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Seasonal distribution of psocids in stored wheat

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Abstract

Psocids are an emerging problem in stored grain and in grain processing facilities in the United States. We conducted preliminary studies to determine which species of psocids were present in a feed mill, a grain elevator, and wheat stored in steel bins. We then conducted a more extensive study in steel bins containing wheat to determine temporal and spatial distribution of psocids in the wheat. We also compared use of cardboard refuges and grain trier samples for sampling psocids in the wheat. The predominant psocid species found in all locations was *Liposcelis entomophila*. In the study on temperospatial distribution, infestation levels before the bins were filled with wheat were low, but some psocids were present in the empty bins. Numbers of psocids in cardboard refuges on the wheat surface were low immediately after bins were filled in July, peaked in late September, dropped to almost zero in December as temperatures dropped during autumn and winter, and then remained at low levels until the study was ended in March. More psocids were found deeper in the grain than closer to the surface. During periods when psocid numbers were high, more psocids were found closer to the bin wall. Numbers of psocids in cardboard refuges was indicative of number of psocids in grain samples. The results indicate that cardboard refuges may provide an efficient method for sampling psocids in bins of wheat, and that psocid populations can increase quickly to high levels during storage even though they are low early in the storage period.

Key words: psocids, sampling, wheat, *Liposcelis entomophila*, *Lepinotus reticulatus*

Introduction

Psocids are persistent pests in grain storages, grain processing facilities, and product warehouses (Rees and Walker, 1990). Psocids can damage stored grain (Kucerova, 2002), and psocid infestations can cause health problems among storage and warehouse workers (Sidik et al., 1986). Many species of psocids reproduce rapidly by obligatory thelytokous parthenogenesis – i.e., production of diploid female offspring from unfertilized eggs (Shires, 1982). Most psocid pests of stored products are from the genus *Liposcelis* (Liposcelididae). The species *Liposcelis bostrychophila* Badonnel – the most studied psocid pest – has a worldwide distribution (Lienhard and Smithers, 2002), and it is commonly found in unprocessed and processed dry foods in households, granaries, and warehouses (Broadhead, 1954; New, 1971; Turner, 1994). *Liposcelis entomophila* (Enderlein) (Srivastava and Sinha, 1975; Ryoo et al., 1990; Cao et al., 2003), *L. decolor* (Pearman), *L. paeta* Pearman (Beckett and Morton, 2003; Cao et al., 2003), *L. brunnea* Motschulsky (reported as *L.*

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liparus by Sinha, 1988), *L. rugosa* Badonnel (Sinha, 1988), *L. corrodens* (Heymons) (reported as *L. subfuscus* by Sinha, 1988), and *L. obscura* Broadhead (Khalafalla, 1990) are also known to be serious pests of stored products in different parts of the world. The species *Lepinotus patruelis* Pearman (Fahy, 1971) and *L. reticulatus* Enderlein (Sinha, 1988) also are pests of stored products. The psocid species confirmed to be infesting grain in North America (Sinha, 1988; Mockford, 1993; Lienhard and Smithers, 2002) are *Lepinotus reticulatus*, *Liposcelis bostrychophila*, *Liposcelis brunnea*, *Liposcelis corrodens*, *Liposcelis decolor*, *Liposcelis entomophila*, *Liposcelis paeta*, and *Liposcelis rugosa*; all except *Liposcelis rugosa* have been reported in the United States.

Before the early 1990s, psocids were not considered serious pests of stored products, but, in some countries such as Australia, they have since become the most frequently encountered storage pest (Rees et al., 2003). The reasons why psocids have recently emerged as a problem in Australia are not completely understood, but could be due to 1) reduction in the use of residual insecticides to treat grain and structures; 2) absence of competition from other storage pests, which seem to be adequately controlled using existing methods; and 3) residual structural insecticides have been replaced by fumigants which kill *Tribolium*, which are predators of psocid eggs.

Many studies have been conducted on management of psocid pests of stored products (e.g., Leong and Ho, 1994; Ho and Winks, 1995; Santoso et al., 1996; Wang et al., 1999a; Ding et al., 2002), but few detailed studies have been conducted on the biology of these insects (Fahy, 1971; Khalafalla, 1990; Wang et al., 1999b; Wang et al., 2000; Wang et al., 2001). Moreover, many of these studies have been conducted outside North America and have focused on *L. bostrychophila*. Wang et al. (1999b, 2000) have conducted life history studies on *L. bostrychophila* and developed predictive models. Sinha (1988) determined temperospatial distribution of psocids in stored wheat in Canada, but no similar studies have been conducted in the United States where there are increasing reports of psocids in stored grain and processing facilities. Thus, the objectives of our study were to 1) determine species of psocids found in grain storages and processing facilities in Kansas, 2) determine the temporal and spatial distributions of psocids in wheat stored in steel bins in Kansas, and 3) determine whether numbers of psocids in wheat samples could be predicted from numbers of psocids in corrugated cardboard refuges.

Materials and methods

Preliminary distribution studies in 2004

We sampled in three types of facilities in 2004 to determine which species of psocids were present. A grain elevator at the Grain Marketing and Production Research Center (GMPRC) was sampled biweekly from 3 June to 30 September on the basement, ground, fifth, sixth, and seventh floors using five 8.9- by 12.7-cm corrugated cardboard refuges per floor; refuges were in place every other week. We also sampled biweekly at a feed mill at Kansas State University (KSU) from 25 June to 17 September on the basement, ground, and first floors using five refuges per floor. Both the elevator and feed mill are in Manhattan, Kansas. In addition, six steel bins of wheat (*Triticum aestivum* L.) at GMPRC and five steel bins of wheat in Enterprise, Kansas, were sampled weekly from 5 to 19 November and 26 August to 18 October, respectively, using cardboard refuges. In the GMPRC bins, three and 20 refuges were placed on the hatch and surface of the grain, respectively, each time bins were sampled. In Enterprise, we placed five cardboard refuges in the wheat at depths of 0, 2.5 cm, 0.3 m, and 1 m to determine vertical distribution of psocids. Refuges were placed on the surface and at the 2.5 cm depth by hand. Steel rods (1.5-m long by 1-cm diameter) that contained housings for refuges were used for sampling psocids at depths of 0.3 and 1 m. Four HOBO temperature/relative humidity monitors (Onset Computer Corp.,

Pocasset, MA, USA) were used to collect data at each depth in each bin, and these were placed in housings to protect them; those at 0.3 and 1 m were attached to the steel rods. We used Taylor's power law (Taylor 1961) (where $s^2 = am^b$ and s^2 = variance, m = mean, and a and b are coefficients; a is largely a sampling factor and b is an index of aggregation) to describe the distribution of psocids on the surface of wheat in the GMPRC bins.

Study on temperospatial distribution of psocids in wheat in steel bins in 2005

Number of psocids in empty bins was estimated by placing 20 cardboard refuges on the floors of the bins for one week. Two steel bins (4.72-m diameter by 3.35-m high at the eaves) were filled in July 2005 with newly harvested hard red winter wheat, and insects in the wheat were sampled biweekly from August 2005 through March 2006. Each bin was filled with 1,200 bushels (32.6 metric tonnes) of wheat to a depth of 2.4 m. A 1.2-m open-ended trier was used to take 1-m-deep samples. These samples were taken from the bin center and in the north, south, east, and west directions at 0.15 and 0.76 m from the bin wall – i.e., samples were taken from nine locations. One week prior to taking the grain samples, twenty cardboard refuges were randomly placed on the surface of the grain in each bin, and these were removed just before grain samples were taken. Grain samples were sieved using a US Standard #10 sieve (2-mm openings) to remove psocids.

On the same day that surface grain samples were taken, samples to determine vertical distribution of psocids were also taken, except that these samples were taken monthly rather than biweekly. Samples were taken from a 2-m-diameter circle in the center of the bins. In each bin, this center circle was divided into northern and southern halves. A 2.4-m partitioned trier with 16 compartments was used to randomly take three samples from each of the northern and southern halves of the center circle. The top two compartments were above the wheat surface, and we combined samples of wheat from two adjacent compartments resulting in samples that weighed approximately 88.5 g. Thus, we obtained seven 88.5-g samples from depths of 0.28, 0.56, 0.84, 1.12, 1.4, 1.68, and 1.96 meters (each compartment was 0.28-m long, and depth indicates depth at the bottom of the compartment). A sample of wheat weighing 88.5 g was also taken from the surface, next to each sampling point, to represent wheat sampled from a depth of 0 m.

Temperature data in each bin were collected using five temperature cables (OPIsystems Inc., Calgary, Alberta, Canada) with sensors at depths of 0, 0.3, and 2.1 m placed at the bin center and north, south, east, and west directions, and approximately 0.46 m from the bin wall. Surface samples for determining moisture content in each bin were obtained using a 1.2-m open-ended trier to take 480-g samples at a depth of 0.9 m at each of the nine surface locations sampled. In addition, three 284-g samples of wheat were taken from depths of 0, 0.3, and 2.1 m at each location in the vertical distribution study; samples from depths of 0.3 and 2.1 m were taken using a 0.38-m deep bin cup (Seedburo Equipment Corp., Chicago, IL, USA). A surface sample was taken with a scoop near the location where the 0.3 and 2.1-m samples were taken. The samples were taken from the middle of each subsection, 23 cm from the center of the section on the N-S line. Moisture content was determined using a Motomco Model 919 ES automatic moisture meter (Motomco Instruments, Paterson, NJ, USA). Data were analyzed to determine 1) seasonal patterns of psocid populations; and 2) effects of depth, distance from bin wall, and location on the surface of the grain on psocid populations using the General Linear Models procedure of SAS (SAS Institute, 2001).

Results

Preliminary distribution studies in 2004

Liposcelis entomophila and *L. decolor* were found in the GMPRC grain elevator (Figure 1A)

and in the KSU feed mill (Figure 1B); greater than 90 % of psocids in both locations were *L. entomophila*. Highest catches in a refuge were 27 in the elevator on 18 August, and 68 at the KSU feed mill on 23 July. Highest catches per refuge in the elevator and feed mill were on floors 6 and basement, respectively. *Liposcelis entomophila* was the predominant species found in the GMPRC grain bins; *Lepinotus reticulatus* was present only in bin 4 (Figure 1C-D). Highest numbers in the hatches were 165 *Lepinotus reticulatus* and > 6,000 *Liposcelis entomophila* on 5 November. On the grain surface, highest numbers were 46 and 373, respectively, on 11 November. Three of the five farm bins sampled contained psocids (Figure 1E); highest number was 86 *Liposcelis entomophila* on 18 October. *Liposcelis entomophila* was found in all three infested bins, and *L. decolor* was found in one of the three infested bins; > 90 % of the psocids in the bin with both species were *L. entomophila*. Bins containing psocids had not been treated with insecticide whereas the two bins that did not contain psocids had been treated with chlorpyrifos-methyl. We found significantly more psocids at depths of 2.5, 30, and 100 cm that at the surface (Figure 1G; F = 6.70; df = 3,54; $P < 0.01$).

The relationship between mean number of *L. entomophila* per refuge and the variance was well described by Taylor's power law (F = 13,808; df = 1,898; $P < 0.01$; $R^2 = 0.94$); i.e.

ln(variance) = 0.032 + 1.679 ln(mean). The slope (1.679) was significantly greater than 1 (t = 118; df = 898; SEM = 0.0143; $P < 0.01$) indicating that *L. entomophila* populations have an aggregated distribution. The antilog of the y-intercept (1.033) is equal to the coefficient "a". We used these coefficients to calculate optimal sample size for *L. entomophila* in steel bins filled with wheat (Figure 1F). The results indicate that as few as 6 refuges can be used to estimate the mean number of *L. entomophila* per refuge.

Study on temperospatial distribution of psocids in wheat in steel bins in 2005

Temperature in the bins declined from the time that monitoring started in August until temperature plateaued in December at around 8°C (Figure 2A). Moisture contents at the surface and at 0.3 m increased from 10.6 and 11.0 %, respectively, at the start of the study to about 11.5 %, but moisture contents at 2.1 m were fairly constant at around 10.5 to 10.8 % (Figure 2B).

Mean number of psocids per refuge in bins 1 and 2 was 2.45 ± 0.39 (SE) and 0.6 ± 0.21, respectively. Psocids in the refuges peaked at 300-400 per refuge in late September (Figure 2C), before falling to nearly 0 during winter. Because of low numbers of psocids in the grain samples taken at different depths, we combined data from 0 to 0.84 m and 0.85 to 1.96 m for analysis. Data for the surface samples were combined with those from 0 to 0.84 m so that the samples from the upper and lower depths were based on the same weight of grain. A greater mean number of psocids was found in samples from the lower depths (0.42 ± 0.09) than in samples closer to the surface (0.13 ± 0.04) (F = 10.9; df = 1,251; $P < 0.01$) (Fig. 2D). Interaction between sample date and distance from bin wall was significant (0.15 vs. 0.76 m) (F = 2.52; df = 16,204; $P < 0.01$) (Figure 2E); it appears more psocids were found closer to the bin wall during periods when psocid numbers were high despite the fact that the moisture content of grain in the two locations was not significantly different. There were no significant differences in numbers of psocids collected among locations on the grain surface (i.e., the bin center and in the north, south, east, and west directions). Preliminary identifications indicate that the only psocid species found in the bins was *Liposcelis entomophila*. Trends in psocid numbers in the refuges were similar to those from the depth and surface samples (Figure 2C-E).

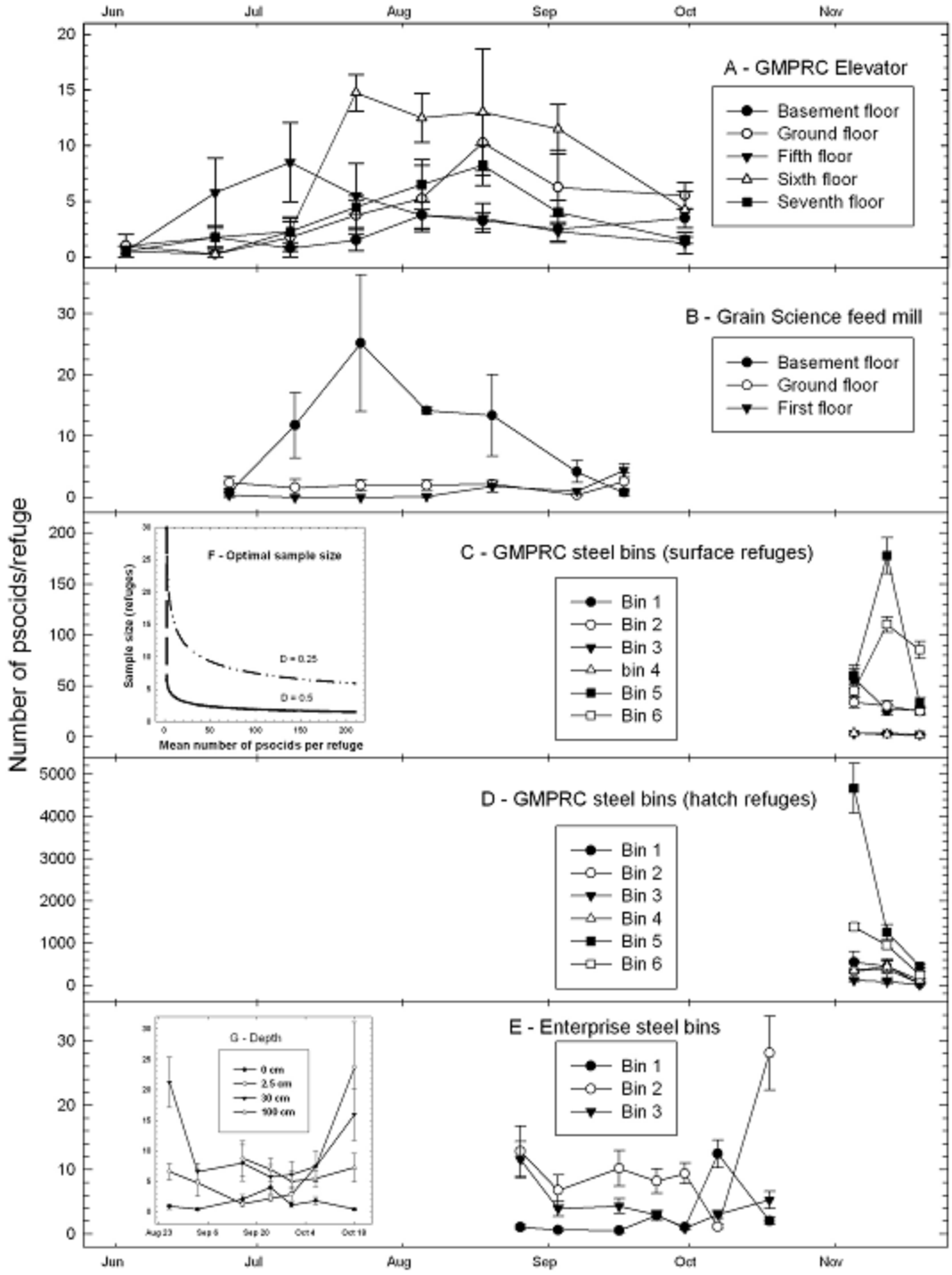

Figure 1. A) Numbers of psocids per week (mean ± SE; > 90 % *Liposcelis entomophila*, rest *L. decolor*) in cardboard refuges on different floors of the GMPRC elevator, B) in refuges in the KSU Grain Science feed mill (> 90 % *Liposcelis entomophila*, rest *L. decolor*), C) in refuges on the surface of wheat in GMPRC steel bins (all *Liposcelis entomophila*, except a mix of *L. entomophila* and *Lepinotus reticulatus* in bin 4), D) in refuges on the hatch in GMPRC steel bins (all *Liposcelis entomophila*, except a mix of *L. entomophila* and *Lepinotus reticulatus* in bin 4), E) in refuges in Enterprise steel bins containing wheat (all *Liposcelis entomophila*, except a mix of *L. entomophila* and *L. decolor* in one bin), and G) in refuges at different depths in the Enterpise steel bins containing wheat, 2004. F) Optimal sample size at two precision levels for psocids in refuges on the surface of wheat in GMPRC steel bins.

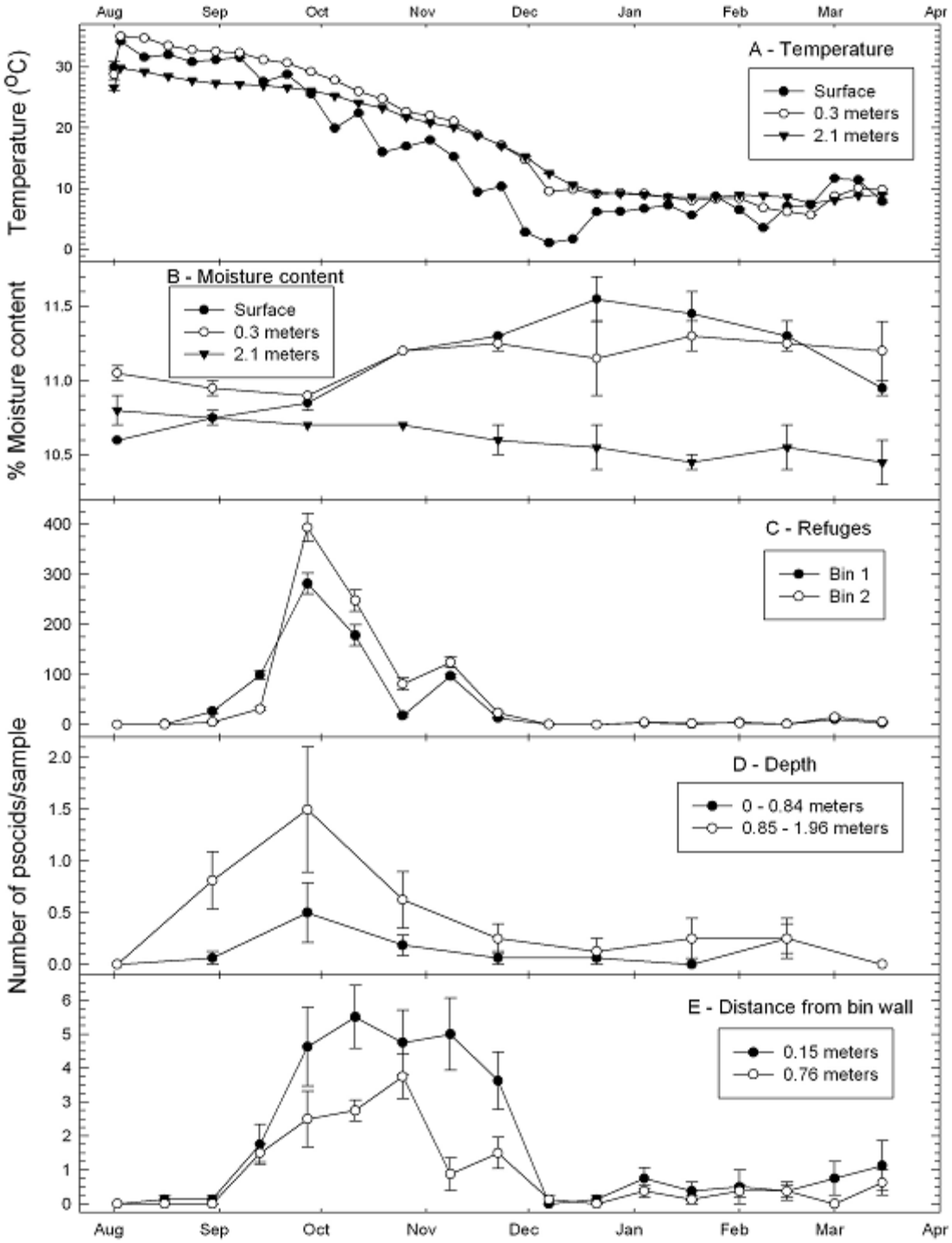

Figure 2. A) Temperature (mean ± SE) measured at three depths in the southern half of the center and B) moisture contents (mean ± SE) of samples of wheat taken at three depths in the center of bin 1 containing stored wheat, 2005. Temperature was similar in both bins, so data are shown for just the southern half of the center of bin 1; moisture content was similar in both bins, so data are shown for just bin 1. C) Number of *Liposcelis entomophila* per week (mean ± SE) in cardboard refuges in bins 1 and 2, D) in grains samples taken from two depths in the centers of bins 1 and 2 combined, and E) in grains samples taken from the surface at two distances from the bin wall in bins 1 and 2 combined containing stored wheat, 2005.

Discussion

Reports on seasonal trends of psocids in stored grain are rare, but, as expected, populations peaked about two months after bins were filled and began to drop after temperature started to drop in the autumn. Low numbers of psocids were found in refuges and grain samples throughout winter. *Liposcelis entomophila* is also found in grain in other countries (for example, see Rees and Walker 1990). Mashaya (1999, 2001) found that *L. entomophila* populations in tobacco processing facilities were abundant when temperature was above 18 °C and relative humidity was above 70 %. Internal environmental conditions based on tobacco processing drove population increase, rather than external environmental conditions. This is supported by work by Wang et al. (1998) who showed that *L. entomophila* eggs did not hatch at 15 °C, and that population increase was greatest at 27.5 to 30 °C.

It appears that cardboard refuges on the surface of grain may be a good predictor of psocids in the grain mass, and a sampling plan based on refuges would be more easily implemented by a storage manager than intensive grain sampling. We plan a second year of more intensive sampling during the time of peak psocid numbers to better define the relationship between numbers of psocids in refuges and those in grain samples to develop a method for estimating psocid numbers in the grain mass based on numbers in refuges.

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