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Insect population dynamics in commercial grain elevators☆

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ABSTRACT

Data were collected in 1998–2002 from wheat stored in commercial grain elevators in south-central Kansas. Bins at these elevators had concrete walls and were typically 6–9 m in diameter and 30–35 m tall. A vacuum-probe sampler was used to collect grain samples in the top 12 m of the wheat in each bin. The primary insect species found in the wheat samples were: *Cryptolestes ferrugineus*, *Rhyzopertha dominica*, and *Tribolium castaneum*. In the top 3.7 m of grain, *R. dominica*, *C. ferrugineus*, *T. castaneum* and *Sitophilus oryzae* made up 44, 36, 19 and 1% of the insects found in the samples, respectively. From 3.8 to 12.2 m, *R. dominica*, *C. ferrugineus*, *T. castaneum* and *S. oryzae* were present at 84, 8, 8, and 1%, respectively. The most prevalent species also changed over time. In June, the start of wheat harvesting and storage in Kansas, insect density was low in the bins. At this time, *C. ferrugineus* was the most common insect, and it was found mostly in the top grain sample (0–1.2 m). In September through November, *C. ferrugineus* and *R. dominica* were at similar densities; however, from February to March, *R. dominica* was more common.

Generally, insect density was greatest at the top and decreased with grain depth. Very few insects were found in samples collected from greater than 12 m (most of the bins contained grain to depths of 24–36 m). Insect density for all species increased rapidly from June through October. During this period less than 20% of the bins had economically significant insect densities (>2 insects/kg). From October until February, the average insect density remained fairly constant but it was greatly reduced in April, May, and June. Bins that had insect densities >2 insects/kg tended to be located adjacent to other heavily infested bins.

1. Introduction

Major insect pests of stored wheat in the USA include *Rhyzopertha dominica* (Fabricius), *Sitophilus oryzae* (L.), *Cryptolestes ferrugineus* (Stephens), *Tribolium castaneum* (Herbst), and *Oryzaephilus surinamensis* (L.). The first two species cause the most grain damage because the immature stages develop inside the grain kernel. The larval head capsules and adult exoskeletons of internal-feeding insects leave fragments in the flour when wheat is milled. Grain managers and regulators use the number of insect-damaged kernels (IDK) in wheat as an indirect measure of the density of infested kernels. If more than 32 IDK are found per 100 g of wheat, the grain is classified as "sample grade" and unfit for human consumption (Hagstrum and Subramanyam, 2006). At most domestic flour mills, the wheat purchasing specifications include a maximum IDK count of 5 or fewer per 100 g wheat (Hagstrum et al., 2008).

Cryptolestes ferrugineus is a very common insect pest that often reaches high densities near the grain surface. Young larvae of this species frequently feed on the germ of whole kernels and on fine material in the grain (Rilett, 1949). They leave the germ before becoming adults and do not cause IDK. Nevertheless, grain infested with this species is likely to receive a lower price than uninfested grain (Reed et al., 1989).

The average storage time for storage of wheat in the USA ranges from 6 to 9 months (Hagstrum et al., 1999). The temperature of stored wheat changes during the year. It often goes into storage in July at 30 °C and remains at this temperature during the summer. It

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Table 1
Percentage of four primary insect species found in wheat sampled at two different grain depths at elevators in Kansas.

	0–3.7 m	3.7–12 m
R. dominica	44.2	83.5
C. ferrugineus	35.7	7.5
T. castaneum	19.0	7.7
S. oryzae	1.0	1.1

slowly decreases in temperature during the fall and winter. At 30 °C, most stored-grain beetle populations will increase 10 fold every 30 days (Hagstrum and Subramanyam, 2006). In the USA, stored-product insects do not infest wheat in the field (Cotton and Winburn, 1941; Chao et al., 1953); so newly-harvested wheat is not infested with stored-grain insects when it is put into storage. Insect densities are initially low during the summer because the initial insects immigrating into the grain bins (Hagstrum, 2000) have not had time to multiply. At 30 °C it typically takes about 30 days for stored-grain beetle populations to increase ten times in number. Several months of storage may be necessary for insects to reach densities of greater than 2 per kg of wheat. If grain can be cooled with aeration fans, this can greatly reduce insect population growth (Flinn et al., 1997). This can be done in the summer using cool nighttime temperatures to reduce grain temperatures to 25 °C, a temperature in which the developmental rate of *R. dominica* is reduced by half. Grain temperatures of less than 17 °C completely suppress stored-grain beetle population growth (Fields, 1992) and these can be achieved using aeration in the fall and winter. While steel bins at commercial elevators in the USA often have aeration fans, large upright concrete bins frequently do not. Thus, the only way to control insects in these concrete bins is with fumigation. In upright concrete bins in the USA, the grain must be turned to add the aluminum phosphide pellets to the grain. If this turning is done in the fall, grain temperatures can be reduced by exposing the grain to cool air as it moves along the belts, and by mixing cool grain in the periphery with warmer grain in the center of the grain mass (Watters, 1963). Any insects that survive fumigation will not develop as fast if the grain is cooler in the following months.

At grain elevators, residual insect infestations in empty bins have been studied by Wright (1991) and Reed et al. (2003), and insects outside bins have been studied by Dowdy and McGaughey (1998) and Arthur et al. (2006). Insect densities in grain residues both inside empty bins and outside bins were more than 10 times greater than those in the grain stored in bins. However, the insects in the stored grain often reached much higher total numbers because the total volume of grain stored in bins is much higher compared to grain residues.

The changes in density and species composition of stored-product insects in grain stored at elevators and moving through the USA marketing system have been reported by Harris et al. (1952, 1953), and Storey et al. (1982). Most of these studies were done by sampling moving grain as it was shipped from an

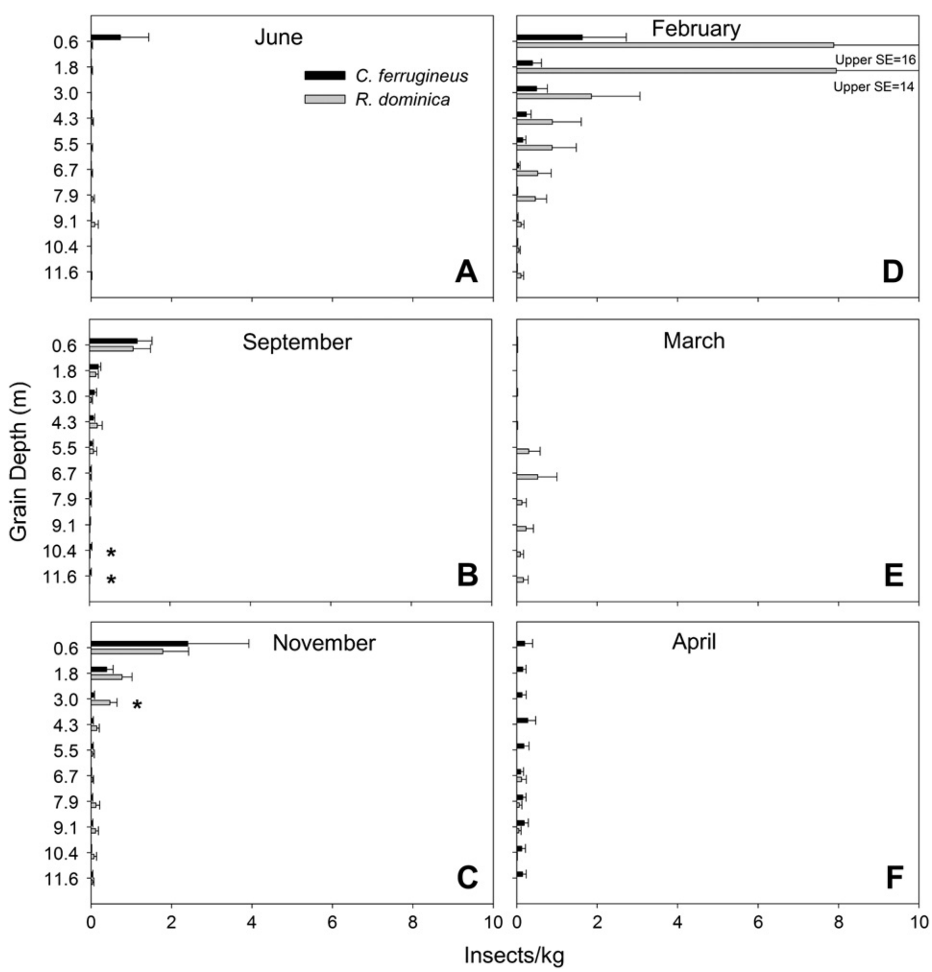

Fig. 1. Density of *R. dominica* and *C. ferrugineus* at different depths of stored wheat in June 2001 through April 2002. The numbers of bins sampled during these month were 58, 160, 86, 43, 33, and 36, in June, September, November, February, March, and April, respectively. Asterisks denote a significant difference ($P \leq 0.05$) among insect species.

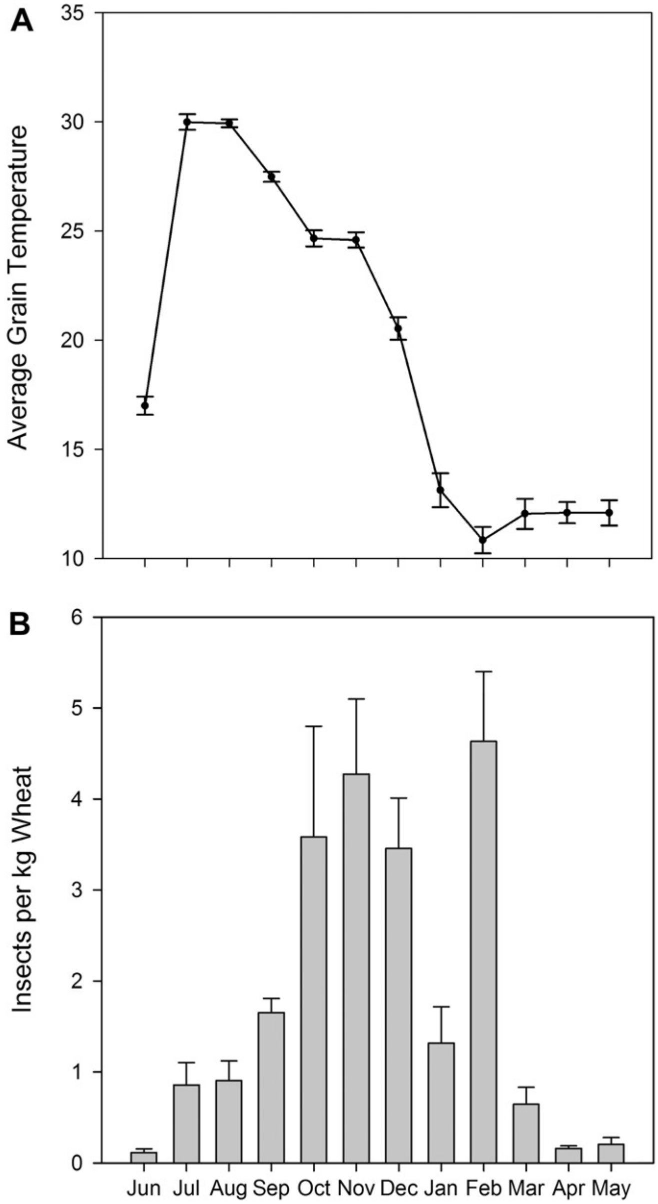

Fig. 2. Monthly average grain temperature in upright concrete bins containing wheat (A) and average monthly insect density for combined *R. dominica*, *C. ferrugineus*, *T. castaneum*, *S. oryzae*, and *O. surinamensis* found in 25,296 wheat samples collected in elevator bins during 1998–2002. (B) Vertical bars indicate standard errors.

elevator. Because grain is frequently fumigated immediately prior to shipment to reduce the likelihood of price penalties, these studies do not provide an accurate picture of the insect population in grain elevators. In addition, to study the vertical distribution of insects in a grain bin, samples need to be taken in the grain bin using a vacuum-probe system. Very few studies have investigated the vertical distribution of insects in commercial grain elevators (Mahmood et al., 1996; Flinn et al., 2004).

The objective of this study was to investigate seasonal changes in insect density, species composition, and spatial distribution of insects in wheat stored in commercial grain elevators in Kansas, USA. This information is critical for developing an understanding of how insects infest grain stored in elevators, for characterizing seasonal changes in insect spatial distribution, and to develop IPM programs for stored-grain management.

2. Materials and methods

Data were collected in 1998–2002 from commercial grain elevators in south-central Kansas. Storage at these elevators was in upright concrete bins, typically 6–9 m in diameter and 30–35 m tall. Maize and other grains were stored in these elevators, but only the wheat was sampled.

A vacuum-probe system was used to obtain grain samples from the bins. The vacuum probe allowed researchers to collect samples at any time and to construct a vertical profile of the insect distribution for each bin. We used a Port-A-Probe (Grain Value Systems, Shawnee Mission, Kansas) which consists of a vacuum pump powered by a 5.3 kW gasoline engine connected by flexible plastic tubing to sections of rigid aluminum tubes 1.2 m long by 3.5 cm wide. Grain samples were extracted from the grain mass by suction and collected in a cyclone funnel. The probe was inserted vertically into the grain through the grain entry port, and a 3.9 L (about 3 kg) sample of wheat was taken during each 1.2 m transect of grain to a depth of 12 m. During 1998–2000, we found that sampling greater than 12 m depth of grain was not worthwhile because very few insects were found at grain depths greater than 12 m, so during 2001–2002, bins were sampled only to a depth of 12 m (Reed et al., 2001). Because more than 90% of insects are found in the top 12 m of grain in this type of bin, sampling only the top half of the grain provided a good indication of whether a bin needed to be fumigated with less sampling effort.

Samples were processed twice over an inclined sieve (89×43 cm, 1.6 mm aperture) (Hagstrum, 1989) to separate insects from the wheat. Material that passed through the screen was collected on a pan below the screen, which then slid into a funnel at the bottom of the pan. A re-sealable plastic bag was attached to the funnel to collect the material that was separated from the grain sample. A hopper above the screen held the grain sample and a funnel at the base of the screen directed material passing over the screen into a plastic bucket. The inclination of the sieve was 24° from horizontal and the opening of the hopper was adjusted such that each 3-kg sample passed over the screen in about 25 s. The sieved material was examined for live insects within 24 h of collection.

Monthly records of grain temperatures were obtained from permanently installed thermocouple cables that were present in most of the sampled bins at each elevator site.

Data were analyzed using PROC TTEST in SAS/STAT 8.00 for Windows (SAS Institute, Cary NC) to compare differences between insect density by month and sample depth.

3. Results and discussion

From 1998 to 2002 over 25,296 wheat samples were collected. The insect species found most frequently in these samples were: *C. ferrugineus*, *R. dominica*, and *T. castaneum*. Low densities of *O. surinamensis* and *S. oryzae* were also found as well as several species of parasitoid wasps, *Anisopteromalus calandrae* (Howard), *Cephalonomia tarsalis* (Ashmead), *Cephalonomia waterstoni* (Gahan), *Habrobracon hebetor* (Say), and *Theocolax elegans* (Westwood). These parasitoid wasps were found at all grain depths but densities were greatest in the upper grain layers.

Species composition changed with grain depth. In the top 0–3.7 m of grain, *R. dominica*, *C. ferrugineus* and *T. castaneum* made up 44, 36 and 19% of all species, respectively (Table 1). From 3.7 to 12.2 m, *R. dominica*, *C. ferrugineus* and *T. castaneum* were present at 84, 8, and 8%, respectively. The most prevalent species also changed during the year (Fig. 1). In June 2001, the start of wheat harvesting and storage in Kansas, adult insect density was low in the bins with wheat. At this time, *C. ferrugineus* was the most common insect found, and it was found mostly in the top grain sample (0–1.2 m) (Fig. 1A). Insect density was highly variable, especially in the upper grain samples. In September 2001, *C. ferrugineus* and *R. dominica* were detected at similar densities and most were detected in the top grain sample (Fig. 1B). In September, at a depth of 10.4 m, there was a significant difference ($P \leq 0.05$) in the density of *C. ferrugineus* and *R. dominica* (0.044 ± 0.017 and 0.104 ± 0.005 per kg, respectively), and at a depth of 11.6 m there was a significant difference ($P \leq 0.05$) in the density of *C. ferrugineus* and *R. dominica* (0.035 ± 0.012 and 0.004 ± 0.003 per kg, respectively). In November, the densities of *C. ferrugineus* and *R. dominica* were similar in the top sample (0–1.2 m); however, from 1.2 to 12.2 m, *R. dominica* was the most common species (Fig. 1C). In November, at a depth of 3 m, there was a significant difference ($P \leq 0.05$) in the density of *C. ferrugineus* and *R. dominica* (0.062 ± 0.030 and 0.469 ± 0.178 per kg, respectively). Insect population density peaked in February 2002, and *R. dominica* became the most common insect species at all grain depths (Fig. 1D). By March 2002, insect densities were much lower than in February, and were primarily *R. dominica* (Fig. 1E). Grain temperatures are typically cooler in March, so this probably decreased population growth (Fig. 2A). In addition, grain temperatures of 13 °C or lower over 30 days have been shown to cause significant mortality to *R. dominica* adults and immatures (Hagstrum and Flinn, 1994). In April 2002, insect densities were also very low, and were primarily *C. ferrugineus* (Fig. 1F). It is known that *C. ferrugineus* is a particularly cold-hardy species (Burks and Hagstrum, 1999). It may be better at surviving cool winter temperatures than *R. dominica*.

Density for the five most common insect species, *R. dominica, C. ferrugineus*, *T. castaneum*, *S. oryzae* and *O. surinamensis*, increased rapidly from June until October (Fig. 2B). From October until February, the average insect density for these five species remained fairly constant at about 3.5 insects/kg of wheat. After February, insect density steadily decreased—probably because of cooler grain temperatures that occurred during this period (Fig. 2A).

In general insect density was greatest in the top grain layers and decreased with grain depth, as has been observed on farm-stored grain (Hagstrum, 1989). Very few insects were found in samples collected from depths greater than 12 m (most of the bins contained grain at depths of 24–36 m). This indicates that insects are entering the grain mass through the top of the grain bin, either though the grain loading hatch, or bin vents at the top of the bin, as with farm-stored grain (Hagstrum, 2000). Studies using probe traps indicated that insects enter grain bins soon after wheat is stored (Reed et al., 2001).

These results suggest that the optimal time to fumigate the grain in Kansas in most cases would be in October or November. This would keep insects from exceeding economically damaging levels (>2/kg wheat). In upright concrete bins in the USA, the grain must be turned to add the aluminum phosphide pellets to the grain. If this turning is done in the fall, grain temperatures can be reduced by exposing the grain to cool air as it moves along the belts, and by mixing cool grain in the periphery with warmer grain in the center of the grain mass (Watters, 1963). Any insects that might survive fumigation will not develop as fast if the grain is cooler. In addition, cool temperatures greatly reduce the ability of stored-grain insects to fly, so immigration of new insects into bins fumigated in October or November should be reduced by the cool air temperatures during this time of the year. Current practices by elevator managers often involve fumigating grain in July or August. Because fumigation has no residual effect, grain fumigated this early can easily become re-infested.

Insects were detected in grain samples in over 40% of the bins in July–December (Fig. 3), but fewer than 20% contained >2 insects/kg, a level that would justify fumigation. This illustrates the potential cost-savings of using a sampling-based approach to make fumigation decisions over a calendar-based approach that results in all bins being fumigated based on time of year and without knowledge of which bins require fumigation. Instead of fumigating all bins at an elevator, which is typical of a calendar-based approach, the sampling-based approach would only fumigate bins in which insect density exceeded a certain threshold.

Bins that had high insect densities (>2 insects/kg) were located adjacent to other highly infested bins (Fig. 4). This is probably because insects in bins with high insect densities would tend to migrate to other nearby bins rather than to bins located farther away. An advantage of a sampling-based approach is that, unlike calendar-based decisions, fumigation failures could be identified and those bins could be re-fumigated before very many migrating insects could infest nearby bins. In elevators that use a calendar-based approach, typically fumigation failures are not noticed until unusual hot spots are noted using thermocouple cables in the grain. These hot spots can be caused by very high insect densities that result in localized heating of the grain (Mani et al., 2001). A sampling-based approach would detect insects much earlier and at much lower densities than those that cause hot spots in the grain,

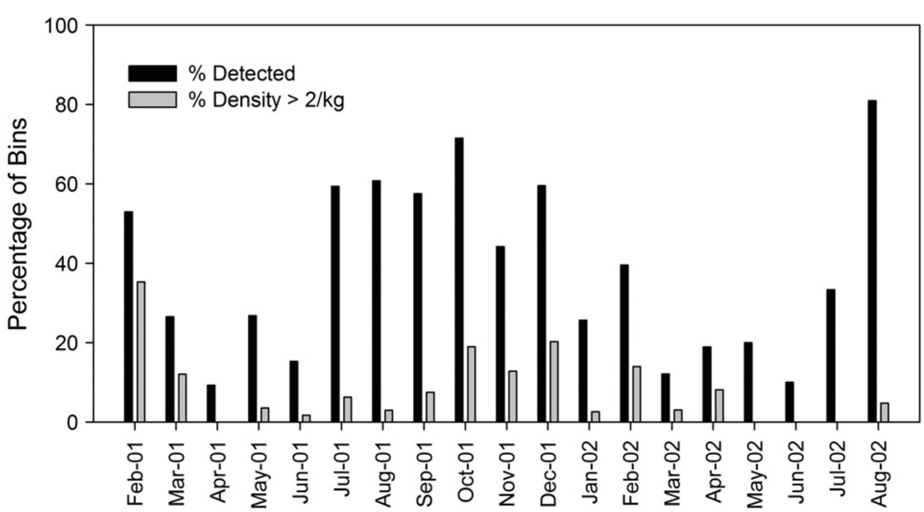

Fig. 3. Percentage of bins with insects detected in grain samples and bins with insect densities high enough to require fumigation (>2 insects/kg).

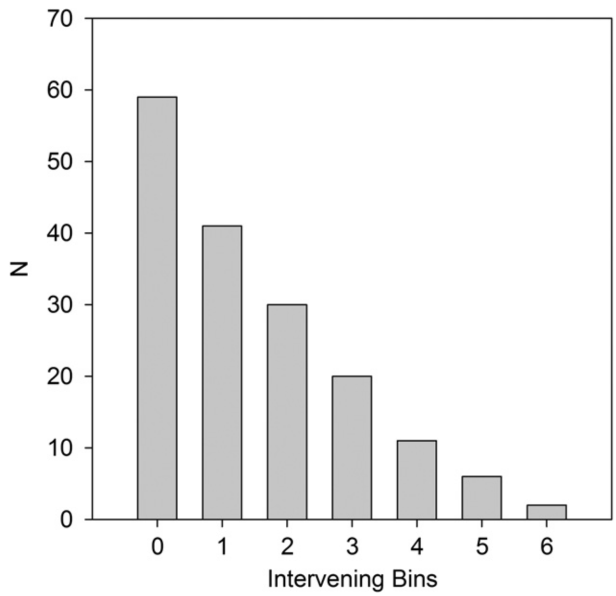

Fig. 4. Number of bins with high insect densities (>2 beetles/kg) and distance (number of intervening bins) between the high insect density bin and other high insect density bins. Note: not shown on the graph were 15 bins with a high insect density and no insects detected at bins located either near to or far from the infested bin.

and therefore, there would be fewer bins with high insect densities that could potentially infest other grain in the elevator.

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