PS7- 13 – 6161

Physical exclusion measures for prevention of pest entry into stored grain silos

***D.E. Maier*[1], *R. Hulasare*[1], *D.J.P. Moog*[1]**

Abstract

The objective of this study was to compare the efficacy of physical exclusion (PE) with ambient aeration (= 23.5 °C) versus ambient aeration (= 23.5 °C) (AA) versus chilled aeration = 18.0 °C (CA) without physical exclusion to prevent migration or cross-infestation by stored product pests in maize stored in 12.5-tonne pilot bins. Physical exclusion tactics implemented were: sealing all joints around the roof vents, placing a nylon mesh inside the roof vents, and placing a circular collar with nylon mesh over the main entry opening. The trials were conducted during the summers of 2004 and 2005 (June to October) and measures for PE were implemented ahead of the summer storage season. For the PE treatment, a strict bin-entry protocol was implemented to avoid any cross-infestation or migration of insects during frequent sampling requiring bin entry. Natural insect infestation levels in all bins were monitored weekly by placing probe traps (WB-II), pheromone baited flight traps, and cardboard rolls. While insect counts were not significantly different between CA and AA in pitfall traps and cardboard rolls, results showed that infestation levels of Indianmeal moths caught in flight traps were significantly lower in bins with PE measures compared to AA. CA generally gave the least insect count among the three strategies and compared to PE, infestation levels between these were not significantly different until the first week of August. PE delayed Indianmeal moth infestation for the first two months of summer storage as compared to AA. Therefore, PE has potential as an effective measure to prevent migration or cross-infestation of insects from outside and minimize if not avoid the use of chemical control methods.

Key words: Physical exclusion, chilled aeration, storage pests, organic, IPM, maize.

Introduction

Among the crops grown in the Midwestern United States, maize is the most widely grown agricultural commodity. Just as any other crop, maize can be infested and damaged during storage by a variety of internally and externally feeding insect species (Arbogast and Throne, 1997). Three of the major pests of stored maize are the maize weevil (MW), *Sitophilus zeamais* Motschulsky, red flour beetle (RFB), *Tribolium Castaneum* Herbst, and the Indianmeal moth, *Plodia interpuncteila* Hübner. The maize weevil is a primary storage pest; an internal feeder whose adults attack whole kernels and the larvae feed and develop entirely within kernels. The red flour beetle and Indianmeal moth are secondary storage pests, which are externally developing insects that feed primarily on damaged maize (i.e., broken kernels, germ, grain dust) or other cereal products (Storey, 1987). Heavy infestation

[1]Agricultural and Biological Engineering Department, Purdue University, 225 S. University Street, West-Lafayette, IN 47907-2064, USA

of IMM adults can result in thick silking over the grain surface which creates potential plugging conditions during maize unloading and conveying. IMM larvae also attack the germs of intact maize (Szabela, 2005). Therefore, IMM larvae and adults are considered primary storage pests by most Midwest U.S. grain storage managers.

Traditionally, control of stored insect pests has been achieved primarily through the use of residual pesticides and fumigation. The 1996 Food Quality Protection Act (FQPA) set stringent health-based safety standards for pesticide residues in foods. In addition, major pest species have developed resistance to a number of the target organophosphate (OP) pesticide affected by the FQPA. Insect pest resistance to malathion (Subramanyam and Hagstrum, 1995; Arthur, 1996), Chlorpyrifos-methyl (Subramanyam and Hagstrum, 1995), dichlorvos (Zettler, 1991), and pirimiphos-methyl (Beeman and Wright, 1990; our unpublished data, 2003) are well documented.

Stored product pests are primarily thermophilic in nature, i.e., their growth and survivability is greatly influenced by temperature. The lower developmental threshold for most stored-product pests is approximately 18 °C (64.4 °F). The optimum developmental range of many stored grain insect pests is approximately 25-35 °C (77-95 °F) (Fields, 1992). The use of aeration to reduce the grain bulk temperature to below optimum development thresholds of stored product insect pests is a well established and documented IPM-based approach to manage insects in bulk grains (Hagstrum et al., 1999) in the Midwestern (Cuperus et al., 1986, 1990) and north central states (Gardner et al., 1988). This research is part of a large scale, long term effort by the Consortium of Integrated Management of Stored Product Insect Pests (www. oznet.ksu.edu/spiramp/) to investigate and develop replacements as a result of FQPA requirements for organophosphorous insecticides that are used directly on post-harvest grain and for the loss of methyl bromide as a result of the Montreal Protocol in processing facilities. One possible strategy that could be implemented with aeration is physically preventing entry of storage pests into silos. Physical exclusion could be implemented on most storage structures and is especially attractive to organic producers who have few alternative means in controlling storage insects. The primary objective of this research was to compare the efficacy of physical exclusion measures with ambient aeration (= 23.5 °C) versus ambient aeration (= 23.5 °C) and chilled aeration (= 18.0 °C) without physical exclusion measures to prevent migration or cross-infestation by stored product pests in maize stored in 12.5-tonne pilot bins.

Materials and methods

Maize storage and temperature management in the pilot bins

Yellow maize was harvested in the fall of 2003 and binned in 12.5 tonne pilot-bins (2.3 m ht., 3 m dia.) in the first week of April 2004 at about 14 % moisture content (wet basis). About 9.59 tons (384 bu) of maize was filled in each bin. Three bins (replicates) were used for each treatment, namely: ambient aeration with physical exclusion (PE), ambient aeration without physical exclusion (AA), and chilled aeration (CA) without exclusion. The three management strategies were implemented during the summer storage period of May to October of 2004 and 2005 and aimed at maintaining grain bulk temperatures below 23.5 °C with ambient aeration (AA and PE) and below 18.0 °C with chilled aeration (CA). At the end of each summer period, the maize in each bin was cooled with ambient aeration and maintained at temperatures below 5 °C through the winter period. The ambient aeration temperature strategy maintaining maize at = 23.5 °C was determined by analyzing local weather data over the past five years and recognizing this setting would allow an automatic controller to operate the aeration fan often enough to maintain the average grain temperature at or below the set-point even during

the warmest summer storage period. The chilled aeration strategy of maintaining maize at = 18.0 °C was selected as the threshold temperature at which most insects reduce metabolism and stop reproduction (Fields 1992).

For the ambient aeration strategy, a PC-based software, OPIGIMAC (OPIsystems, Inc., Calgary, Alberta) was set to turn on the 0.56 kW Sukup axial fans (Sheffield, Iowa) based on a targeted maximum grain temperature of 23.5 °C ± 2 °C. The airflow rate was 2.9 m^3/min/t (2.6 cfm/bu) which was higher than the normally recommended airflow rate. This was done to quickly cool the grain to maintain experimental conditions in small bins that could quickly warm up on hot summer days. The chilled aeration strategy to maintain the targeted grain temperature of 18.0 °C was implemented using a chiller jointly developed by Purdue University and AAG Manufacturing, Milwaukee, WI (Maier and Rulon, 1996). The chiller has refrigeration and airflow capacities of 48 t/day and 1.3 m^3/min/t (1.2 cfm/bu), respectively. OPIGIMAC was set to turn on the chiller ducted to three bins based on a maximum grain temperature of 18.0 °C and off at a minimum grain temperature of 10 °C in order to maintain a target grain temperature of 15.6 °C (60 °F). Additionally, the chiller was only allowed to operate between 8:00 PM and 8:00 AM in order to maximize the chilled airflow and grain cooling effect.

The grain mass and headspace temperatures were monitored with 26 thermistors on temperature cables, one at the center and four at the four cardinal directions 0.3 m from the bin wall. Thermistors are 0.6 m spaced along each cable with the first one 0.3 m above the perforated silo floor. Temperature data was logged at an hourly interval by the OPIGIMAC data acquisition system. A weather station located at the pilot bin site logged ambient air temperature and relative humidity data.

Determination of natural infestation levels of stored product insects of corn

Natural populations of stored product insects in all bins were monitored by placing probe traps (WB-II), pheromone baited flight traps, and cardboard rolls. Five probe traps were placed in each bin with one in the center and at the four cardinal directions 0.3 m from the bin wall. The cardboard rolls were placed on the grain surface near the probe traps. Cardboard rolls are a favored refuge for IMM larvae (Philipps, 2005). One flight trap per bin was placed in the headspace to trap adult IMM. Weekly insect counts were taken for all insect monitoring devices and replaced for the subsequent sampling interval. The efficacy of exclusion measures was determined statistically using SAS version 9.1 by analyzing the probe trap catch data in the replicated treatments and comparing exclusion versus non-exclusion results (PE versus AA and PE versus CA).

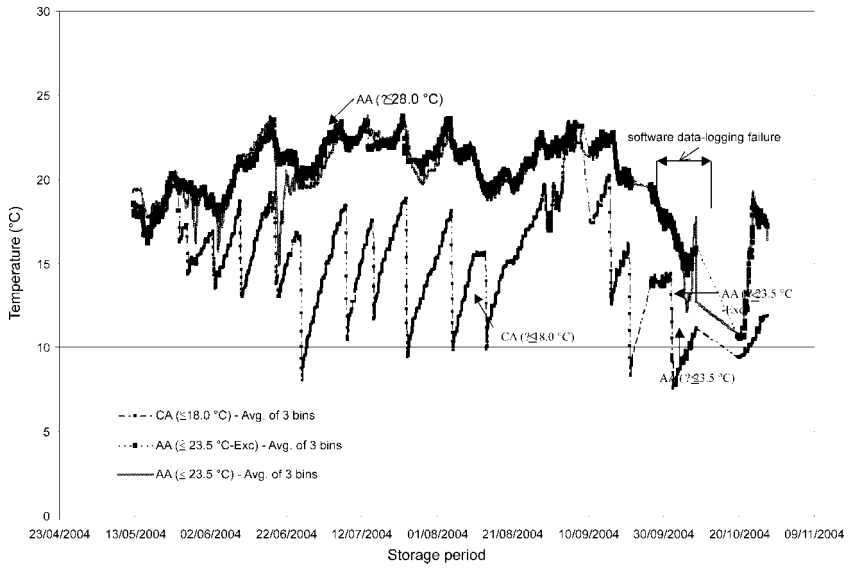
Results and discussion

Temperature profiles in the stored corn for the three management strategies

The average temperature of bulk maize in the three management strategies is shown in Figure 1. The profile for a temperature management strategy was the average of the temperature profiles of the bin replicates. The maximum average maize temperature did not exceed 23.5 °C for 2004 and slightly higher for 2005 at 27 °C in the ambient aeration strategy (AA and PE). The highest daytime ambient temperature recorded was 33.3 °C during the first week of August 2004 and 37.1 °C for the last week of June 2005. During this hottest period, AA, PE, and even CA strategies were not able to maintain the desired grain bulk temperature on some days. Given the fact that the aeration controller was set to a target of = 23.5 °C, sufficiently mild summer temperature allowed for maintaining average maize temperature below 27.0 °C in the ambient aeration strategy. The grain temperature for the chilled aeration strategy was below 18.0 °C most of the time except during the malfunction of the chiller in the first week of

Sept 2004 (3rd to 8th Sept). The ambient aeration strategy was generally successful in maintaining the average maize temperature for the entire bulk in each year below the maximum set point of 23.5 °C. The longest cooling cycle in an ambient aerated bin was 15 hours. This was the time it took the highest temperature of 41.4 °C (0.6 m below the grain surface) in August 2004 to reach a temperature below 23.5 °C. For the chilled aeration strategy, within one hour of turning the chiller on, temperature at that same location in the bin could be reduced from 23.4 °C to 11.4 °C. The 2004 temperature recording gap was due to a hardware failure that occurred towards the end of the storage period (10th to 19th Oct 2004). It did not have much of an effect because the ambient temperatures by then were low enough and the fan did not need to operate to maintain grain temperatures below the set point.

A



B

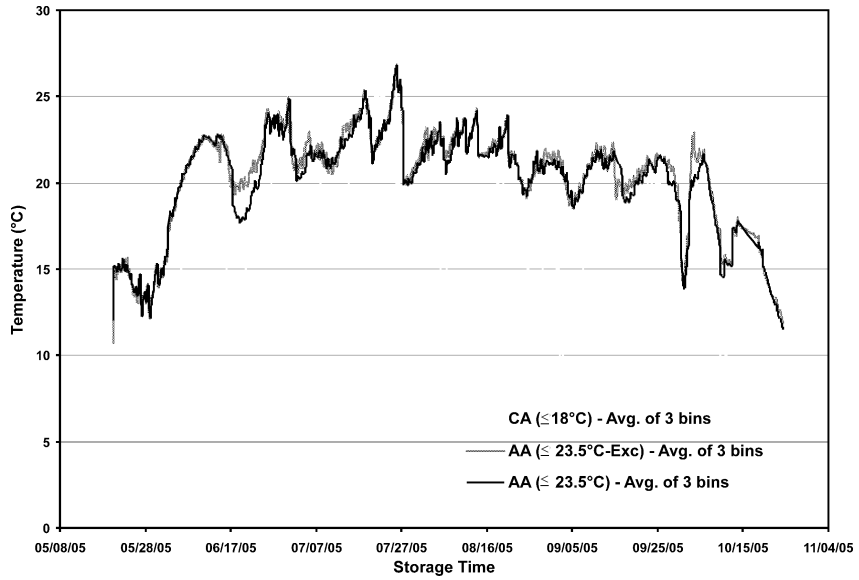


Figure 1. A - Average temperature profiles for 2004 in maize stored in bins with different insect management strategies: ambient aeration with physical exclusion (PE = AA (= 23.5 °C-Exc)), ambient aeration without physical exclusion (AA), and chilled aeration without physical exclusion; B - Average temperature profiles for 2005 in maize stored in bins with different insect management strategies: ambient aeration with physical exclusion (PE = AA (= 23.5 °C-Exc)), ambient aeration without physical exclusion (AA), and chilled aeration without physical exclusion.

Comparison of natural insect populations

In all three monitoring devices, generally for both years, the insect populations increased with time from June to August and decreased towards the end of the summer storage period in October. Based on the pitfall trap data, it is evident from 2004 that insect populations (Figure 2a) for both AA and PE increased with time from June to August then decreased towards October. PE had a lower (max difference 50 %) insect population compared to AA for the initial six weeks of storage but was higher (max difference 24 %) for the next four weeks. PE gave a much lower (max difference 62 %) insect population than AA from September to October. CA showed the least insect activity, with almost no increase in population except for the peak of 5 insects per day in mid September. From the 2005 data (Figure 2b), insect populations for PE was similar to CA while AA showed the highest insect populations. More population cycles were observed in this year at the same sampling times, though the counts were lower compared to 2004 even for CA. The difference in insect count from the pitfall traps among the strategies was statistically significant ($\alpha < 0.0001$) for both years. Considering the whole storage period, for 2004 PE was significantly higher from CA and AA, while the latter two was not significantly different. For the month August of the same year, PE was substantially lower than AA. During the whole sampling period of 2005, AA was higher than PE and CA.

The adult IMM numbers per day from the pheromone baited flight traps for 2004 (Figure 3a) showed in general that CA yielded the least insects during the entire storage period. PE performed almost as well as CA in terms of insects collected for the first two months of storage, while AA yielded an almost tripled number of insects trapped compared to the other strategies in July 2004. Only during the peak period of IMM activity in late August 2004 did PE resulted in a slightly lower trap count than AA (presumably due to breakdown in bin entry procedures). IMM activity tapered off after mid-August. In that year, the difference in IMM adult count between PE and CA was not statistically significant. Although, PE and AA were also not significantly different, the effect of PE on preventing IMM infestation cannot be discounted. From the 2005 data (Figure 3b), insect activity was lower compared to the previous year in terms of IMM trapped. Among the three strategies, AA again yielded the maximum number of adult IMM trapped. PE yielded the fewest IMM trapped during some phases of the storage period, while CA did not yield the lowest insect count as consistently as in 2004. As a matter of fact, in mid-July, the largest number of IMM adults were trapped in the CA system. As in 2004, IMM adult count in the PE treatment was not statistically different from CA and AA. However, in comparison to 2004, AA was significantly higher than PE.

The larval count of IMM per day collected from the cardboard rolls is presented in Figure 4. In 2004 and similar to the data for IMM adult, CA yielded the lowest number of insects collected until the end of August. Afterwards, CA showed higher trap counts than AA and PE. Generally, AA yielded the highest number of larvae/pupae while PE fell between AA and CA. But effect of strategy was not statistically significant for that year among the three strategies. This could be partially attributed to the reason that average headspace temperatures in the pilot bins were also not significantly different among the three strategies. Thus similar high larvae counts on the grain surface would be expected even for CA. Also, the delay in build-up of larvae due to the slightly cooler grain temperature would also appear reasonable. In 2005, unexpected results were observed that differed from the general trends observed from all traps in 2004 as well as the pitfall and flight traps in 2005. For 2005, CA gave the maximum number of larval counts (maximum = 2.75 larvae/day), with PE second lowest (maximum = 2.0 larvae/day), and AA the lowest (maximum = 0.75 larva/day). The result for CA was significantly higher compared to the other two strategies. Although this was unexpected, the counts for all

three strategies were much lower in 2005 than in the previous year when larvae/pupae counts reached 33 per day. The more than ten fold decrease in insect counts observed in all treatments in 2005 may not allow for an objective conclusion about any of the treatment effects.

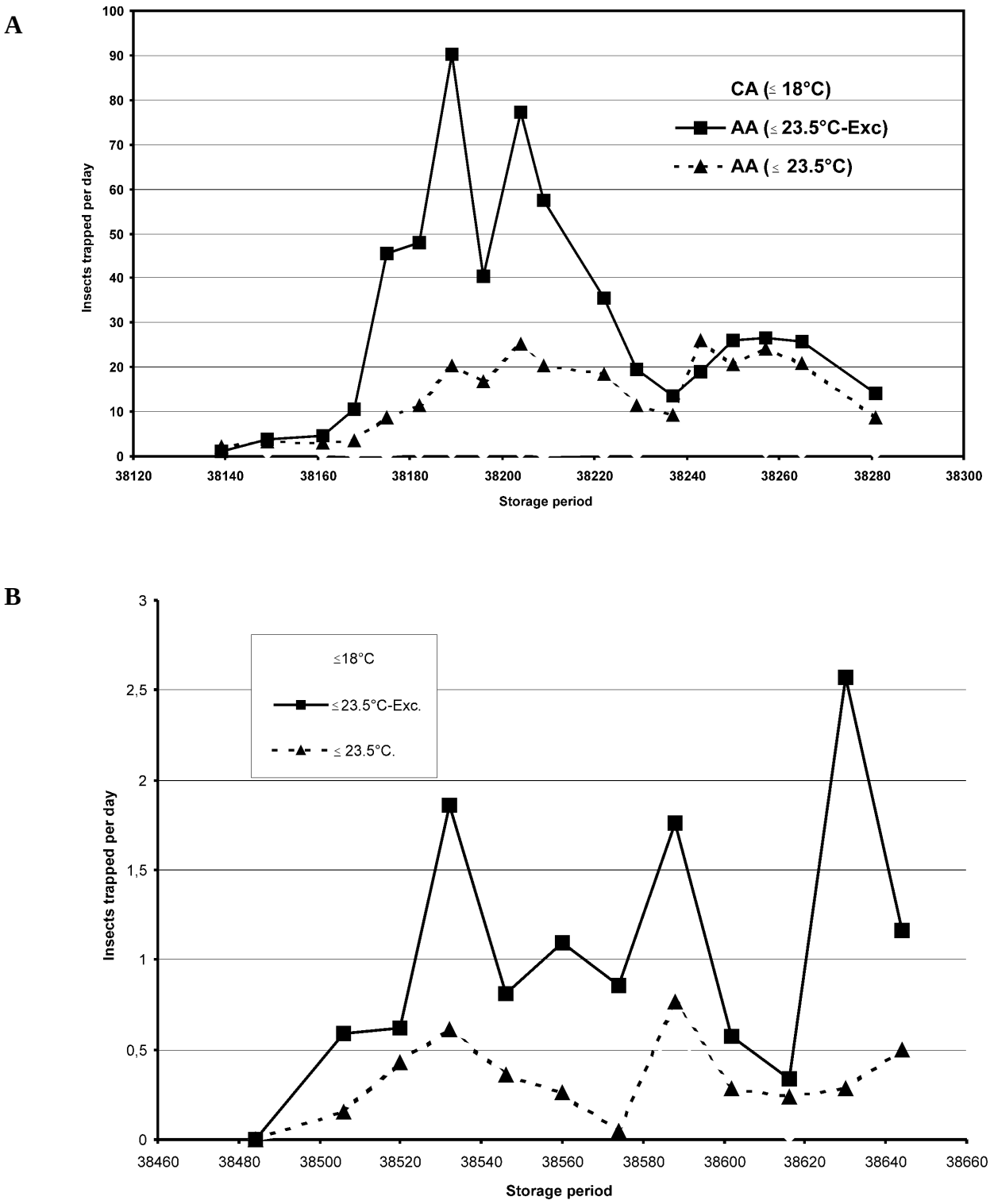


Figure 2. A - Number of insects collected from pitfall traps in 2004 placed in bins storing maize with three different insect management strategies; B - Number of insects collected from pitfall traps in 2005 placed in bins storing maize with three different insect management strategies.

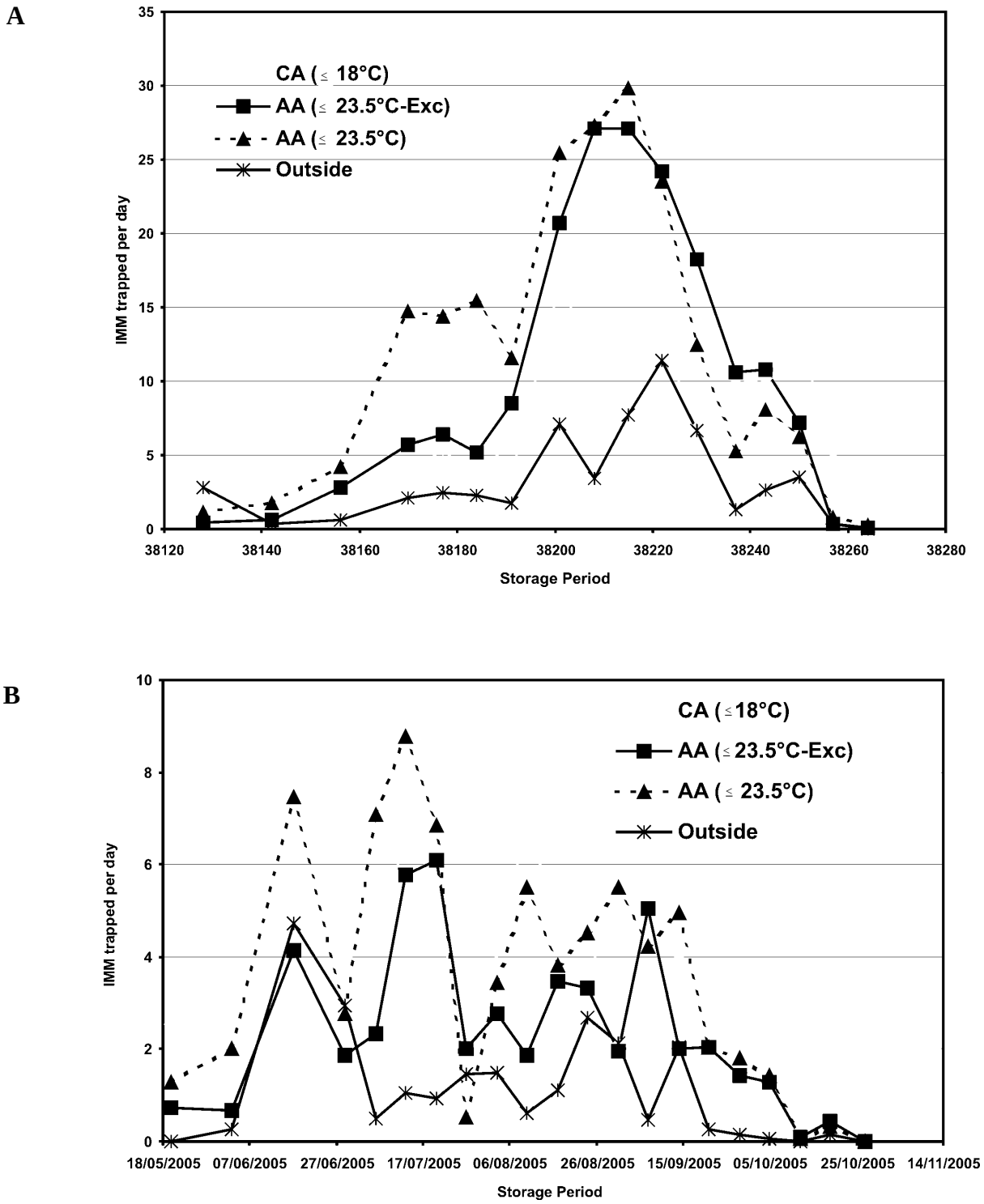


Figure 3. A - Number of IMM adults collected in 2004 from flight traps placed in bins storing maize with three different insect management strategies: ambient aeration with physical exclusion (PE = AA (= 23.5 °C-Exc)), ambient aeration without physical exclusion (AA), and chilled aeration without physical exclusion; B - Number of IMM adults collected in 2005 from flight traps placed in bins storing maize with three different insect management strategies: ambient aeration with physical exclusion (PE = AA (= 23.5 °C-Exc)), ambient aeration without physical exclusion (AA), and chilled aeration without physical exclusion.

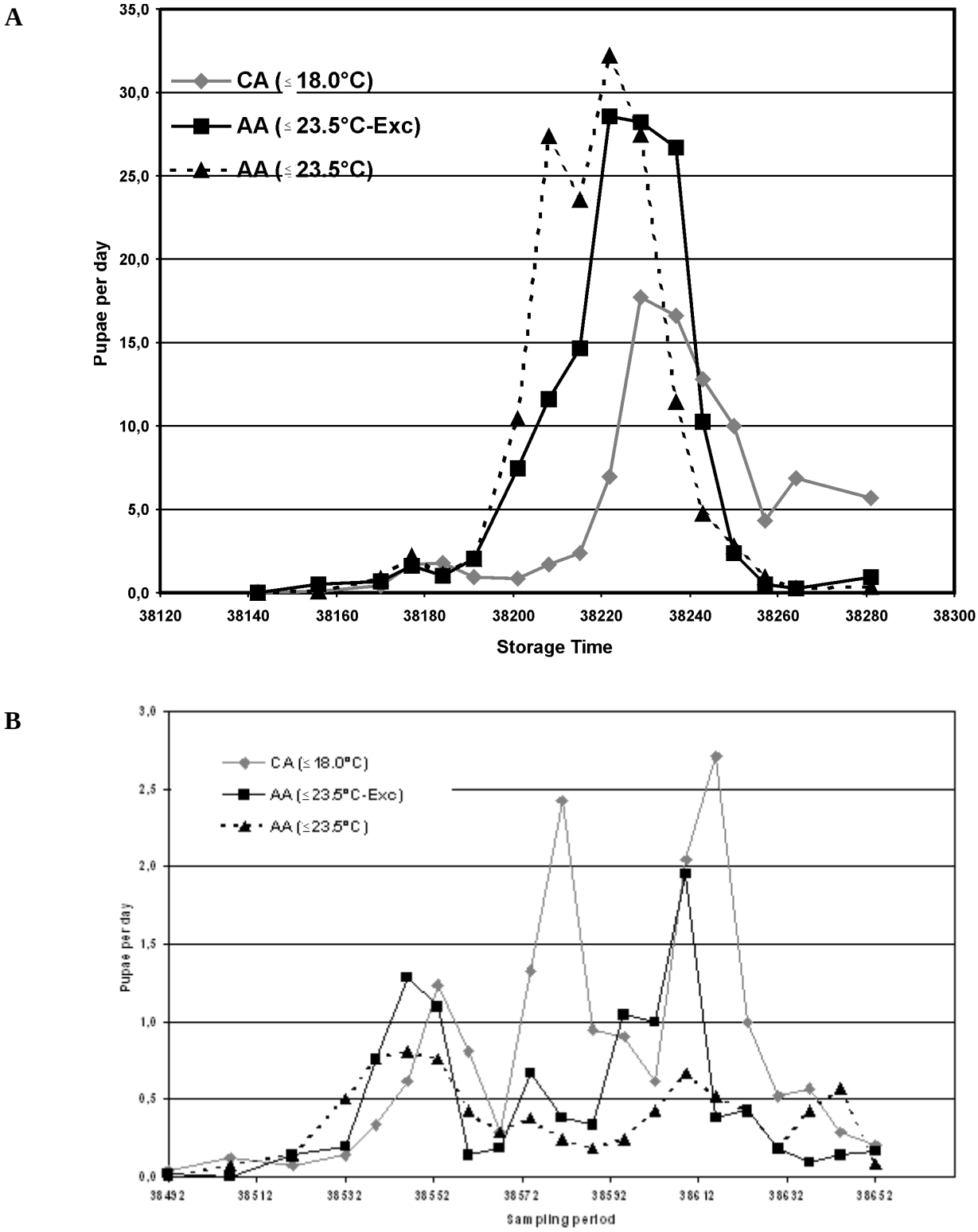


Figure 4. A - Number of IMM pupae collected in 2004 from cardboard traps placed in bins storing maize with three different insect management strategies: ambient aeration with physical exclusion (PE = AA (= 23.5 °C-Exc)), ambient aeration without physical exclusion (AA), and chilled aeration without physical exclusion; B - Number of IMM pupae collected in 2005 from cardboard traps placed in bins storing maize with three different insect management strategies: ambient aeration with physical exclusion (PE = AA (= 23.5 °C-Exc)), ambient aeration without physical exclusion (AA), and chilled aeration without physical exclusion.

In general, the chilled aeration strategy (=18.0 °C) consistently had the lowest insect numbers in pitfall traps and flight traps compared to both ambient aeration strategies with and without physical exclusion. This was expected because lower grain temperatures suppress insect activity and thus population increase. The effect and benefit of lower grain temperatures could also be observed when insect counts in all traps decreased towards the end of the storage period when colder ambient conditions prevailed. Although CA was generally the best strategy among the three, the use of physical exclusion as a complementary measure to ambient aeration in minimizing storage pests showed promising results. PE was almost as effective as CA especially with respect to insects caught in pitfall traps. It even delayed IMM infestation for the first two months of summer storage while ambient aeration without exclusion showed an early increase in adult IMM. During periods when PE gave higher insect counts than AA, physical exclusion measures were likely compromised due to improper bin entry procedures especially in 2004. Additionally, exclusion measures were initiated late in May 2004 by which time migration of insect pests may have occurred to some extent. Frequent sampling involved removal of the screened bin entry collar. In 2004, instead of replacing it, it was set aside while staff entered the bin, recovered the trap catches, and exited the bin allowing insects to migrate and cross contaminate from the outside. In 2005, the bin entry procedures were modified and the screened bin entry collar was replaced immediately after staff entry and exit. This minimized the chances for contamination of storage pests from the outside. As a result, PE prevented the entry of non-moth stored product insects into the bins much more effectively.

Implementation of physical exclusion measures in corrugated steel silos used to dry and store grains is practical and for specialty grains highly desirable. Silos with open eaves could be modified by permanently sealing the eaves in order to eliminate a major entry point for insects. The lost venting area can be replaced with additional roof vents that would allow air to escape during high airflow drying/aeration. Although eave vents were developed to direct dripping from under roof condensation to the outside of silos, problems brought about by condensation can be minimized or avoided. This was proven by lack of such problems when storing grain at safe moisture contents in welded steel tanks with sealed eaves at many grain elevators. In addition, roof fans to extract exhaust air can be installed on bins used for dryaeration of hot corn and natural air/low temperature in-silo drying. Screens as used in this research could be placed in roof vents and over man holes to physically exclude insects trying to migrate or cross-contaminate grain. Screens could be removed during loading and unloading operations to avoid dust accumulation and plugging. This could also be treated with an approved empty bin residual insecticide before placement in order to prevent laying of eggs on and entry of larvae through the screen openings.

Acknowledgement

This research is part of a large-scale, long-term effort funded by the USDA-CSREES Risk Assessment & Mitigation Program (RAMP), Project No. S05035. entitled “Consortium for Integrated Management of Stored Product Insect Pests” (www.oznet.ksu.edu/spiramp) to investigate and develop alternative prevention, monitoring, sampling and suppression measures for organophosphate insecticides used directly on post-harvest grains that are under scrutiny as a result of the U.S. Food Quality Protection Act (FQPA) and for methyl bromide, which will soon be completely unavailable as a fumigant for pest control in U.S. grain processing facilities as a result of the Montreal Protocol. The collaboration and participation of grain producers, handlers and processors as well as numerous equipment and service suppliers in this project across the U.S. has been greatly appreciated.

References

Arbogast, R.T., Throne, J.E., 1997. Insect infestation of farm-stored maize in South Carolina: towards characterization of a habitat. Journal of Stored Products Research 33, 187-198.

Arthur, F.H., 1996. Grain protectants: current status and prospects for the future. Journal of Stored Products Research 32, 293-302.

Beeman, R.W., Wright, V.F., 1990. Monitoring for resistance to chlorpyrifos-methyl, pirimiphos-methyl, and malathion in Kansas populations of stored-product insects. J. Kansas Entomol. Soc. 63, 385-392.

Cuperus, G.W., Prickett, C.K., Bloome, P.D., Pitts, J.T., 1986. Insect populations in aerated and unaerated stored wheat in Oklahoma. J. Kans. Entomology. Soc. 59, 620-627.

Cuperus, G.W., Noyes, R.T., Fargo, W.S., Clary, B.L., Arnold, D.C., Anderson, K., 1990. Management practices in a high-risk, stored wheat system in Oklahoma. Am. Entomol. 36, 129-134.

Fields. P.G., 1992. The control of stored-product insects and mites with extreme temperatures. Journal of Stored Products Research 28, 89-118.

Gardner, R.D., Harein, P.K., Subramanyam, Bh., 1988. Management of stored barley in Minnesota: practices versus recommendations. Am. Entomol. 34, 22-26.

Hagstrum, D.W., Reed, C., Kenkel, P., 1999. Management of stored-wheat insect pest. Integrated Pest Management Review. 4, 127-142.

Maier, D.E., Rulon, R.A., 1996. Evaluation and optimization of a new commercial grain chiller. Applied Engineering in Agriculture. 12, 725-730.

Philipps, T., 2005. Personal communication with Dr. Tom Philipps. Oklahoma State University, Silkwater, Oklahoma, USA.

Storey, C.L., 1987. Effect and control of insects affecting corn quality. In Corn Chemistry and Technology, 185-199. S. A. Watson and P. E. Ramstad (Eds.). American Association of Cereal Chemists, St. Paul, Minnesota, USA

Subramanyam, Bh., Hagstrum, D.W., 1995. Resistance measurement and management. In Integrated Management of Insects in Stored Products, 331-397. Bh. Subramanyam and D. W. Hagstrum (Eds.). Marcel Dekker, New York, New York, USA.

Szabela, D., 2005. The fate and efficacy of spinosad for insect management in farm stored corn. MS thesis. Department of Agricultural and Biological Engineering, Purdue University, West Lafayette, Indiana, USA.

Zettler, J.L., 1991. Phosphine resistance in stored product insects in the United States. In Proc. 5th International Working Conference of Stored Product Protection, 1075-1081, INRA/SDPV Bordeaus, France.