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Using five sampling methods to measure insect distribution and abundance in bins storing wheat

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Abstract

Newly-harvested wheat stored in each of two bins on each of two farms in Kansas during each of 3 years was sampled every 3–4 days at two locations (in the center and midway between the center and bin wall) within each bin. The variation in insect numbers between bins, locations within a bin, farms and years differed with insect species and sampling method. Five sampling methods were used to monitor insect populations in three regions of each bin: (1) in the head space above the grain; (2) on the grain surface; and (3) within the top 50 cm of the grain mass. *Cryptolestes ferrugineus* (Stephens) and *Ahasverus advena* (Waltl) were more evenly distributed among these three regions of a bin than the other species. *Typhaea stercorea* (L.) were found mainly in the head space and on the grain surface. These distribution patterns were consistent throughout the 126-day storage period. *R. dominica* (F.) were found in the head space and within the grain mass early in the storage period, and mainly in the grain mass as grain cooled in the autumn. The majority of *Plodia interpunctella* (Hübner) (91%) were caught in sticky traps in the head space. Two of the three less abundant species, *Sitophilus oryzae* (L.) and *Tribolium castaneum* (Herbst), tended to be found most often on the grain surface and the other, *Oryzaephilus surinamensis* (L.), within the grain mass. The sampling method often influenced the results. Emergence traps captured greater numbers of *A. advena* than other species. More *R. dominica* were found in grain samples than in traps in the autumn. Pushing probe traps below the surface of the grain reduced the numbers of *T. stercorea, A. advena, S. oryzae* and *T. castaneum* captured. Differences between species and times during the storage period in the effectiveness of different sampling methods need to be considered in making pest management decisions. Published by Elsevier Science Ltd.

Keywords: Insect distribution; Sampling; Trapping; Monitoring; Pest management; Stored wheat

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1. Introduction

The numbers of insects found in stored wheat can vary with the duration of storage, grain temperature, moisture content or the sampling method used, and between bins, locations within a bin, farms and years. These factors do not influence insect density independently. The effect of duration of storage on insect numbers depends upon the suitability of grain temperature and moisture content for insect population growth (Hagstrum, 1996). Some of the differences in insect densities between bins, locations within a bin, farms, or years also are likely to be due to differences in grain temperature and moisture content. Grain temperature can influence trap catches more than the numbers of insects found in grain samples (Hagstrum et al., 1998). Management decisions can be influenced by the choice of sampling method, and knowledge of the variation in numbers of insects can be important in understanding insect ecology and developing sampling programs.

Previous studies have sampled the same grain bins or flat storages for insects during more than one year. In some studies, the same grain was sampled over a 7- to 20-year period to examine the succession of insect species during long-term storage (Arbogast and Mullen, 1988; Coombs and Woodroffe, 1963; Sinha, 1988). More often, the grain stored during the first year was sold, newly-harvested grain was sampled during the second year, and the objective was to determine whether similar numbers of insects were found during different years (Cuperus et al., 1986; Hagstrum, 1989; Hagstrum et al., 1994, 1996; Ingemansen et al., 1986; Madrid et al., 1990; Smith, 1985; Subramanyam and Harein, 1989).

Insects infest newly harvested wheat after it is stored (Hagstrum, 1989; Vela-Coiffier et al., 1997). Therefore, the level of insect infestation in stored grain can depend mainly upon the number of insects present on a farm in grain, or grain residues in bins that is carried over from the previous year. The levels of insect infestations in wheat stored on farms were found to be higher for bins close to heavily infested bins than those further away (Hagstrum, 1987, 1989; Hagstrum et al., 1996). Ingemansen et al. (1986) found that insect infestation levels in newly-harvested oats were similar to the peak insect densities in the oats that had been stored in the same bin during the previous year.

The variation in insect densities among locations within a bin of stored wheat determines the number of samples needed to estimate insect density (Hagstrum et al., 1985). The variation within a bin was studied by using a stratified sampling plan which divided a bin into nine regions including the center, and the edge and midway in four compass directions. The study sampled two bins on each of two farms during only one year. The variation in insect density was largest between two grain samples taken with a grain trier at the same location (30.5%), followed by variation among the four bins (28.9%), and the variation between bins in the pattern of insect distribution among regions (20.9%). The large variation in insect density between two grain samples taken at the same location suggests that insect distribution may be determined on a scale of a few centimeters. The present study extends the Hagstrum et al. (1985) study by using several different sampling methods and sampling over a 3-year period.

The objective of the present study was to collect data needed to improve sampling programs for stored-grain insects. The distribution of insect species among three regions of a bin, the advantages and disadvantages of different sampling methods, and the contribution of bin, location within a bin, farm and year to the overall variation in insect numbers were studied.

2. Materials and methods

Adult insect populations infesting hard red winter wheat stored in two bins of 109-ton capacity on one farm (bins A and B) and 87-ton (bin C) and 98-ton (bin D) capacity on a second farm were monitored at 3- to 4-day intervals 36 times during each of 3 years. The wheat stored during the previous year was sold each year and newly-harvested wheat was stored on 11 July 1995, 9 July 1996, and 10 July 1997. The two farms were 3.2 km apart in Dickinson County (39°00′ latitude, 97° 10′ longitude) near Enterprise, Kansas.

Sampling was done at two locations within each bin, in the center or midway between the center and the bin wall, using five sampling methods. The five methods included emergence traps to sample insects taking flight from the grain surface, and probe traps (Storgard WB Probe II, Trece, Salinas, CA) with all of the holes above the grain surface (surface probe traps) to sample insects walking around on the grain surface. Wing-type sticky traps (23 × 28 cm, Sentry, Billings, MT) were used to sample insects flying around in the head space. Probe traps 7.6 cm below the grain surface (deep probe traps), and a 1.27 m open-ended grain trier (Model 39-A-OH, Seedburo Equipment, Chicago, IL) were used to sample insects within the grain mass.

The emergence traps were 37 cm high four-sided pyramid-shaped metal frames covered with fine mesh cloth that had an insect collection jar at the top. A funnel in the collection jar prevented insects from escaping. The emergence trap covered a 30.5 cm by 30.5 cm area of the grain surface. Probe traps are 45 cm long × 3.3 cm diameter cylindrical tubes with perforations in the top 27.5 cm section through which insects drop into the trap. Therefore, the traps with all of the holes above the grain surface captured only insects crawling around on the grain surface and traps pushed 7.6 cm below the grain surface captured only insects moving around within the grain mass. The probe traps were inserted into the grain at a distance of 7.6 cm from the emergence traps. The sticky traps were hung 38 cm below the bin roof directly above the emergence traps.

Two grain samples of approximately 0.2 kg each were taken by inserting a grain trier 7.6 cm away from the emergence trap to a depth of 50 cm. Adult insects were separated from the grain samples with an oblong-hole grain sieve (0.18 × 1.27 cm, Seedburo Equipment, Chicago, IL) and counted. Each grain sample was weighed (Model GT2100, Ohaus, Florham Park, NJ) and insect density was expressed as the number of adult insects/0.5 kg grain sample. The moisture content of each grain sample was determined in the laboratory with a moisture meter (Model GAC II, Dickey-John Corp., Auburn, IL). Grain temperatures were measured 25 cm below the grain surface at the deep probe trap locations using a Digi-Sense thermistor reader (Model 8523, Cole-Palmer Instrument Co., Chicago, IL) with YSI series 400 thermistor probes (Yellow Springs Instrument, Yellow Springs, OH).

Linear regression was used to describe the rates of change in grain temperature over the 126-day storage period in each of the four bins during each of 3 years (SAS Institute, 1990). Break points between gradual and rapid cooling were chosen to provide the best fits for the two regression lines. The same software also was used to calculate mean grain moisture content and insect densities, plot seasonal changes in mean insect density, do the analysis of variance and calculate the contribution of each variance component. Multiple comparison tests for the significance of differences between means were done using the LSMEANS/PDIFF option.

Comparisons among sampling methods were replicated in different bins and years. The variance components were calculated by species and sampling methods for each of the nine successive 2-week periods, and the means and standard deviations are reported. During each of the 2-week periods, two grain samples were taken and traps were checked every 3-4 days at each of two locations within each bin.

3. Results

3.1. Seasonal changes in grain temperature

Wheat was harvested and stored during each of the 3 years in two bins on each of two farms at average temperatures ranging from 28.8 to 39.8°C (Table 1). Wheat generally cooled gradually during the first 55 days of storage in 1995 and the first 70 days of storage during 1996 and 1997, and then cooled more rapidly. Except for bin D in 1997, in which wheat temperatures increased by 0.01°C per day, the gradual cooling rates ranged from 0.01 to 0.16°C per day. Also, the wheat in bin D cooled at a rate of 0.19°C per day throughout the 1996 storage period. During 1995 and 1996, the rapid cooling rates ranged from 0.18 to 0.23°C per day, but during 1997, rapid cooling rates ranged from 0.30 to 0.33°C per day. Mean grain moisture contents of the wheat stored in four bins ranged from 7.6 to 12.6% (Table 2), and varied more among bins during 1995 than during the other years.

Table 1
Seasonal changes in grain temperatures (°C) in two bins on each of two farms during each of 3 years

		Period of gradual cooling[a] (Days)				Period of rapid cooling (Days)				
		Intercept		Slope		Intercept		Slope		r^2
Year	Bin	Mean	SE	Mean	SE	Mean	SE	Mean	SE	
1995	A	35.4	0.4	−0.09	0.01	37.6	1.5	−0.20	0.01	0.80
1995	B	37.3	0.4	−0.14	0.01	34.7	1.4	−0.18	0.02	0.77
1995	C	37.7	0.6	−0.16	0.02	40.1	1.2	−0.20	0.01	0.85
1995	D	30.3	0.4	−0.04	0.01	39.7	0.8	−0.21	0.01	0.94
1996	A	31.6	0.8	−0.07	0.02	44.1	0.8	−0.22	0.01	0.96
1996	B	28.8	0.5	−0.03	0.01	37.1	0.8	−0.18	0.01	0.93
1996	C	32.8	0.4	−0.05	0.01	43.3	1.3	−0.23	0.01	0.91
1996	D	–	–	–	–	39.8	0.5	−0.19	0.01	0.95
1997	A	33.1	0.3	−0.01	0.01	51.2	1.4	−0.31	0.01	0.93
1997	B	35.0	0.6	−0.07	0.01	49.7	1.5	−0.30	0.01	0.92
1997	C	33.7	0.3	−0.05	0.01	52.7	2.0	−0.33	0.02	0.89
1997	D	30.3	0.7	0.01	0.01	52.5	1.9	−0.33	0.01	0.90

[a] The regression equation, temperature = $a + b$ *days of storage, was fitted to data for the first 55 days of storage in 1995 and the first 70 days of storage in 1996 and 1997 (gradual cooling period) and the remainder of the storage period (rapid cooling period). During 1996, the grain in bin D cooled at the same rate throughout both of these storage periods and a single equation was fitted to the data.

3.2. Seasonal trends for insects

Numbers and species of insects found depended upon the sampling method (Fig. 1). Throughout the 126-day storage period, deep probe traps caught significantly more *Cryptolestes ferrugineus* (Stephens) than other sampling methods (F = 7.43–20.47, P < 0.01, df = 4,571). Significantly more *Rhyzopertha dominica* (F.) were found with deep probe traps and sticky traps than with other sampling methods during the first 70 days of storage (F = 2.78–7.33, P < 0.01, df = 4,571), with deep probe traps between 70 and 98 days of storage (F = 6.52–6.67, P < 0.01, df = 4,571), and with grain samples after 84 days of storage (F = 6.67–9.30, P < 0.01, df = 4,571). Significantly more *Typhaea stercorea* (L.) were caught in surface probe traps (F = 6.97–30.14, P < 0.01, df = 4,571) and significantly more *A. advena* were captured with sticky traps, surface probe traps and deep probe traps (F = 5.76–31.77, P < 0.01, df = 4,571) than with other sampling methods throughout the 126-day storage period. The majority of insects caught in emergence traps was *Ahasverus advena* (Waltl). *Rhyzopertha dominica* was not caught in emergence traps. Trap catches for all four species decreased as the grain cooled during the autumn.

3.3. Variation between bins, farms and years

Over a 3-year period, the wheat in bins A and B on one farm tended to be more heavily infested than that in bins C and D on another farm (Table 2) with several exceptions. For example, bin C had many more *R. dominica* and *A. advena* during 1996 than bins A or B. On a farm, the bin that was most heavily infested differed between species and years. The ranges for the total numbers of *C. ferrugineus* (82–3549) or *R. dominica* (2–863) found in a bin during the 126-day storage period were quite wide. The total numbers of *T. stercorea* or *A. advena*

Table 2
Mean grain moisture contents (n = 72) and total numbers of four of the most abundant insect species found using five sampling methods in each of four bins of stored wheat during each of 3 years

Year	Bin	Grain Moisture (%) Mean[a]	SE	*Cryptolestes ferrugineus*	*Rhyzopertha dominica*	*Typhaea stercorea*	*Ahasverus advena*
1995	A	8.5h	0.04	885	34	1666	1738
1995	B	7.6i	0.04	1285	67	1489	1759
1995	C	8.6h	0.03	95	2	520	1845
1995	D	12.3b	0.03	178	29	681	872
1996	A	12.6a	0.06	1370	170	2781	2312
1996	B	11.3e	0.02	730	43	3716	1774
1996	C	11.3e	0.04	317	863	1008	5278
1996	D	11.8c	0.04	82	27	148	1311
1997	A	10.7f	0.04	3146	45	2206	1419
1997	B	11.5d	0.05	3549	117	1499	479
1997	C	11.7c	0.03	258	46	1829	1667
1997	D	10.4g	0.03	143	10	520	486

[a] Means followed by the same letter are not significantly different at the 1% level.

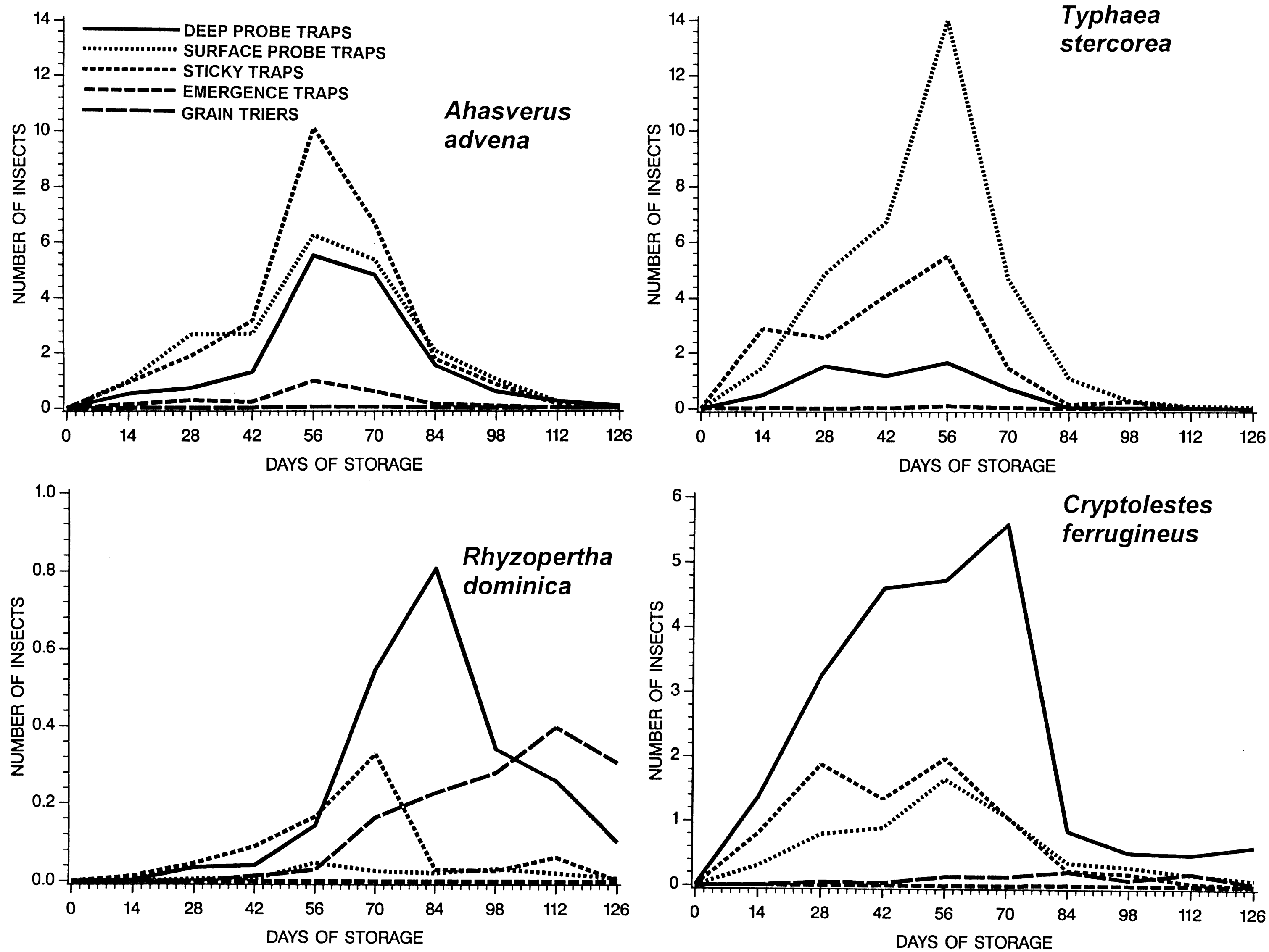

Fig. 1. Changes during the storage period in the mean number of insects per 0.5 kg of grain sample taken with a grain trier, or the mean number of insects per day caught in each of four kinds of traps. Numbers of insects found during each of nine 2-week periods were an average for four bins, three years, and eight grain samples or four trap catches. No *T. stercorea* were found in grain samples.

were generally larger than the numbers of *C ferrugineus* or *R. dominica* except in bins A and B during 1997.

The contribution of bin, location within a bin, farm and year to the overall variance for insect density differed with insect species and sampling method (Table 3). Many of the variance components were small because the variation in insect numbers between samples taken at the same location within a bin (Error) was large ranging from 37–95%. The variance component for years tended to be small. The mean percentage of the overall variation in insect numbers

Table 3
Means for percentages of variation in insect numbers explained by variance components and interactions during nine 2-week storage periods

	Sticky trap		Surface probe trap		Deep probe trap		Grain sample		Emergence trap	
Variable or interaction	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Cryptolestes ferrugineus										
Farm	6.3	1.1	15.7	2.8	10.3	2.5	1.9	0.5	–	–
Year	1.7	0.7	2.1	1.6	0.4	0.3	0.7	0.4	–	–
Farm*Year	3.2	1.1	4.6	3.5	11.6	3.7	7.2	2.1	–	–
Bin (Farm*Yr)	0.3	0.2	6.2	2.8	6.6	4.1	4.0	1.7	–	–
Location (Farm*Year*Bin)	28.1	5.1	11.6	1.6	34.0	9.8	11.6	3.2	–	–
Error	60.4	6.7	59.7	6.6	37.0	8.3	74.7	3.4	–	–
Rhyzopertha dominica										
Farm	1.3	0.7	0	–	0.3	0.1	0	–	–	–
Year	2.5	1.4	2.5	1.2	7.5	2.2	1.9	1.0	–	–
Farm*Year	3.8	2.5	2.4	1.9	0	–	3.0	2.0	–	–
Bin (Farm*Year)	2.5	1.3	6.9	3.7	27.2	8.3	22.2	8.4	–	–
Location (Farm*Year*Bin)	11.6	3.1	1.7	1.1	8.2	2.5	8.9	4.3	–	–
Error	78.2	4.9	86.5	4.1	56.8	9.8	64.0	7.7	–	–
Typhaea stercorea										
Farm	5.5	1.9	7.7	4.1	2.6	1.0	0	–	1.9	0.6
Year	3.3	1.7	2.6	1.3	0.7	0.5	0	–	1.8	1.7
Farm*Year	8.8	4.0	13.6	4.5	4.7	2.1	3.1	1.4	0.4	0.4
Bin (Farm*Year)	0.2	0.2	10.4	4.0	6.5	4.5	0	–	5.3	2.4
Location (Farm*Year*Bin)	16.4	5.4	2.4	1.5	2.3	1.0	1.8	1.1	5.2	3.2
Error	65.7	7.2	63.3	4.2	83.2	3.1	95.0	2.4	85.3	5.2
Ahasverus advena										
Farm	2.2	2.8	3.4	1.8	2.0	1.1	1.1	0.6	0.3	0.3
Year	6.6	2.4	8.9	3.3	7.3	0.7	1.1	0.6	5.4	1.8
Farm*Year	5.0	2.4	6.0	2.5	4.2	1.9	1.6	1.2	3.5	1.7
Bin (Farm*Year)	2.4	0.9	12.5	2.8	17.3	4.4	0	–	4.1	2.1
Location (Farm*Year*Bin)	13.7	5.2	2.8	1.3	6.4	2.5	3.4	1.6	10.6	3.9
Error	70.0	6.9	66.3	3.8	62.9	5.6	92.7	2.7	76.1	4.1

due to differences among farms was large for the surface (15.7%) and deep (10.3%) probe trap catches of *C. ferrugineus*. The Farm*Year interaction was large for the *C. ferrugineus* catches in deep probe traps (11.6%) and *T. stercorea* catches in surface probe traps (13.6%). The mean contributions of bin nested within farm and year to the overall variance was large for the numbers of *T. stercorea* captured in surface probe traps (10.4%) and the *A. advena* captured in both surface (12.5%) and deep (17.3%) probe traps. Also, the mean for bin variance component was large for the number of *R. dominica* captured in deep probe traps (27.2%) or those found in grain samples (22.2%). The means for location nested in farm, bin and year variance component were large for the catch of all four species in sticky traps (11.6–28.1%), the catch of *C. ferrugineus* in surface probe traps (11.6%), deep probe traps (34.0%) and grain samples (11.6%), and the catch of *A. advena* in emergence traps (10.6%).

3.4. Other species

Three additional species were captured in small numbers, i.e., a total of 38 rice weevils, *Sitophilus oryzae* (L.), 50 sawtoothed grain beetles, *Oryzaephilus surinamensis* (L.), and 167 red flour beetles, *Tribolium castaneum* (Herbst). Over the 3-year period, all three species generally were found at least once in each of the four bins, except for bin D in which *S. oryzae* was never found. Ninty-seven percent of *T. castaneum*, 94.7% of *S. oryzae* and 66% of *O. surinamensis* were found on the same farm in bins A and B. Seventy-four percent of *S. oryzae* were captured in surface probe traps and 78% of *O. surinamesis* were captured in deep probe traps. Sixty-nine percent of *T. castaneum* were captured in surface probe traps and 19.2% were captured in deep probe traps. Indian meal moths, *Plodia interpunctella*, were found every year in all of the bins and a total of 8387 were captured. However, 91% were captured in sticky traps.

4. Discussion

Insect populations in stored wheat generally increase steadily until grain begins to cool in the autumn (Hagstrum, 1987). Except for bins of grain with 7.6–8.6% mean moisture contents during 1995, mean grain moisture contents were similar in different bins (10.7–12.6%), and suitable for *C. ferrugineus* and *R. dominica* development (Hagstrum and Milliken, 1988). *Ahasverus advena* and *T. stercorea* generally do better at higher grain moistures (Jacob, 1988, 1996). Initial grain temperatures of 28.8–35.4° were suitable for *C. ferrugineus* and *R. dominica* development but *A. advena* and *T. stercorea* do better at cooler temperatures. Grain harvested at high temperatures (37.3–39.8°C) tended to cool more rapidly early in the storage period than grain harvested at cooler temperatures, becoming more favorable for insect development. Although the pattern of seasonal changes in mean grain temperatures was generally similar during different years, temperatures generally began to fall rapidly after approximately 8 weeks of storage during 1995, and roughly 2 weeks later during 1996 and 1997. Grain cooling is a result of seasonal decreases in outside air temperature, and the difference between 1995 and the other years is probably the result of outside air temperatures beginning to cool earlier during 1995. Grain temperature can influence trap catch as well as insect population growth. Probe trap catches begin to decrease below 23°C and are very low below 14°C (Hagstrum et al., 1998).

The contribution of different variance components is important because the most cost-effective sampling program takes more samples at the locations or times that reduce the overall variance the most (Hagstrum et al., 1985). In the current study, differences between farms, bins and locations within a bin tended to contribute more to the overall variation in insect numbers than differences between years. The large contribution of the numbers of *C. ferrugineus* caught in surface probe traps and deep probe traps to the farm variance component is probably a result of fairly consistent differences in the numbers of this species between farms over the 3-year period as shown in Table 2. The location variance components were large for *C. ferrugineus* with three sampling methods and for all species with sticky traps. Large location variance components are probably the results of *C. ferrugineus* being consistently more abundant in the center of the grain mass than elsewhere (Hagstrum et al., 1985), and more insects consistently being caught with sticky traps near the peak of the bin roof than with those near the eaves (Hagstrum et al., 1994). The large differences between bins in the numbers of *R. dominica* (range of 2–863) compared with other species is probably the reason for the large bin variance components for this species. As in the earlier study by Hagstrum et al. (1985), samples taken from the same location in a bin contributed the most to the overall variance (37–95%).

The five methods used in the current study sampled three regions of a grain storage bin, i.e.: (1) the head space above the grain; (2) the grain surface; and (3) the grain mass. *C. ferrugineus* and *A. advena* were most evenly distributed among these three regions. *T. stercorea* were found mainly in the bin head space and on the grain surface. These distribution patterns were consistent throughout the 126-day storage period. *Rhyzopertha dominica* were found in the head space and within the grain mass early in the storage period and mainly in the grain mass in the autumn. The majority of *P. interpuctella* was caught in the head space. Two of the three less abundant species, *S. oryzae* and *T. castaneum*, tended to be found most often on the grain surface and the other, *O. surinamensis*, within the grain mass.

The sampling method often influenced the results. Emergence traps captured greater numbers of *A. advena* than other species. More *R. dominica* were found in grain samples than in traps in the autumn. Pushing probe traps below the surface of the grain reduced the numbers of *T. stercorea, A. advena, S. oryzae* and *T. castaneum* captured. Differences between species and times during the storage period in the effectiveness of different sampling methods need to be considered in making pest management decisions.

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