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Chilled Versus Ambient Aeration and Fumigation of Stored Popcorn Part 2: Pest Management

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Abstract—During the summer of 1994, a prototype grain chiller was tested to determine its efficacy as a pest management tool and its economic competitiveness with conventional pest management techniques. Four popcorn bins (121.5 tonnes) at a commercial facility were utilized. Two bins were managed using traditional ambient aeration and fumigation. The remaining two bins were managed with chilled aeration. Insect probe, larval, and pheromone traps were placed in each bin and monitored weekly. Significantly fewer *Plodia interpunctella* (Hübner) were trapped in the chilled aeration bins compared to the traditionally managed popcorn bins. Very few insect species were found in the probe traps, with the exception of hairy fungus beetles, *Typhaea stercorea* (L.) in July and August. Fewer beetles were found in the chilled bins when compared to the traditionally managed bins. Costs of chilled aeration (0.11 cents/kg) were competitive with the costs of conventional pest management practices (fumigation and ambient aeration) (0.096–0.17 cents/kg). © 1997 Elsevier Science Ltd. All rights reserved

Key words—aeration, grain chilling, *Plodia interpunctella*, integrated pest management, *Typhaea stercorea*

INTRODUCTION

Grain starts deteriorating from the time of harvest, due to interactions between the physical, chemical and biological variables within the environment. One of these variables, insect infestation, creates numerous quality problems and causes substantial economic losses. Pest managers attempt to maintain grain quality through manipulation of the storage environment. Proactive management steps include sanitation, ambient aeration, and residual grain protectants. Fumigation can either be used as a preventative step prior to storage, or as a reactive measure to eliminate a pest problem. The application of a residual grain protectant is usually recommended for long-term storage (more than one-season).

The popcorn and food-grade maize industries have zero tolerance for insect activity. Consequently, storage bins are routinely fumigated on a calendar basis, regardless of the level of insect infestation. Thus, bins are potentially fumigated 3 or more times during a summer storage period. Additionally, aeration fans are operated manually during the summer months, or not operated at all after fall cool-down.

At a recent USDA workshop (June 1993, Crystal City, VA) on alternatives to methyl bromide, aeration (ambient and chilled) of stored grains, pulses, milled products, and animal feeds was rated as one of only four high-priority research areas (Anonymous, 1993). Although aeration, especially

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chilled aeration, is an existing technology, its utilization as a preventative pest management tool has not been fully investigated.

Insects are very sensitive to temperature changes in their environment (Mullen and Arbogast, 1984). Temperature fluctuations can influence insect population growth by reducing rates of development, survivorship, and age-specific fecundity (Hagstrum and Throne, 1989). Most stored grain insects will not lay eggs below 15°C, and eggs laid above 15°C will not hatch if the temperature falls to that level (Sinha and Watters, 1985). Larval development is also slowed in the range of 5–10°C and may result in death after a short period of time (Sinha and Watters, 1985). Conversely, insects thrive at temperatures above 29°C, and should reach threshold limits within a few months if no preventative measures are taken.

In temperate climates, grain managers can slow insect population growth by aeration with cool, ambient air (Cuperus *et al.*, 1986, 1990). During autumn harvest of grain, grain managers can utilize aeration fans during cool days or nights to remove the heat of drying or harvest. However, grain stored in tropical or temperate climates that is either harvested (wheat and rice) or stored (food maize and popcorn) over the summer, often cannot be cooled by aeration fans due to high ambient temperatures. Therefore, pest management is achieved by fumigation, chemical protectants, and/or aeration.

Numerous studies have examined the use of ambient aeration as a pest management tool (DeJean, 1992; Calderon, 1974; Armitage and Burrell, 1978; Bhatnagar and Bakshi, 1975; Burrell, 1967). In grain growing regions of the United States and Canada, most grain is cooled naturally, shortly after harvest. Fields (1990) found that if fall cooling occurred rapidly when insects had not been previously exposed to cool temperatures, all adult rusty grain beetles (*Cryptolestes ferrugineus* (Stephens)) were killed. Thus, rapid cooling of warm grain appears to prevent thermal acclimation by insects. Certain insect species may acclimatize rapidly to low temperatures, thus allowing them to survive. Evans (1979, 1983) examined the influence of thermal acclimation and humidity on the survivorship of several species of beetles. He found considerable interaction between temperature and humidity, as well as variation between insect species.

There are few published reports on the effectiveness of chilled aeration of grain, independent of ambient conditions (Burrell, 1974; Burrell and Laundon, 1967). Burrell (1967) achieved 97% control of *Sitophilus granarius* (L.) when infested barley was chilled to 3–4°C. Maier *et al.* (1996b) found that chilling maize was an effective management practice for Texas, Indiana, and S. Carolina, U.S.A., during times of the year when low ambient temperatures did not persist long enough to move a cooling front through the grain mass. Mason *et al.* (1994) found that chilled aeration was an effective pest management tool for stored maize when compared with either ambient aeration or fumigation. Populations of *Sitophilus* spp., *Oryzaephilus surinamensis* (L.), *Tribolium confusum* (Jac. du Val.), and *Typhaea stercorea* (L.) were significantly lower in the chilled aeration bins. The use of chilled aeration to maintain grain quality offers an effective and safe alternative to the use of chemical protectants and fumigants (Mason *et al.*, 1994; Maier, 1992, 1994). The purpose of this study was to determine the feasibility of using a prototype chilled aeration system to control pest populations in stored popcorn.

METHODOLOGY

Aeration

Studies were initiated during the summer of 1994 at a commercial popcorn facility. Four popcorn bins (121.5 tonne; 6.4 m diam.; 5.5 m eaves height) were utilized. Two bins (1 and 2) were managed with chilled aeration, and two bins (3 and 4) were managed with conventional methods (ambient aeration and fumigation). All bins, regardless of treatment, were fumigated prior to unloading, to assure that no insects were present in the packaging plant.

Temperature monitoring

Popcorn and headspace temperatures were recorded hourly, using commercial thermocouple cables connected to an automatic data logger (StorPerfect, ICS, Manitou Beach, MI). Each cable had six thermocouples at 1 m intervals. Each bin had two cables, one located 0.3 m from each south wall, and the other suspended at the center of each bin. The data logging system also recorded hourly ambient temperatures and r.h.

Treatment application

Chilled aeration treatments were applied to bins (1 and 2) based on a thermal threshold. Chilled aeration cycles occurred when grain temperatures along the peripheral wall exceeded 20°C (See Maier *et al.*, 1996a for details). Insect traps were not removed from the chilled aeration bins during chilling treatments.

Conventional bins (3 and 4) were managed by the commercial operator. This included decisions on when to fumigate and/or aerate. Fumigations were conducted during the weeks of 23 June and 5 August. Insect traps were removed from the conventional bins during fumigation treatments, and from all bins before fumigating at unloading. Bins were fumigated with phosphine for 3–4 d minimum, and then aerated. At the completion of aeration, the insect traps were replaced in the bins.

Study termination

The end of the storage season was determined by the processing schedule of the popcorn processing plant. Thus, aeration data were collected until 15 August (Maier *et al.*, 1996a) and pest management data until 25 August 1994.

Pest monitoring

Adult insect activity was monitored by placing nine insect probe traps just below (2.5 cm) the grain surface within each popcorn bin. One trap was placed in the center of the bin, while the remaining traps were placed either halfway to each wall or 0.3 m from each wall, at each cardinal compass point. Additionally, one commercially available Indian meal moth (*Plodia interpunctella* (Hübner)) pheromone trap (AgriSense Corp.) was placed within the headspace of each bin, and externally, approximately 1.5 m off the ground. Larval activity was determined by placing rolls of corrugated cardboard (10 × 30 cm, rolled lengthwise) just below the grain surface. Two rolls were placed 15 cm to either side of each probe trap. Paired rolls were connected to each other with a fluorescent string, 45 cm long.

Traps were monitored on a weekly basis, starting on 19 May 1994, and continuing through 25 August 1994. Insects were removed from the probe traps and placed in labeled plastic vials for later identification in the laboratory. Insects found in pheromone traps were also removed weekly, counted, and identified. Immature insects collected from cardboard rolls were fed ground dog food, and stored in an incubator at 30°C 14:10 L:D, until adult emergence, at which time identifications were made.

Weekly grain samples were taken at each grain probe trap location using a torpedo sampler. A deep sample was taken at a depth of approximately 1.8 m and a shallow sample at 0.9 m. Deep and shallow samples were pooled at each trap location to yield a composite sample. A 36–40 g subsample from each composite sample was placed into 1-quart glass jars. Jars were stored at 30°C 14:10 L:D. Four and six weeks after sampling, jars were examined for the presence of internal infesting insects and insect feeding or damage.

Data analysis

Trap data were analyzed using SAS (SAS Institute, 1988). Due to low grain probe trap catches for most species, no significant location effect was found ($P > 0.05$). Therefore, data from the nine trap locations within each bin were pooled before re-analysis. All data was subjected to an ANOVA and means were separated using a t-test. Significant levels were set at $P < 0.05$.

RESULT AND DISCUSSION

Costs of treatments

Aeration fans were operated 14 and 15 times for a total of 98 and 100 h for bins 3 and 4, respectively, during the summer storage period. Run times lasted from 2 to 24 h. The estimated energy consumption to operate the fans was 549 and 560 kWh for a cost at this site of $27.45 and $28.00, respectively. Thus, total aeration operating costs were $55.45, or 0.023 cents/kg of popcorn.

Table 1 summarizes the number of times the chiller was operated, the respective run times, the estimated energy consumption, and the costs to operate the chiller. In addition to the initial cooling in June, Bin 1 was rechilled once and Bin 2 twice. The total chilling hours for bins 1 and 2 were 306.4 and 280.7 h, respectively. The chilling costs were $260.75, or 0.11 cents/kg of popcorn. This is 4.7 times the cost of the ambient aeration expenses incurred in this experiment. However, the difference in hourly run time costs between the aeration fans versus the grain chiller is only 14 cents/h (i.e. 28 cents/h for the aeration fans versus 42 cents/h for the chiller based on connected kW-load). The costs for chilling could have been slightly reduced, if the first rechilling of Bin 2 had been avoided. It was initiated as a precaution because the chiller was scheduled to be shipped off to another site, and thus rechilling occurred prematurely. Additionally, rechilling efficiency can be improved if the 'partial rechilling' concept is implemented (see Maier *et al.*, 1996a for further discussion.).

Furthermore, the comparison between chilling and ambient aeration does not include the cost of fumigation. Fumigation costs were estimated by the commercial operator at 0.037–0.073 cents/kg (1–2 cents/bu). Thus, ambient aeration plus two fumigation treatments per bin cost approximately 0.096–0.17 cents/kg. This in turn makes chilled aeration competitive with the conventional pest management practices.

Pest numbers

Insect populations in all trap types (aerial, probe, larval) were very low through early summer (May and June). However, that did not prevent a fumigation treatment in the conventionally managed grain bins (Bins 3 and 4) on 24 June. Non-economically important insects trapped included *Cartodere* spp., Psocoptera, Acari, Collembola, and Miridae (Table 2). Like species of economic importance, these populations increased during the last two months of trapping (July and August). Typically, fewer insects were found in the chilled bins than the conventionally managed bins. Despite fumigation, numbers continued to increase after aeration of fumigated bins was completed. For example, a total of 94 Psocoptera were trapped in the conventionally managed bins prior to fumigation. The week after fumigation (week of 5 August), 167 were trapped (Table 2).

Hairy fungus beetles, *Typhaea stercorea*, were the most numerous stored product beetle trapped. One beetle was trapped in a chilled bin (Bin 1) on 29 June (Fig. 1). On 13 July, one beetle was trapped in a chilled bin (Bin 2) and in each of the conventionally managed bins (Bins 3 and 4). Significant differences in trap catch were found on 20 July through 3 August, after which conventionally managed bins were fumigated. When trapping resumed in the conventionally managed bins, higher numbers of hairy fungus beetles were found (Fig. 1). Within one week (17 August–25 August), trap catch increased almost 5 times in the conventionally managed bins, while in the chilled bins, trap catch doubled. On six of the eight sample dates when hairy fungus beetles were trapped, significantly more beetles were found in the conventionally managed bins (Bins 3 and 4) than in the chilled bins (Bins 1 and 2). On the remaining two sample dates, either no beetles were trapped in the conventionally managed bins due to trap removal for fumigation (10 August) or only 1 beetle was trapped, and that was in a chilled bin (30 June).

P. interpunctella, Indian meal moth, showed similar population growth trends to *T. stercorea*. Populations increased in both treatments during the month of July (Fig. 2). Trap catches in chilled bins ranged from 1 to 9 during July. In contrast, July trap catches in conventionally managed bins

Table 1. Operating times and energy costs of the prototype grain chiller during cooling and rechilling of the stored popcorn. (Local electricity costs are 5 cents/kWh)

Bin No.	Start Date	Run Hours	Energy, kWh	Costs, $	Load, kWh
2	6 June	85.2	835	41.75	9.8
2	27 June	45.0	413	20.65	7.2
2	18 July	150.5	1301	65.05	7.8
Subtotals		280.7	2549	127.45	8.2
1	20 June	145.6	1300	65.00	8.9
1	25 July	160.8	1366	68.30	8.5
Subtotals		306.4	2666	133.30	8.7
Totals		387.1	5215	260.75	Avg 8.4

Table 2. Miscellaneous insects found in insect probe traps (9 traps/bin) from both conventionally managed (ambient aeration and fumigation) and chilled aeration grain bins

Date	Species	Total Number Conventional	Chilled
5/26/94	*Cartodere* spp.	1	
6/16/94	Psocoptera	4	
	Acari	1	
6/23/94	Staphylinidae		1
	Carabidae		1
	Anthicidae	1	
	Psocoptera	3	
6/30/94	*Trogoderma* spp.		1
	Carabidae		2
	Staphylinidae		1
	Anthocoridae	1	
	Psocoptera	2	
7/7/94	Psocoptera	5	
	Anthicidae	1	
7/14/94	Carabidae		2
7/21/94	Psocoptera	23	17
	Collembola	1	
7/28/94	Psocoptera	95	55
	Collembola	8	
8/4/94	Psocoptera	94	37
	T. molitor	2	
8/11/94	Psocoptera		55
8/18/94	Psocoptera	167	58
8/25/94	*C. consticta*	9	
	Miridae	6	

ranged from 10 to 39. Trap catches in Bin 4 were twice as high as Bin 3 during the month of July. Due to the large variation between the two conventionally managed bins (Bins 3 and 4) during July, no significant differences between treatments (chilled versus conventional) were found, even though treatment means were numerically quite different (Fig. 2).

During August, significant differences between treatments were found during all three weeks that

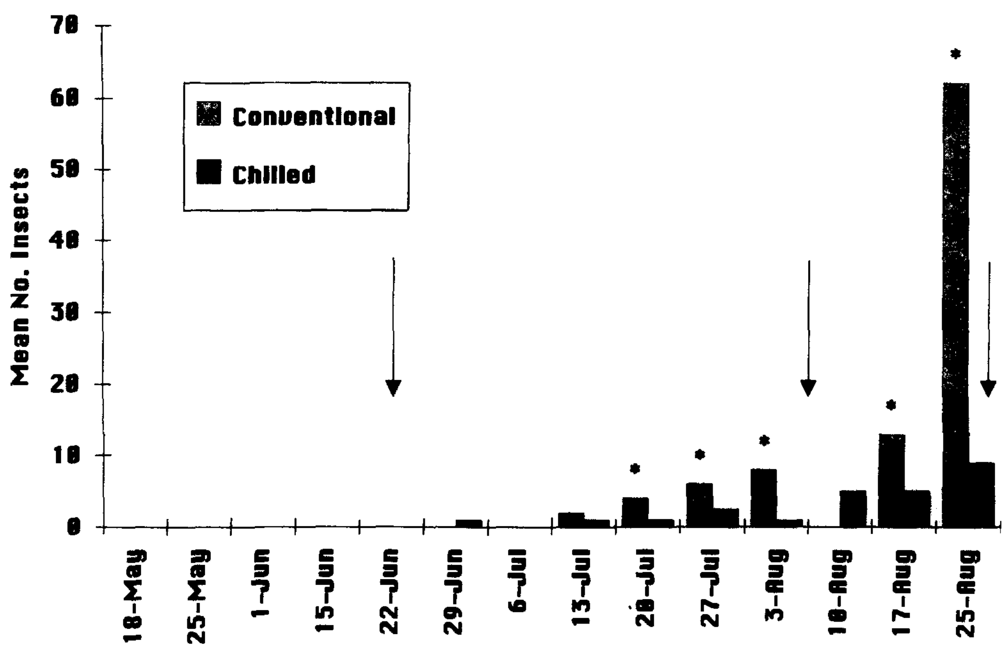

Fig. 1. Mean number of hairy fungus beetles, *Typhaea stercorea*, collected in grain probe traps (9 traps/bin) of conventional (ambient aeration and fumigation) and chilled aeration bins. Bars, by date, with asterisks are significantly different at the $P < 0.05$ level of significance. Arrows indicate fumigations.

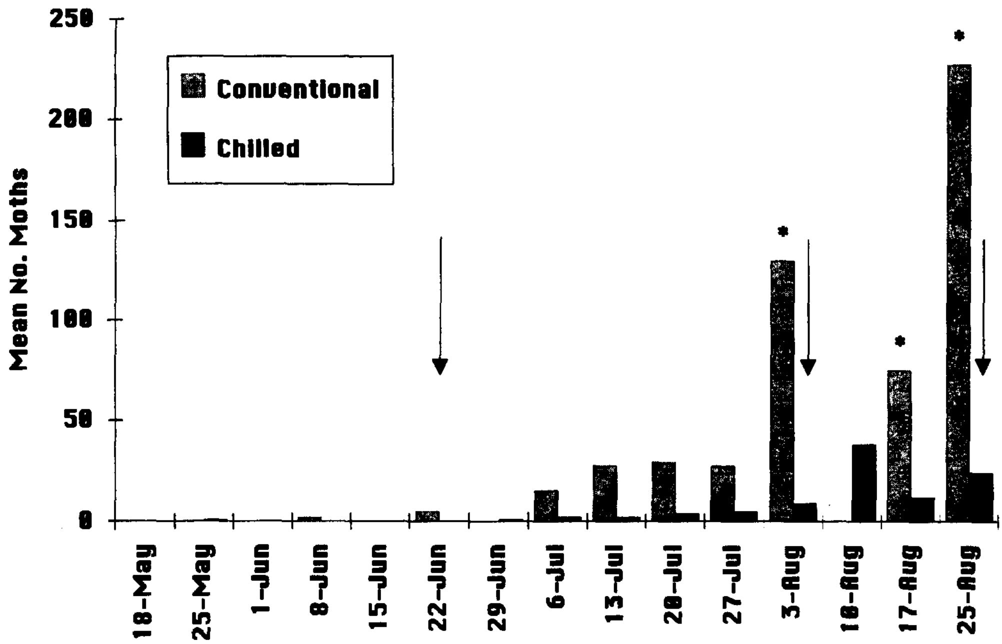

Fig. 2. Mean number of Indian meal moths, *Plodia interpunctella*, collected in pheromone baited traps (1 trap/bin) within the headspace of conventional (ambient aeration and fumigation) and chilled aeration bins. Bars, by date, with asterisks are significantly different at the $P < 0.05$ level of significance. Arrows indicate fumigations.

traps were in the four popcorn bins (Fig. 2). Tremendous populations of *P. interpunctella* were found in the conventionally managed bins, despite fumigation treatments. Differences found between treatments were not due to extreme temperature differences in the headspace (Fig. 3). Headspace temperatures decreased during chilling cycles, but rebounded quickly to near prechilling levels and were similar in the four bins. Average headspace temperatures in the chilled bins 1 and 2 were 21.5 and 21.8°C, respectively. In the conventional bins, the average temperatures were

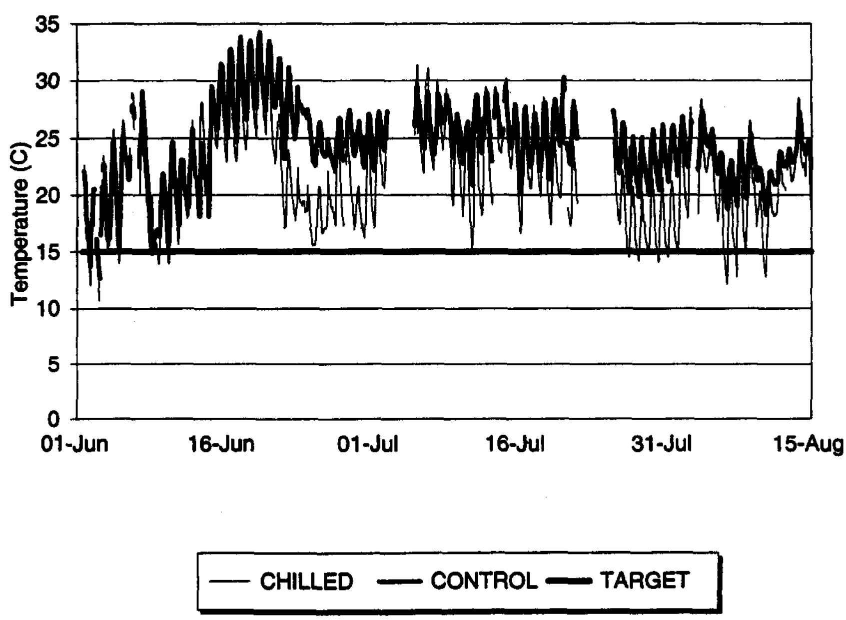

Fig. 3. A comparison of headspace temperatures for chilled bins versus conventional (ambient aeration and fumigation) managed bins. The grain target temperature line of 15°C was the temperature to which the grain bulk was to be chilled.

identical, i.e. 24.3°C. Headspace temperatures in the chilled bins ranged from 9.5 to 34.6°C, and in the conventional bins from 12.4 to 34.3°C.

Very few immature insects were found in the corrugated cardboard larval traps. *P. interpunctella* pupae were found on only three dates (21 July (2 pupae), 28 July (8 pupae) and 18 August (7 pupae)) in one of the two conventionally managed bins (Bin 3). No immature insects were found in the chilled bins or the other conventionally managed bin (Bin 4). It is unclear why no immature insects were found in Bin 4, as there were large numbers of adult moths in both bins 3 and 4. One possible reason for this is that although the total fan run times for the conventional bins were less than the chilled bins, fans in conventional bins were operated 14–15 times compared to the 2–3 times for the chilled bins. By running the fans more frequently, grain odor plumes were created more frequently around bin eaves, attracting the moths.

Based on the fact that very few immature *P. interpunctella* were found in all bins, and grain was in excellent condition when unloaded (no hot spots were found), it appears that both *P. interpunctella* and *T. stercorea* were therefore attracted to the popcorn, rather than breeding in high numbers within the bins. It appears that chilled aeration reduced the attractiveness of bins rather than modifing the population growth of the insects. This seems particularly true because the headspace and top layer of grain had similar temperatures in both types of bin (chilled aeration and conventionally managed). Thus, cooler grain temperatures prevent establishment of infestations, rather than limiting their increase. Additionally, warm grain would have more 'popcorn' odor than cold grain. There were no significant ($P > 0.05$) differences on any of the dates tested in the number of moths trapped in the outside pheromone traps. Thus, equal numbers of moths were potentially available to infest both types of bins. Research is continuing to investigate this possible explanation.

In conclusion, the use of chilled aeration significantly lowered pest populations when compared to conventionally managed bins. Despite fumigation and ambient aeration, *P. interpunctella* and *T. stercorea* populations continued to grow, while in chilled aeration bins, populations remained low. Although insects in the chilled bins were not prevented, levels were low enough to prevent the need for multiple summer fumigations. Energy costs of chilled aeration when compared to fumigation plus ambient aeration were comparable.

DISCLAIMER

Trade names are used in this study solely to provide specific information. Mention of a trade name does not constitute a warranty of the product by the authors nor by Purdue University, nor an endorsement of the product to the exclusion of other products not mentioned.

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