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Effect of temperature management on confined populations of red flour beetle and maize weevil in stored maize – Five Year Summary of Pilot Bin Trials

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Abstract

The objective of this study was to determine the effect of two temperature management strategies: chilled aeration (CA) = 18.0 °C and ambient aeration (AA) = 23.5 °C on confined populations of maize weevil (MW) and red flour beetle (RFB) in maize stored in 12.5-tonne pilot bins. Three bins were used for each of the two strategies with temperature thresholds maintained by a PC-based software to control fan operation. Confined populations of MW and RFB were investigated for survival and progeny development using insect bioassays that made use of PVC pipes filled with maize, sealed with fine mesh, and embedded in the grain bulk. A cage of each insect species was removed monthly (June to October) for insect counts and incubated at optimum conditions for progeny development over two months. Considering all five years, maximum progeny counts of MW were lower for CA (90 to 1,200) compared to AA (400 to 1,830). Similarly, for RFB, CA (1 to 190) yielded lower maximum progeny counts compared to AA (11 to 630). The results demonstrated that CA effectively suppressed natural infestation levels as well as confined populations of MW and RFB compared to AA.

Key words: Chilled aeration, Ambient aeration, Corn, Stored-Product Pests, Maize weevil, Red flour beetle, Insect Population, IPM.

Introduction

Storage of maize and other grains is challenged by pest problems that contribute to quality deterioration. One primary storage pest is the maize weevil (MW), *Sitophilus zeamais* Motschulsky which is an internal feeder whose adults attack whole kernels and whose larvae feed and develop entirely within kernels (Storey, 1987). Adult weevils normally live for about 5 months, and during this time each female lays 200 to 300 eggs inside the grain kernels. In a few days the eggs hatch to larvae which feed inside the kernels where they remain and develop into adults before emerging. Another storage pest is the red flour beetle (RFB), *Tribolium castaneum* Herbst, which is an externally developing insect that feeds on damaged corn or other cereal products (Storey, 1987). The adults are very active, can fly and move about rapidly when disturbed. Females can lay up to 450 eggs (Calvin, 1990).

The U.S. Federal Grain Inspection Service Standard stipulates grain containing two or more live weevils per kilogram of grain will be classified with the special grade “Infested”

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(USDA-GIPSA-FGIS, 2001). Therefore, it is important that this insect species be adequately controlled, and if possible eliminated in stored grain. 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 target organophosphate (OP) pesticides tested under the FQPA. Insect pest resistance to malathion (Subramanyam and Hagstrum, 1995; Arthur, 1996), chlorpyrifos-methyl (Zettler, 1991; Subramanyam and Hagstrum, 1995), dichlorvos (Zettler, 1991), and pirimiphos-methyl (Beeman and Wright, 1990) 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) (Howe, 1965). 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. Thus, with the above points in mind, the primary objective of this study was to determine survival, reproduction, and suppression of caged populations of maize weevil and red flour beetle in stored maize using two temperature management strategies: ambient aeration (= 23.9 °C) and chilled aeration (= 18.3 °C) during five years of pilot-bin studies.

Materials and methods

Maize storage and temperature management in the pilot bins

Yellow maize was harvested in the fall of 2000 for the first phase and in 2003 for the second phase of the study. The maize was binned in 12.5 ton pilot-bins (2.3 m ht., 3 m dia.) in the first week of April 2001/2004 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 temperature management treatment during the storage period of May to October for each year at temperature = 23.5 °C for ambient aeration (AA) and at = 18.0 °C for chilled aeration (CA). At the end of each summer period, the maize in each bin was cooled with ambient aeration and maintained at temperature 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 to enough 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 which was needed 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 temperature 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.

Preparation and placement of insect bioassays

Adults of maize weevil, *Sitophilus zeamais* (Motschulsky) and red flour beetle, *Tribolium castaneum* reared in laboratory cultures were used to prepare the insect bioassays in PVC cages. Cages were made from PVC pipe that was 5.1 cm (2 in) diameter and 10.2 cm (4 in) long. The food source in the cages for both species was grade 1 yellow maize obtained from the stored maize bulk of one of the pilot bins and closed at both ends with a 0.4 mm monofilament mesh to prevent adults and immature stages from escaping, while allowing airflow through it, when installed in the upright position. Maize used as a food source in the cages was frozen at about -10 °C for a week to ensure insect-free food before commencement of the trials. Each single-species cage contained 180 g kernels at 14.0 % moisture with 25 and 12 unsexed adults of RFB and MW, respectively.

A set of five single-species insect cages for each of two insect species were placed 0.3 m from the wall and embedded 0.6 m below the grain surface and placed one at the center and on each four cardinal directions. All insect cages were placed in the bins at the beginning of the trial (May) and a cage of each insect species was removed from a randomly selected location each month (June to October) for counts of dead and live insects. After screening, the maize samples were subsequently incubated in the laboratory at 29 °C (± 0.5 °C) and 70 % RH (± 3.0 %) for progeny development over a period of 60 days. The location from which a set of cages was pulled each month was determined using a randomized block design, with the group of bins for a temperature strategy as blocks. Within each block, the cage pull-out months were assigned at random to the cage locations in the bins. The set of cages in each bin randomly selected to be pulled out last (October) had a temperature sensor installed to measure temperature inside the cages. It was recorded by a HOBO data logger (Onset Computer Corp., Bourne, Massachusetts). This enabled measurement of temperature inside the cages over the entire storage period (June to October).

Determination of progeny numbers from insect bioassays

A first count of live and dead insects was recorded for all cages pulled out each month for both species. The live and dead insects were discarded and remaining grain was divided into three 100 mL double layer plastic cups with lids and placed in growth chamber set at optimum conditions for growth and development of the two species (29.0 ± 0.5 °C and 70.0 ± 3.0 % RH). Subsequently, every three days progeny count was taken by sieving all grain from each cup, counting total adults then discarding them and returning the remaining corn with immatures to the incubator. The progeny count for both species was continued for two months (60 days) from the date of removal of cages from the bins. A period of 60 days was presumed to be sufficient for any immatures (larvae and eggs) to develop into adults in all temperature management strategies. The final progeny number for each species was first count plus cumulative number of adults over 60 days minus the initial adult numbers (12 and 25 for MW and RFB, respectively). The final progeny number indicated total development and survival from an initial adult population. The final progeny numbers for each strategy were determined by averaging over the replicates (3 bins for each strategy).

Results and discussion

Progeny of Red Flour Beetle

Based on the progeny count of adult RFB, comparison between CA and AA was done as seen in Figures 1 to 5. Between the two strategies, CA gave lower progeny counts (maximum 190 adults in 60 days) for all five years considered. This strategy can be effective in controlling RFB, as progeny count did not exceeded 20 in 60 days for 3 out of 5 years and had less than five adults in 2002 and 2004. Overall mean insect count for CA was modestly high only during 2003. In that year, means of the two strategies were not statistically different from each other. In contrast, AA gave higher progeny counts with the maximum number of adults reaching 440 in July 2005, more than twice the maximum for CA. On the other hand, AA was not statistically different from CA in 2002 and 2004. To determine whether AA aided in controlling RFB, it was compared with NA. AA performed better only during the first year of the three years when NA was part of the experiment, but their difference was not statistically significant. Unexpectedly, NA was even a better strategy than AA for 2002 and 2003. The highest RFB progeny count (maximum 630 adults) was obtained from AA among the three treatments. The difference between AA and NA was statistically significant only in 2003.

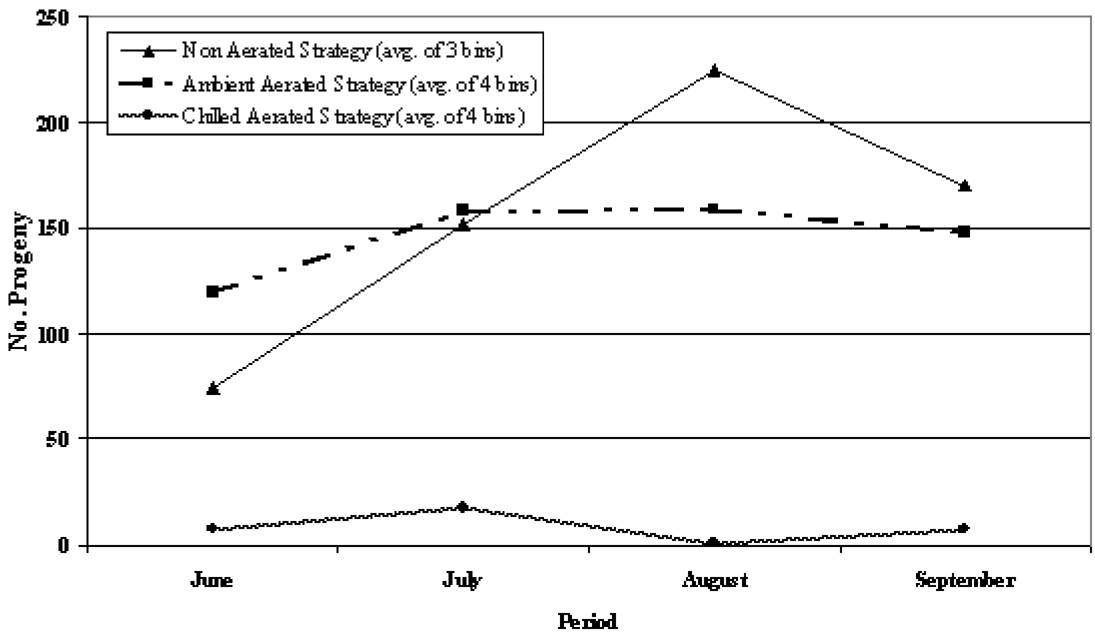

Figure 1. Progeny count of red flour beetle for 2001.

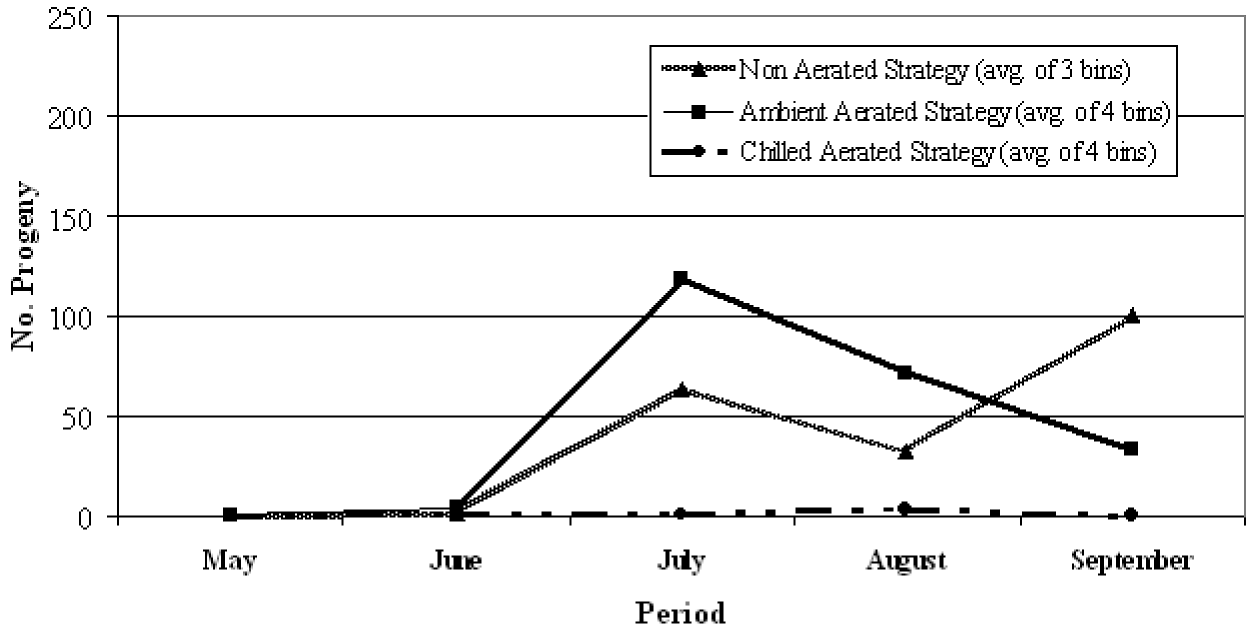

Figure 2. Progeny count of red flour beetle for 2002.

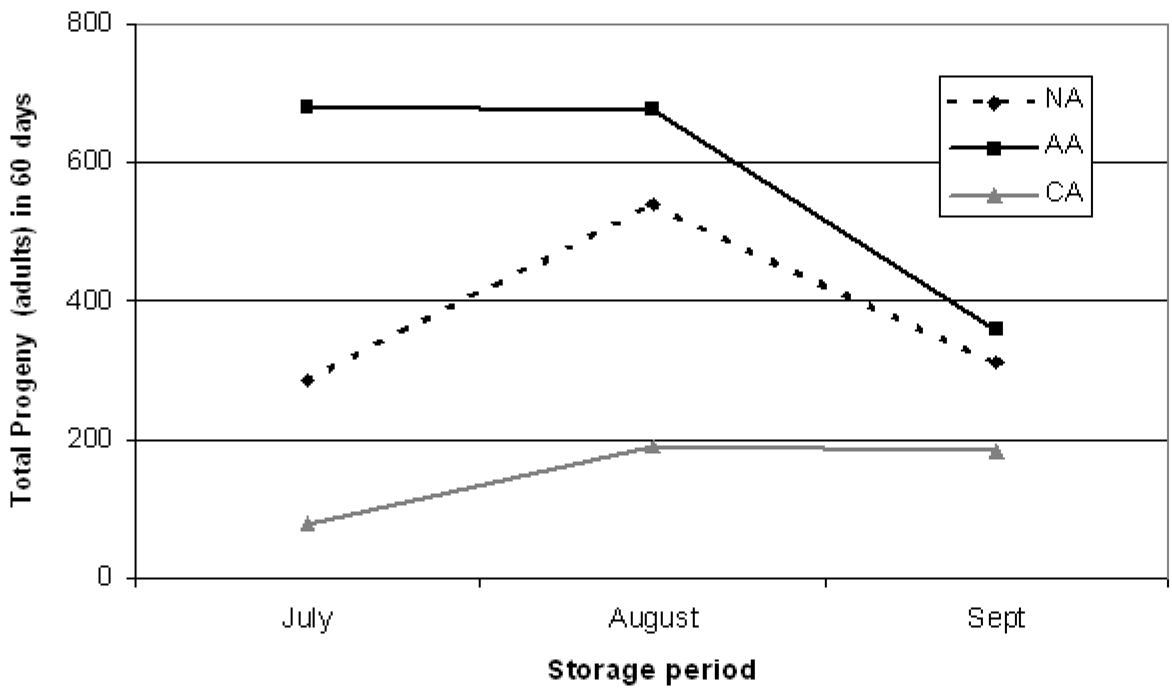

Figure 3. Progeny count of caged red flour beetle for 2003.

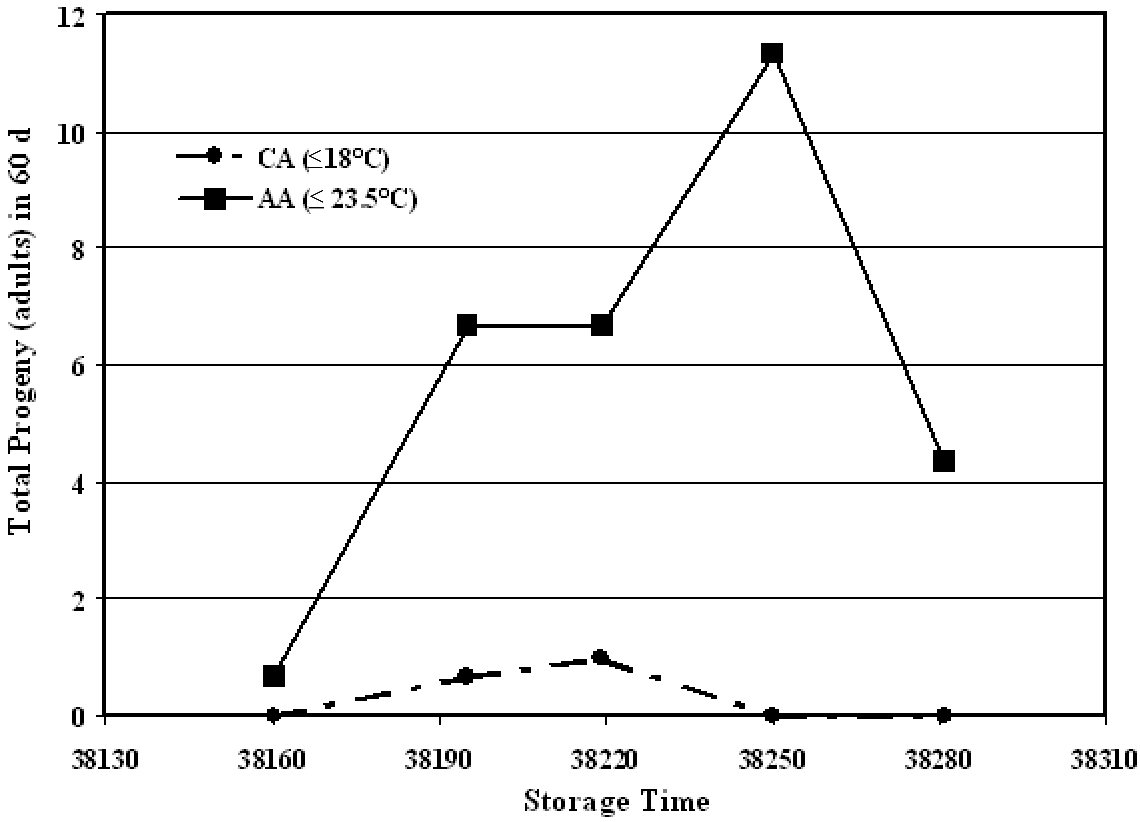

Figure 4. Progeny count of caged red flour beetle for 2004.

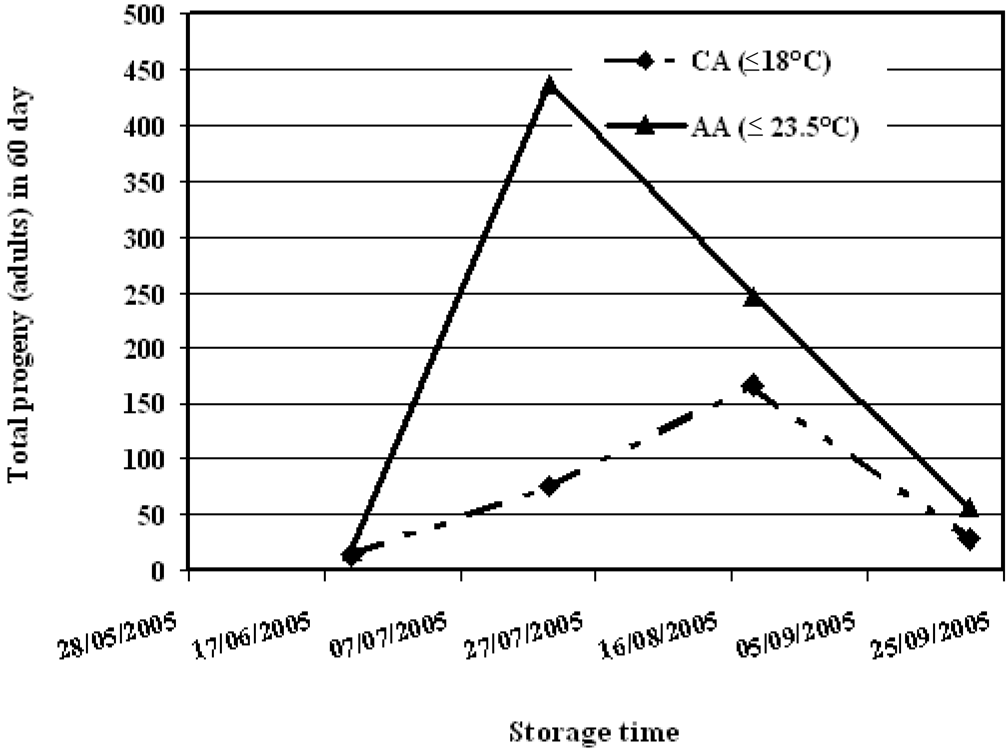

Figure 5. Progeny count of caged red flour beetle for 2005.

Progeny of Maize weevil

Comparison of CA and AA in terms of MW progeny count is presented in Figures 6 to 10. Similar to the RFB results, CA gave statistically significant lower insect counts than AA in most years. The maximum total MW adults observed in 60 days was about 1,200 in September of 2005 for CA while it was about 50 % higher for AA (1,850). Excluding 2005, which yielded relatively high insect populations, MW did not exceeded 640 for CA and 1,350 for AA in any month. For the latest (2005) and first year (2001), CA was not significantly different from AA. Comparing AA with non-aerated bins, AA yielded relatively higher MW counts than NA during each of the first three years. Contrary to what was expected, AA gave the highest MW progeny count for all three years when the NA strategy was part of the experiments. In 2002 and 2003 AA was significantly different while no significant difference was obtained between CA and NA. A substantial difference was observed in 2002 when the maximum number of MW adults was only 450 for NA while it was more than double (1,100) for AA.

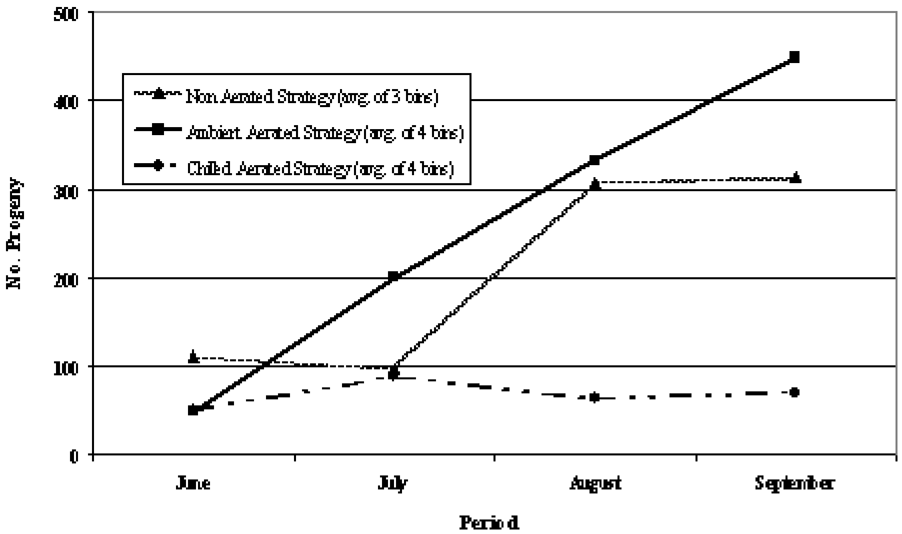

Figure 6. Progeny count of caged maize weevil for 2001.

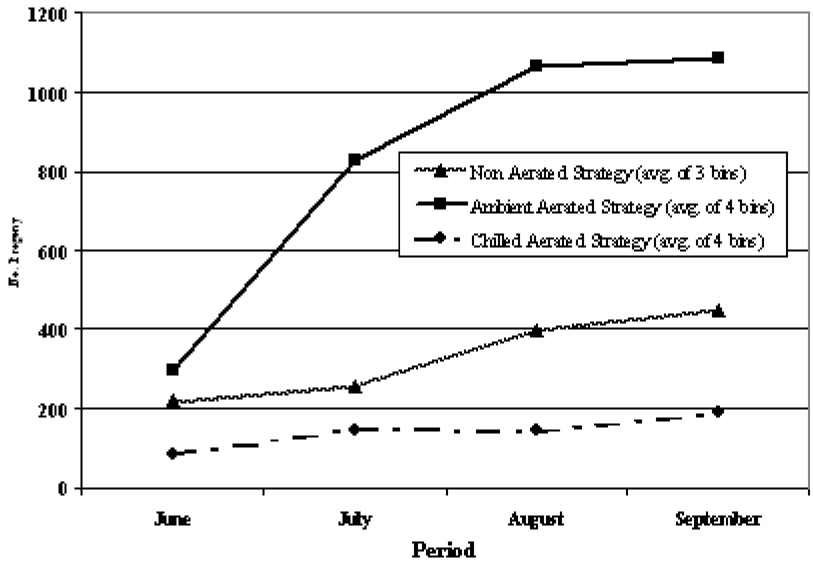

Figure 7. Progeny count of caged maize weevil for 2002.

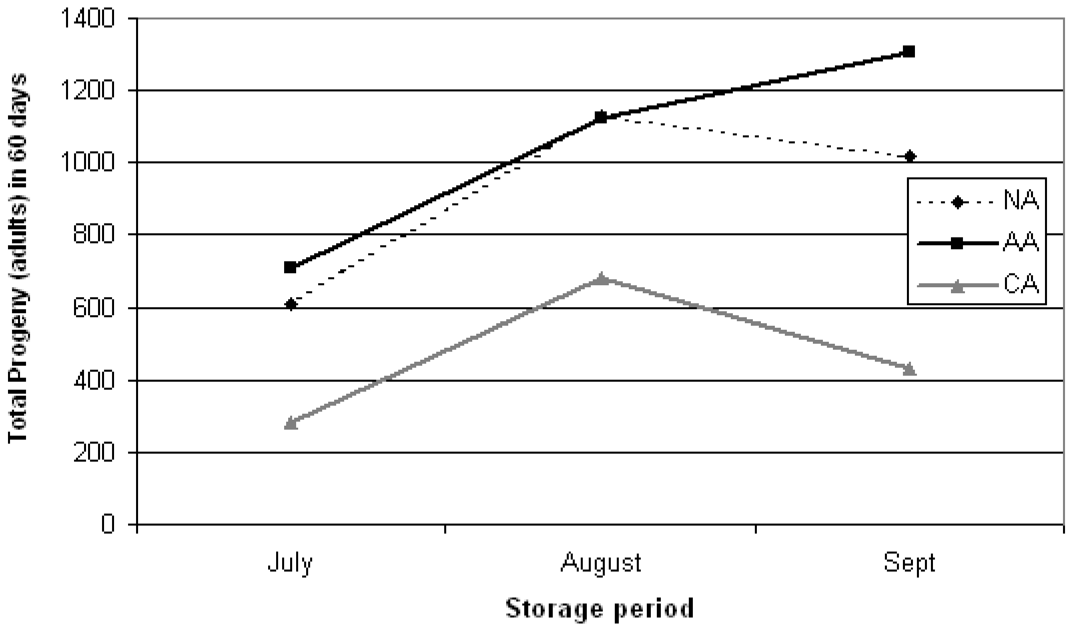

Figure 8. Progeny count of caged maize weevil for 2003.

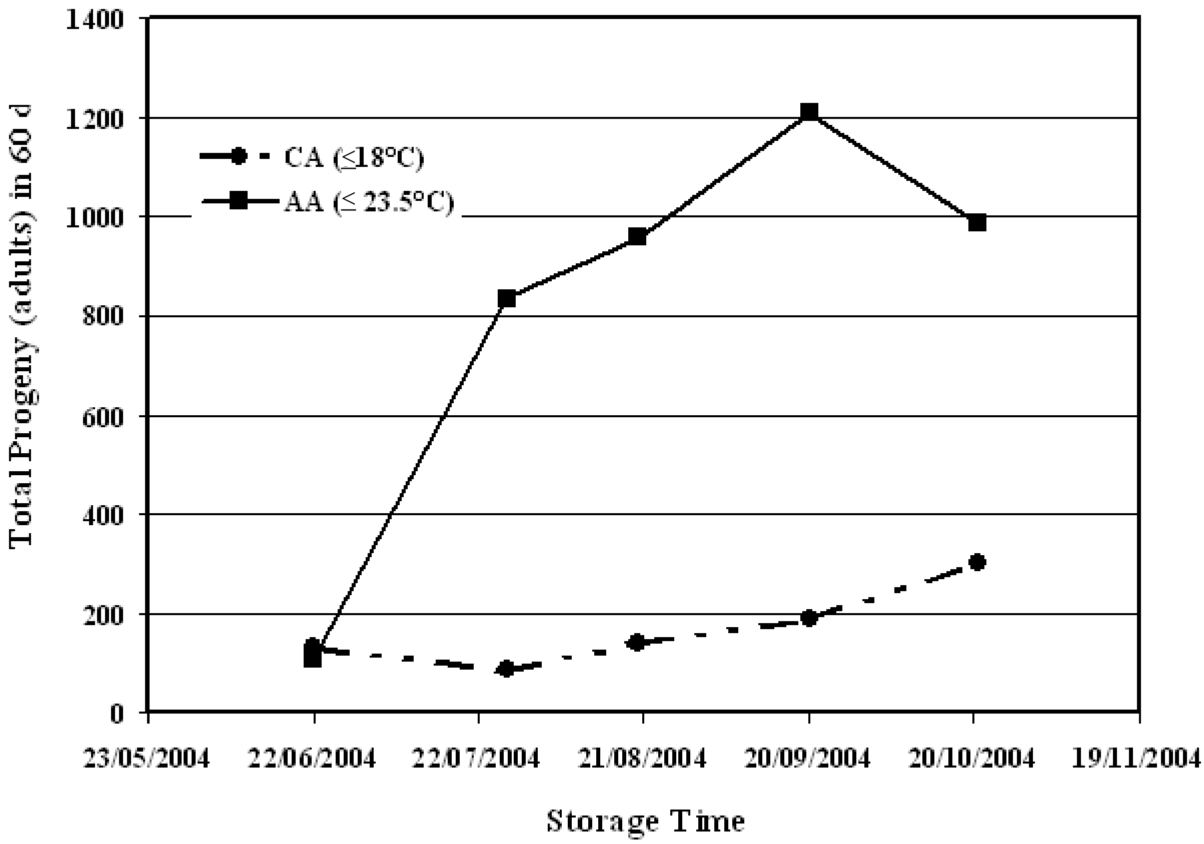

Figure 9. Progeny count of caged maize weevil for 2004.

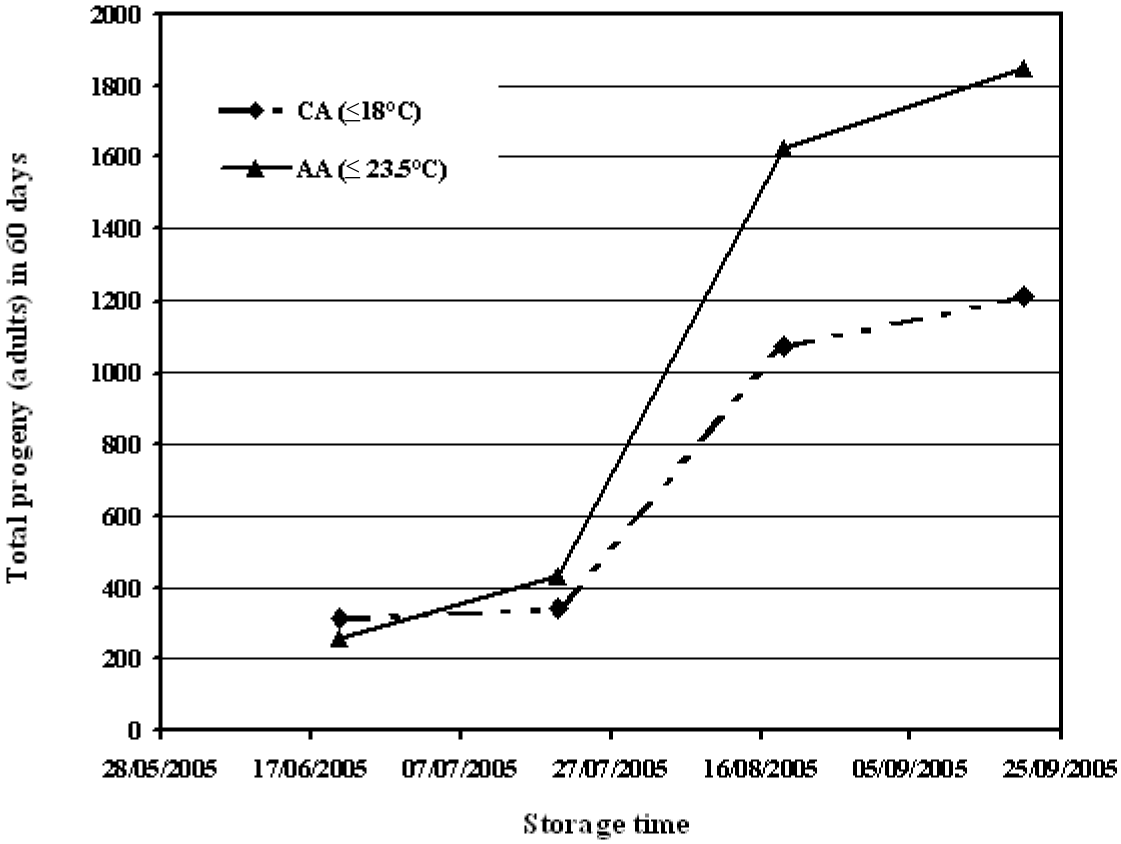

Figure 10. Progeny count of caged maize weevil for 2005.

Conclusions

Aeration by chilling the grain mass to = 18.0 °C proved to be consistently the more effective strategy compared to aeration using ambient air in terms of lower progeny recorded for both MW and RFB. This further proved that maintaining the grain bulk at lower temperatures reduces insect activity and minimizes population growth. Previous studies by McCune et al. (1963) and Noyes at al. (1987) suggested aeration to grain temperatures below 15.0 °C in order to suppress MW populations. Fields (1992) stated that 18.0 °C is the threshold temperature below which maize weevil reproduction is inhibited, which this study has further confirmed. For RFB, the minimum temperature is 22.0 °C (Zakladnoi and Ratanova, 1986 citing Houb's data, 1965), which is higher than for MW. This explains why less progeny was observed for RFB compared to MW under CA. AA resulted in higher grain temperatures than CA, though generally lower ones than NA, which did not effectively control progenies of MW and RFB. A possible cause for high progeny is aeration of warm grain with warm air, which can attract more insects because volatiles are released and carried out of the bin with the exhaust air stream. Aeration during the early summer season tends to increase the temperature of winter-cooled grain while non-aerated grain warms up slowly as a function of solar radiation and environmental influences.

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