond moth., *Cadra cautella* (Walker). Adults of *T. castaneum, T. variabile,* and *P. interpunctella* accounted for 70.9% of the total trap catch across the eight feed mills. Trap catch of *T. castaneum* among mills was 43.6% of the total; it was 18.6% for *T. variabile* and 9.2% for *P. interpunctella. T. castaneum* captures made up 49.1% of the total trap captures inside the mill, ≈11% each in the receiving and load-out areas and 1.1% in the mill exterior. Most of the *T. variabile* (89.9%) were trapped outside the mill, followed by the load-out area (66.9%), receiving area (38.2%), and inside the mill (10.0%). Captures of *P. interpunctella* were fewest in the load-out area (2.8%) and outside the mill (2.2%), but captures in the receiving area and inside the mill were essentially similar (10 and 10.2%, respectively).

Across the eight feed mills, captures of seven insect species were between <1% and <8% of the total of all species. These seven species included the small-eyed flour beetle, *Palorus ratzeburgi* (Wissmann); *Cryptolestes* spp., *T. confusum, T. stercorea, A. advena, C. pumilio,* and *S. paniceum.* Some insect species were captured in great numbers in certain mills. For example, *P. ratzeburgi, S. paniceum,* and *C. pumilio* were found in high frequency in mill 3. *P. ratzeburgi* from mill 3 accounted for 97.7% of the 3,391 individuals of this species captured among all eight mills. Across all eight mills, 562 *S. paniceum,* and 801 *C. pumilio* adults were captured. More than 83% of each of these species were captured in mill 3. *C. impressifrons* from inside mill 4 made up 93.7% of the 414 insects of this species captured among the mills; *O. surinamensis* was captured in large numbers in mill 7 (94.4% of the total 234 insects of this species).

Table 4. Matrix of Morisita's indices showing similarity of species composition among the eight feed mills

Mill ID	1	2	3	4	5	6	7	8
1	1.00	0.34	0.67	0.29	0.58	0.12	0.65	0.47
2		1.00	0.13	0.06	0.22	0.28	0.23	0.16
3			1.00	0.31	0.66	0.05	0.79	0.51
4				1.00	0.23	0.08	0.27	0.17
5					1.00	0.52	0.94	0.63
6						1.00	0.43	0.17
7							1.00	0.50
8								1.00

Morisita's index ranges from 0 to 1, where 0 indicates no similarity and 1 indicates complete similarity in species composition among the mills.

The Simpson's index of species diversity was low for mill 3, moderate for mills four and 8, and high for the remaining mills (Fig. 1). The insect species trapped were most similar between mills 5 and 7, as indicated by the Morisita's index of 0.94. In general, Morisita's index showed that there was little similarity between mills in species composition (Table 4). Cluster analysis showed that mills 5 and 7 were most similar in terms of species composition, as seen by the shortest mean distance between the clusters (Fig. 2). In general, the distance between clusters was large, suggesting that the mills differed in species composition.

The mean number of insects captured in the mill interior was significantly different ($P < 0.05$) among the sampling occasions or visits, except for mill 2 (Table 5). Similarly, in mills 1, 2, 3, 5, or 8, the mean number of insects captured in traps placed in the receiving, load-out, and mill exterior varied among the visits (Table 6). In general, trap captures both in the mill interior and in receiving, load-out, and mill exterior were significantly greater ($P < 0.05$) during July and August. Trap captures, especially in August were greatest both inside and outside of mill 1 compared with captures at the other mills. In mill 1, twice as many insects were captured in traps (204 adults per trap) placed in the receiving, load-out, and mill exterior areas than in traps placed in the mill interior (101 adults per trap).

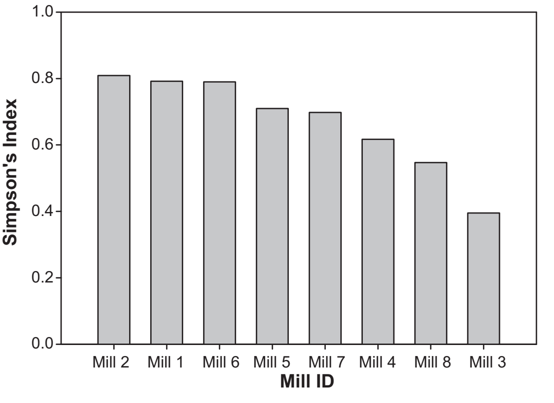

Fig. 2. Simpson's index of species diversity within each of the eight feed mills.

Table 5. Number (mean ± SE) of insects captured in traps placed inside each of the eight feed mills during 2003

Visit[a]	No. insects/trap/mill[b]							
	1	2[c]	3	4	5	6	7	8
1	3.8 ± 0.7c		6.2 ± 1.7d		7.1 ± 1.2c			
2	4.2 ± 1.0c	2.2 ± 0.5	48.2 ± 7.7b	0.5 ± 0.1b	4.1 ± 0.9c	0.0 ± 0.0b	1.5 ± 0.1b	0.6 ± 0.3b
3	101.4 ± 52.1a	4.1 ± 1.3	62.7 ± 10.4a	12.9 ± 2.5a	40.1 ± 5.0a	1.0 ± 0.2a	12.9 ± 2.5a	33.5 ± 9.2a
4	15.0 ± 2.7b		11.5 ± 2.0c		28.1 ± 4.4b			

The number of traps in mills 1, 2, 3, 4, 5, 6, 7, and 8 was 100, 25, 100, 50, 100, 50, 50, and 37, respectively.
[a] Visit 1, 7–28 Jan.; 2, 17 Mar.–12 June; 3, 2 July–21 Aug.; and 4, 13 Oct.–17 Nov.
[b] For each mill, means within a column followed by different letters are significantly different ($P < 0.05$; Fisher's protected LSD test).
[c] Number of insects captured was not significantly different between the visits ($F = 0.73$; df = 1, 48; $P = 0.398$; one-way ANOVA).

Discussion

Insect activity was detected at all mills as evidenced by captures in traps in the mill interior and exterior during January to November visits, and insect activity showed an increase with an increase in temperature. The increased captures in August suggest that pest management measures should be instituted during the winter or before the onset of warm temperatures to discourage populations from reaching damaging levels.

Three moth species were captured in sticky traps. Of the 27 insect species captured in pitfall traps at the eight mills, six species were not stored-product insects. These species were *C. impressifrons, S. lecontei, C. pumulio, C. lugubrious, G. quadrisignatus,* and *Anthicus* spp. The larvae and adults of *C. impressifrons* and *S. lecontei* feed on live or dead insects and are capable of attacking seeds of germinated, but not yet emerged, seedlings of several grains. *C. pumilio* adults and larvae feed on eggs and small larvae of house flies (Haines 1991). Casual observations during visits indicated the presence of house flies (Muscidae) at mills. Their presence indicates unhygienic conditions within food stores, such as rotting materials or dead animals. The ability of *C. pumilio* to acquire and internally harbor pathogenic strains of bacteria such as *Salmonella enteritidis* (Gaertner) (Gray et al. 1999) makes the presence of this species a risk for maintaining feed safety. *C. pumilio* also was reported from feed mills in the United States by Rilett and Weigel (1956) and Pellitteri and Boush (1983) and from feed mills in Greece by Buchelos and Katopodis (1995). Individuals of *C. lugurbius* and *G. quadrisignatus* were occasionally found in our survey, and these species are attracted to rotting fruit and have been reported associated with damp or spoiled grain (Haines 1991). *Anthicus* spp. are associated with decaying vegetation or grain (Haines 1991), and availability of decaying grain at the mill sites may be the likely reason for their presence. *Anthicus* spp. and *Carpophilus* spp. also were reported from the Kansas State University feed mill by Roesli et al. (2003).

The types and numbers of stored-product insect species captured in traps (21 beetle pests and three moth pests) in our survey were different than those reported from feed mills in the United States by several researchers. For example, nine species were common between our survey and that of Rilett and Weigel (1956), and 12 species were common between our survey and that of Triplehorn (1965). Our survey and those of Loschiavo and Okumura (1979) and Pellitteri and Boush (1983) had 17 and 16 species, respectively, that were similar. These differences could be attributed to differences in the sampling methods used by various researchers. We used traps to survey the mills, and we did not sample finished products or product accumulations on the mill floor. It is possible that additional species may have been detected if product samples also were collected from the mills instead of using traps alone.

Feed mills typically use corn, *Zea mays* L., in their feed, and the presence of *Sitophilus* spp., especially *S. zeamais,* is not surprising because these species are associated with whole grains and immature stages of these species develop within grain kernels (Arbogast 1991). However, the numbers of these species captured in pitfall traps were small (≤0.8%) relative to those of other species. The corn that is received at the

Table 6. Number (mean ± SE) of insects captured in traps placed outside (receiving, load-out, mill exterior) each of the eight feed mills during 2003

Visit[a]	No. insects/trap/mill[b]							
	1	2	3	4[b]	5	6[c]	7[c]	8
1	1.4 ± 0.8b		0.0 ± 0.0c		0.0 ± 0.0c			
2	1.7 ± 1.3b	1.4 ± 0.5b	21.6 ± 12.3b		2.1 ± 1.2b,c			0.2 ± 0.2b
3	204.3 ± 50.5a	6.0 ± 0.7a	27.7 ± 7.3a		19.3 ± 16.3a,b			13.3 ± 4.6a
4	212.3 ± 89.9a		0.5 ± 0.5c		19.5 ± 11.3a			

The number of traps in mills 1, 2, 3, 5, and 8 was 10, 25, 10, 10, and 13, respectively.
[a] Visit 1, 7–28 Jan., 2, 17 Mar.–12 June; 3, 2 July–21 Aug.; and 4, 13 Oct.–17 Nov.
[b] For each mill, means within a column followed by different letters are significantly different ($P < 0.05$; Fisher's Protected LSD test).
[c] Traps were not placed outside at these mills.

mills is processed within a month, thereby preventing these species from becoming well established in the mills. Species of *Cryptolestes, Oryzaephilus,* and *Tribolium* are associated with whole grain, broken kernels, or grain dust (Sinha and Watters 1985, Arbogast 1991), which are present in abundance in the feed mill. *A. advena* and *T. stercorea* have been reported from stored grain (Subramanyam and Harein 1990), although they are known to survive and reproduce on molds associated with cereal grains (Sinha and Watters 1985). Molds are abundant in mills that produce animal feed in the midwestern United States (Russell et al. 1991), and they may explain the presence of *A. advena* and *T. stercorea* reported in our survey. In addition, *T. stercorea* has been implicated as a carrier of pathogens such as *Salmonella* (Hald et al. 1998); therefore, presence of this species in feed mills may not be desirable. The abundance of *T. castaneum,* especially in the mill interior, is due to the availability of abundant feed dust, which this species prefers (Arbogast 1991), and which is produced from grains during processing. It is important to realize that the pitfall traps had lures specifically for *Tribolium* spp. and these lures also could have contributed to increased capture of this particular species at the exclusion of other stored-product insects. Conversely, the small numbers of other stored-product beetles captured in pitfall traps could be due to the low absolute densities of these species in mills or their inability to be attracted to the food-bait oil in the traps. Therefore, it is desirable to survey for stored-product insects by sampling and sifting static and moving feed-mill stock to determine if populations are established in the mill and to assess absolute densities of the various species.

Large numbers of *T. variabile* were reported from the receiving, load-out, and mill exterior areas of the feed mills. This species has been reported in flour and feed mills (Loschiavo 1960), is capable of developing on a variety of stored foods (Strong and Okumura 1966), and has been reported to occur outdoors (Strong 1970). *P. interpunctella* and *C. cautella* are commonly associated with flour and feed mills (Kiritani et al. 1963), and the larvae feed on a variety of cereal and noncereal products (Sinha and Watters 1985). *P. farinalis* is a cosmopolitan pest, whose larvae are associated with damp, spoiled grain and grain products (Sinha et al. 1962) and straw and moldy leaves (Berns 1958). This moth was captured only in the basement of mill 3, which was damp and had a musty odor. In our survey, *P. interpunctella* was the most abundant of all three moth species captured, and captures were greater in receiving and the mill interior compared with the load-out and mill exterior areas. Our observations are contrary to those reported by Doud and Phillips (2000), who reported greater captures of this moth in sticky traps outside than inside a flour-milling facility in Oklahoma.

The diversity of insect species present in mills and lack of a strong similarity among mills in species composition could be related to the geographic locations of the mills, type of feed produced, and degree of sanitation and pest management practiced. Mill 6 had the best sanitation among all the mills, and traps placed in this mill captured very few insects.

In summary, 24 stored-product insect species were captured in traps in the receiving, mill interior, load-out, and mill exterior areas. More species were captured in the mill interior than in the other areas, because of conducive environmental (e.g., temperature and food, moisture) conditions (Mills 1992). The exact source of insect populations outdoors is unknown, but it is conceivable that there is a fair amount of movement of insects from the mill interior to exterior and vice versa. The presence of stored-product insects outdoors suggests the potential for immigration of these species into the mill interior after an integrated pest management intervention. Simple practices, such as closing doors, screening windows, using plastic strips, or installing air curtains near doorways (Imholte and Imholte-Tauscher 1999, Mullen and Pedersen 2000) may help in excluding insects present outdoors. Regular sanitation of mill floors and equipment, equipment maintenance, inspection of inbound raw ingredients, stock rotation, use of crack/crevice sprays, and responsive tactics such as fumigation or heat treatment may be necessary before summer to prevent populations of stored-product insects from reaching unacceptable levels.

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