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Aeration Alone Versus Chlorpyrifos-Methyl Treatment Followed by Aeration for Wheat Stored in Georgia: Simulated Field Test

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J. Econ. Entomol. 88(6): 1764–1770 (1995)

ABSTRACT Wheat treated on 7 July with 6 ppm chlorpyrifos-methyl was artificially infested with lesser grain borer, *Rhyzopertha dominica* (F.), and rice weevil, *Sitophilus oryzae* (L.), and subsequently aerated when temperatures cooled, was compared with untreated wheat infested and aerated at the same conditions. Temperatures were monitored from 7 July to 5 April inside the bins and populations of the introduced species and a natural infestation of red flour beetle, *Tribolium castaneum* (Herbst), were assessed using probe traps and a grain trier. Average daily temperatures at 7 sample positions in untreated wheat were from 17.01 ± 0.53 to 21.46 ± 0.52°C, and were not significantly different from average temperatures at corresponding positions in treated wheat, which were from 16.00 ± 0.63 to 18.98 ± 0.60°C. Initial chlorpyrifos-methyl residue on treated wheat was 5.75 ± 0.51 ppm, but after 6 wk residues declined by 67.2–52.7%. Lesser grain borers collected from probe traps and trier samples were significantly more numerous in untreated wheat than in treated wheat on the 1st sample date (20 August); however, populations were larger in treated wheat on 2 later sample dates (12 November and 29 March). Few rice weevils or red flour beetles were collected from treated wheat. There was significantly more dockage (ground flour and insect frass) in untreated wheat than in treated wheat on 4 of 6 sample dates, while the percentage of insect-damaged kernels was significantly greater in untreated wheat than in treated wheat on all sample dates.

KEY WORDS lesser grain borer, rice weevil, red flour beetle, wheat, aeration, chlorpyrifos-methyl

WHEAT IS HARVESTED in the midwestern and north-central United States from July to September, depending on planting date, variety, and growing conditions. Chlorpyrifos-methyl is an organophosphate insecticide labeled as a protectant and is used when wheat is loaded into storage. Although this insecticide degrades rapidly at high temperatures and moisture contents (Desmarchelier and Bengston 1979; Arthur et al. 1991, 1992), residues may prevent economic damage from insect pests until ambient temperatures cool in the fall. Further cooling of bulk grain by mechanical aeration can reduce storage temperatures below the developmental thresholds for most insect pests, thereby limiting population growth for much of the storage period.

Soft red winter wheat, *Triticum aestivum* (L.), grown in Georgia is usually harvested from late May to mid-June (GAF 1993). Because favorable environmental conditions for insect pest population growth and development occur during the summer months, wheat is seldom held on-farm. Growers usually contract for a specific price at harvest, and both on-farm and commercial storages can be used temporarily until the wheat is transported to processing facilities. Chlorpyrifos-methyl can be used as a protectant, and wheat is often fumigated with phosphine before shipment.

Aeration is an important component for management of bulk corn and bulk wheat stored in the cooler regions of the United States, but is seldom used to manage insect pest populations in corn stored in the Southeast. However, even in the deep South judicious use of aeration during the winter can limit pest populations in stored corn (Arthur and Throne 1994, Arthur 1994b). Because wheat would be stored during the summer, traditional use of aeration to cool grain would have to be delayed until late September or early October.

Protectant insecticide treatment at the time wheat is loaded into storage combined with fall aeration is one integrated management strategy for wheat stored in Georgia. This method would give

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farmers the option of storing wheat for several months if they could obtain a more favorable price. The objective of this test was to compare aeration alone to protectant treatment with chlorpyrifos-methyl and subsequent aeration.

Materials and Methods

This study was conducted at ambient conditions at the Stored-Product Insects Research and Development Laboratory, Savannah, GA. Mixed-variety winter wheat purchased from a local granary was fumigated with phosphine to eliminate any hidden infestation. Six cylindrical steel bins were used in the test. Each bin had a top opening (60.96 cm in diameter), which was covered with a metal lid. The center setion was 60.96 cm high and 1.22 m in diameter. The bottom section tapered to a grain exit opening of 60.96 cm, which was covered by a flat plate. Aeration systems were constructed in each bin by first cutting a hole (10.16 cm diameter) in the top portion, and attaching a 1/125-hp Dayton 4C440 shaded pole blower so that the opening of the blower protruded inside the bin. A 21.9-cm vertical section of 10.16-cm-diameter PVC pipe was glued to the blower, and a 91.0-cm coiled section of perforated sewer pipe (10.16-cm-diameter) was attached to the bottom of the pipe. The end of the sewer pipe was plugged so that air was blown through the perforations.

Three bins containing untreated wheat were filled with ≈2,454.55 kg wheat each on 7 July. Of this amount, 136.36 kg were put in each bin so that the coiled pipe would lay flat, then the remaining wheat was loaded into the bins using a conveyor. Three bins were filled with wheat treated with a calculated dosage of 6.0 ppm chlorpyrifos-methyl. An insecticide delivery system equipped with a fan-tip Teejet nozzle 650033 (Spraying Systems, Wheaton, IL) was used to treat 272.72-kg lots by spraying the wheat as it fell from a chute into a hopper-bottom cart. The cart was carried outside by a forklift and emptied onto a conveyor belt. After the bins were filled, airflow rates were set at ≈0.065 CFM per 27.27 kg (1 bushel). All 6 aeration blowers were controlled by a thermostat, which was initially set at 18.3°C. The activation temperature was periodically lowered during storage as follows: from 29 September to 27 October, 15.5°C; 27 October to 1 November, 12.8°C; 1 November to 1 March, 7.2°C; 1 March to 5 April, 10.0°C.

Temperatures in the bins were monitored and recorded using Omnidata 800 series Easy Loggers (Omnidata, Logan, UT). Probes were placed in the following approximate positions: bottom center, 15.24 cm from the bottom opening midway between the sides; midsouth, 5.08–10.16 cm from the south side wall and 60.96 cm from the surface; midcenter, 60.96 cm deep midway between the sides; midnorth, 5.08–10.16 cm from the north side wall and 60.96 cm deep; top south, 5.08–10.16 cm from the side wall and 5.08 cm deep; midcenter, 5.08 cm deep midway between the sides, and top north, 5.08–10.16 cm from the north side wall and 5.08 cm deep.

Each bin was infested on 7 July by introducing ≈1,000 1- to 2-wk-old adult *Rhyzopertha dominica* (F.) and ≈1,000 1- to 2-wk-old adult *Sitophilus oryzae* (L.) into the top surface of each bin. On 20 August the untreated wheat was sampled by using a standard 5.9-cm cup grain trier (Seedboro, Chicago, IL) to remove a 250-g sample from the approximate position of the temperature probes. Moisture content was determined using a Burrows DMC-1000 computer (Seedboro). The sample was sieved, live insects were tabulated and discarded, and the amount of dockage (ground flour and insect frass) in the sample was weighed. A 100-kernel subsample was examined for insect damaged kernels, then weighed on a balance. The sampling process was repeated for the 3 bins containing treated wheat. A 2nd 250-g sample was taken and held at −17.5°C until analyzed for chlorpyrifos-methyl residue. A generalized procedure for organophosphates was used to quantify chlorpyrifos-methyl residues (Arthur et al. 1988). After trier samples were taken, a WB Probe II plastic pitfall trap (Gustafson, Plano, TX) was placed in the same 7 sample locations within each bin. After 1 wk the traps were removed and live insects were tabulated and discarded. The sampling process was repeated on 29 September, 12 November, 28 December, 15 February, and 29 March. A natural infestation of the red flour beetle, *Tribolium castaneum* (Herbst), was detected on the 1st sample date, and data for this species were included with the 2 introduced species. Additional introductions of the lesser grain borer and the rice weevil were not necessary because the substantial populations in the untreated bins provided an ample source for reinfestation.

The means procedure of the statistical analysis system (SAS Institute 1987) was used to average the hourly temperatures recorded by each probe as one daily value. Data for untreated and treated bins were averaged and plotted using SigmaPlot software (Jandel Scientific Corte Madera, CA). Data for insect species and damage estimates were analyzed by sample position and by treatment using the GLM and T-test procedures in SAS. (SAS Institute 1987). Correlations were determined using the correlation procedure.

Results

Plots of average daily temperature were similar for untreated bins and treated bins during the 271-d storage period (Fig. 1). All graphs show the initial activation of the aeration system in late September. There were no differences in average temperature at the 7 sample positions between untreated bins and treated bins (Table 1), however maximum and minimum temperatures for each

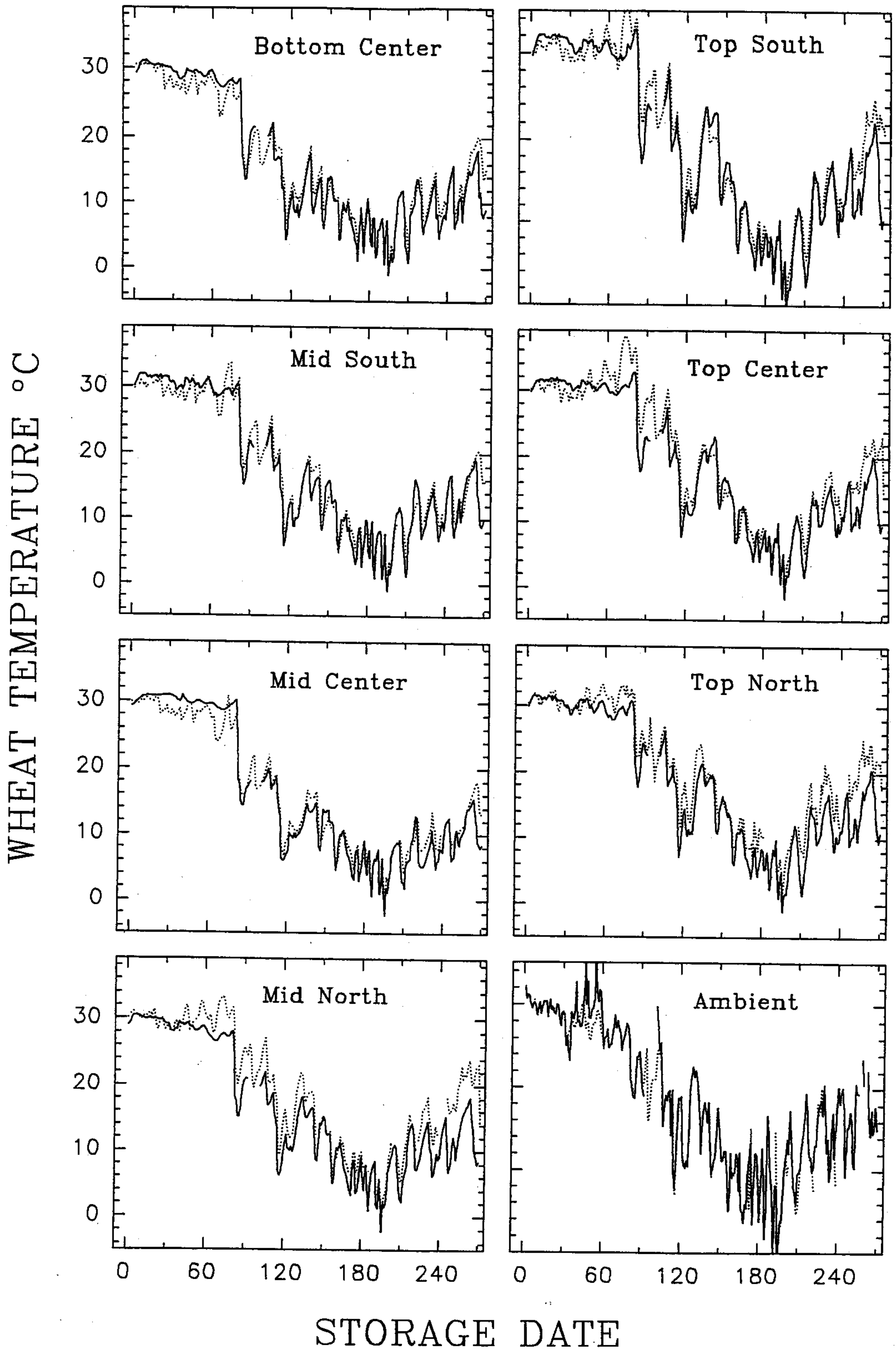

Fig. 1. Average daily temperatures at 7 probe positions in aerated untreated wheat (. . .. . .) and aerated wheat treated with chlorpyrifos-methyl (—), plus average daily ambient temperature outside 1 aerated and 1 unaerated bin. Wheat was stored from 7 July to 5 April.

Table 1. Average
each of 7 probe posi

Probe position	
Bottom center	17.
Midsouth	18.
Midcenter	17.
Midnorth	20.
Top south	20.
Top center	21.
Top north	21.
Ambient	19.

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Table 2. Average
wheat sampled duri

Position	
Bottom center	2.7
Midsouth	2.3
Midcenter	1.8
Midnorth	2.4
Top south	2.3
Top center	2.3
Top north	2.2

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[1987]).

Table 3. Average number ± SEM of lesser grain borers, rice weevils, and red flour beetles collected at each sample position in trier sample and probe traps in untreated wheat and treated wheat

Position	Untreated		Treated	
	Trier sample	Probe trap	Trier sample	Probe trap
		Lesser grain borer		
Bottom center	5.0 ± 2.46b	3.3 ± 1.57b	9.8 ± 7.47c	5.2 ± 2.26b
Midsouth	2.3 ± 1.70b	0.9 ± 0.29b	2.8 ± 1.66c	3.6 ± 1.97b
Midcenter	7.5 ± 2.79b	21.2 ± 7.00b	18.3 ± 9.16bc	8.2 ± 3.05b
Midnorth	3.8 ± 1.33b	5.0 ± 2.05b	10.4 ± 6.01c	13.4 ± 5.00b
Top south	3.5 ± 1.42b	2.4 ± 0.70b	13.7 ± 6.26c	43.5 ± 22.63ab
Top center	97.9 ± 33.46a	174.9 ± 66.38a	51.7 ± 13.47a	93.9 ± 40.27a
Top north	25.6 ± 6.92b	59.7 ± 19.81b	41.5 ± 12.78ab	92.1 ± 43.84a
		Rice weevil		
Bottom center	0.7 ± 0.35b	1.3 ± 0.45c	0.0 ± 0.00a	0.0 ± 0.00a
Midsouth	5.2 ± 2.92ab	1.5 ± 0.52c	0.0 ± 0.00a	0.0 ± 0.00a
Midcenter	3.8 ± 2.31b	6.0 ± 3.81bc	0.0 ± 0.00a	0.0 ± 0.00a
Midnorth	1.5 ± 0.79b	2.1 ± 0.75bc	0.0 ± 0.00a	0.0 ± 0.00a
Top south	3.2 ± 0.96b	11.7 ± 3.52bc	0.0 ± 0.00a	0.1 ± 0.06a
Top center	9.1 ± 2.41a	26.9 ± 10.18a	0.0 ± 0.00a	0.1 ± 0.11a
Top north	5.1 ± 1.18ab	15.6 ± 5.17ab	0.1 ± 0.05a	0.1 ± 0.11a
		Red flour beetle		
Bottom center	0.3 ± 0.14c	1.2 ± 0.23b	0.0 ± 0.00a	0.1 ± 0.05b
Midsouth	0.0 ± 0.00c	0.9 ± 0.37b	0.0 ± 0.00a	0.0 ± 0.00b
Midcenter	0.6 ± 0.31c	5.3 ± 2.57b	0.0 ± 0.00a	0.0 ± 0.00b
Midnorth	0.4 ± 0.20c	4.0 ± 2.72b	0.0 ± 0.00a	0.1 ± 0.05b
Top south	3.5 ± 1.13bc	8.9 ± 3.16b	0.1 ± 0.05a	0.1 ± 0.05b
Top center	26.4 ± 6.58a	125.0 ± 33.17a	0.0 ± 0.00a	0.6 ± 0.28a
Top north	7.7 ± 1.64b	22.8 ± 6.23b	0.0 ± 0.00a	0.5 ± 0.32ab

Means within columns followed by the same letter are not significantly different ($P \geq 0.05$, Waller–Duncan k ratio t-test, SAS Institute [1987]).

in the weight of the 100-kernel subsamples between untreated wheat and treated wheat.

Discussion

The rapid degradation of organophosphates such as chlorpyrifos-methyl may limit their effectiveness as protectants for wheat stored during the summer, especially in Georgia. In this test residue loss after 6 wks of storage was from 52.7 to 67.2% of the original deposition of 5.75 ppm. Average daily temperature during this time was ≈30°C, and controlled environment studies with chlorpyrifos-methyl on corn and wheat document increased degradation at storage temperatures of 30°C or more (Arthur et al. 1991, 1992). Application of chlorpyrifos-methyl prevented rice weevils and red flour beetles from establishing infestations even though residues declined during the storage period. However, lesser grain borer populations were

Table 4. Total number ± SEM of lesser grain borer, rice weevils, and red flour beetles collected in trier samples or probe traps from untreated wheat and treated wheat

Sample type	Treatment	Sample date					
		20 Aug.	29 Sept.	12 Nov.	28 Dec.	15 Feb.	29 Mar.
				Lesser grain beetle			
Trier	Untreated	12.3 ± 5.4	75.7 ± 30.1	10.9 ± 4.6	6.9 ± 2.5	7.4 ± 4.0	11.7 ± 4.3
	Treated	0.0 ± 0.0*	32.6 ± 9.7*	24.8 ± 7.6*	24.8 ± 7.6	20.8 ± 8.3	42.8 ± 14.4*
Probe	Untreated	134.0 ± 54.0	80.2 ± 29.5	5.8 ± 2.0	0.3 ± 0.1	1.7 ± 1.0	7.9 ± 2.1
	Treated	3.9 ± 1.5*	55.0 ± 17.0	88.9 ± 40.6*	2.2 ± 0.9*	8.3 ± 4.6*	64.4 ± 33.2*
				Rice weevil			
Trier	Untreated	3.9 ± 2.0	5.0 ± 2.5	7.6 ± 1.9	3.3 ± 1.3	1.0 ± 0.4	3.6 ± 1.2
	Treated	0.0 ± 0.0*	0.0 ± 0.0*	0.0 ± 0.0*	0.0 ± 0.0*	0.0 ± 0.0*	0.0 ± 0.0
Probe	Untreated	6.2 ± 1.1	5.7 ± 2.7	18.0 ± 8.7	3.3 ± 2.3	1.7 ± 1.0	20.9 ± 5.8
	Treated	0.0 ± 0.0*	0.0 ± 0.0*	0.1 ± 0.1*	0.0 ± 0.0*	0.1 ± 0.1*	0.0 ± 0.0*
				Red flour beetle			
Trier	Untreated	1.0 ± 0.3	3.9 ± 1.6	6.2 ± 3.0	8.7 ± 5.1	7.6 ± 3.8	6.0 ± 1.8
	Treated	0.0 ± 0.0*	0.0 ± 0.0*	0.0 ± 0.0*	0.0 ± 0.0*	0.0 ± 0.0*	0.0 ± 0.0*
Probe	Untreated	16.9 ± 8.3	34.5 ± 15.3	32.0 ± 24.8	1.3 ± 0.6	4.3 ± 1.9	54.9 ± 19.9
	Treated	0.7 ± 0.3*	0.0 ± 0.0*	0.1 ± 0.1*	0.0 ± 0.0*	0.0 ± 0.0*	0.2 ± 0.1*

*, Average of each species in untreated versus treated wheat was significantly different ($P < 0.05$, PROC t-test, SAS Institute [1987]).

Table 5. Moisture (ground flour and inse percentage of insect-d subsample, and weight sample positions (all v

Measurement Position
Moisture content Bottom cent Midsouth Midcenter Midnorth Top south Top center Top north
Dockage weight Bottom cent Midsouth Midcenter Midnorth Top south Top center Top north
Damaged kernels Bottom cent Midsouth Midcenter Midnorth Top south Top center Top north
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Table 5. Moisture content and dockage weight (ground flour and insect frass) in 250-g wheat samples, percentage of insect-damaged kernels in a 100 kernel subsample, and weight of that subsample for each of 7 sample positions (all values totaled over sample date)

Measurement	Position	Untreated	Treated
Moisture content	Bottom center	12.5 ± 0.11a	12.7 ± 0.11a
	Midsouth	12.4 ± 0.07a	12.5 ± 0.07a
	Midcenter	12.4 ± 0.12a	12.6 ± 0.09a
	Midnorth	12.5 ± 0.09a	12.6 ± 0.09a
	Top south	11.7 ± 0.11b	12.7 ± 0.08b
	Top center	10.8 ± 0.11c	11.6 ± 0.11c
	Top north	11.4 ± 0.11b	11.7 ± 0.08c
Dockage weight	Bottom center	2.9 ± 0.72b	1.6 ± 0.87a
	Midsouth	0.6 ± 0.07cd	0.3 ± 0.16a
	Midcenter	2.7 ± 0.39b	1.5 ± 0.54a
	Midnorth	1.9 ± 0.42bc	1.5 ± 0.63a
	Top south	0.3 ± 0.04d	0.2 ± 0.03a
	Top center	5.8 ± 0.95a	0.9 ± 0.30a
	Top north	1.7 ± 0.48bcd	0.8 ± 0.31a
Damaged kernels	Bottom center	7.0 ± 1.37bc	2.7 ± 1.18a
	Midsouth	6.0 ± 0.80cd	0.9 ± 0.50a
	Midcenter	9.8 ± 1.58b	4.1 ± 1.65a
	Midnorth	5.7 ± 1.01cd	3.5 ± 1.19a
	Top south	2.9 ± 0.32d	0.6 ± 0.24a
	Top center	18.9 ± 1.99a	3.6 ± 0.74a
	Top north	6.8 ± 1.20bc	3.2 ± 1.03a
Wt of 100 kernels	Bottom center	2.8 ± 0.05a	2.7 ± 0.04a
	Midsouth	2.8 ± 0.04a	2.7 ± 0.03a
	Midcenter	2.8 ± 0.04a	2.7 ± 0.02a
	Midnorth	2.8 ± 0.04a	2.8 ± 0.04a
	Top south	2.6 ± 0.04b	2.7 ± 0.04a
	Top center	2.4 ± 0.03c	2.7 ± 0.03a
	Top north	2.5 ± 0.04b	2.7 ± 0.03a

Means within columns followed by the same letter are not significantly different ($P \geq 0.05$, Waller–Duncan k ratio t-test [SAS Institute 1987]).

abundant in untreated wheat and wheat treated with chlorpyrifos-methyl.

Pyrethroid chemicals may be more effective than organophosphates for wheat stored in warm climates. Although no pyrethroids are currently registered in the United States, developmental studies with deltamethrin and cyfluthrin indicate excellent potential for use as grain protectants. Residues of deltamathrin and cyfluthrin applied at 0.5 ppm will protect stored wheat from lesser grain borers for ≈10 mo, but at least 1.0 ppm is required to give equivalent control of rice weevils (Arthur 1994 a and c). Combination treatments of chlorpyrifos-methyl + either deltamethrin or cyfluthrin are also effective (Arthur 1994a, c).

Aeration will suppress insect infestations but may not completely eliminate existing infestations. Studies by Burrell (1967), Armitage and Stables (1984), and Armitage and Llewellin (1987) on wheat stored in Great Britain showed that aeration controlled populations of the granary weevil, *Sitophilus granarius* (L.), but did not eliminate populations of the sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.), even when aeration was used during the winter months. Surveys of wheat storages in Oklahoma indicated aeration reduced populations of several beetle species, however fumigation was occasionally necessary to control infestations even when aeration was used (Cuperus et al. 1986). In my test, insect populations were reduced during the winter but quickly increased in response to temperature increases.

Wheat stored in Georgia is extremely vulnerable to insect infestation because of the extended summer storage period. Chlorpyrifos-methyl treatment will prevent rice weevils and red flour beetles from becoming established but may not prevent population growth and development of the lesser grain borer should infestations occur. Aeration cannot be effectively used until late September or early October. Proper monitoring of insect populations to determine the necessity of fumigation or controlled atmosphere treatments during the summer should be a component of management programs. If additional pyrethroid protectants are labeled for use on stored wheat, adequate protection during storage may be achieved without fumigation.

Acknowledgments

I thank M. Cooper, G. M. Murray, and J. E. O'Bryan for their technical assistance. Gustafson, Incorporated provided the chlorpyrifos-methyl used in this study. I also

Table 6. Moisture content and dockage weight (ground flour and insect frass) in 250-g wheat samples, percentage of insect-damaged kernel in a 100-kernel subsample, and weight of that subsample for each of 6 sample dates (all values totaled over sample position)

Measurement	Treatment	Sample date: 20 Aug.	29 Sept.	12 Nov.	28 Dec.	15 Feb.	29 Mar.
Moisture content	Untreated	12.5 ± 0.14	12.1 ± 0.19	11.8 ± 0.19	11.7 ± 0.16	12.0 ± 0.11	11.7 ± 0.13
	Treated	12.7 ± 0.16	12.3 ± 0.12	12.0 ± 0.12	12.3 ± 0.13*	12.2 ± 0.07	12.1 ± 0.12*
Dockage wt	Untreated	0.4 ± 0.08	2.1 ± 0.90	2.7 ± 0.60	2.5 ± 0.34	3.3 ± 0.68	2.8 ± 0.54
	Treated	0.0 ± 0.00*	0.1 ± 0.03*	0.7 ± 0.02*	1.0 ± 0.37*	2.1 ± 0.70	1.9 ± 0.67
% damaged kernels	Untreated	1.7 ± 0.35	4.3 ± 1.23	8.0 ± 1.57	9.2 ± 1.20	11.9 ± 1.46	13.9 ± 1.54
	Treated	0.0 ± 0.0*	0.5 ± 0.18*	1.3 ± 0.39*	2.7 ± 0.73*	4.8 ± 1.26*	6.6 ± 1.40*
Wt of 100 kernels	Untreated	2.6 ± 0.06	2.6 ± 0.05	2.7 ± 0.05	2.7 ± 0.06	2.7 ± 0.05	2.6 ± 0.05
	Treated	2.7 ± 0.04	2.7 ± 0.04	2.8 ± 0.03	2.8 ± 0.03	2.7 ± 0.03	2.6 ± 0.02

*, Average in untreated versus treated wheat was significantly different ($P < 0.05$, PROC t-test, [SAS Institute 1987]).

thank L. J. Mason and J. D. Sedlacek for reviewing the manuscript.

References Cited

Armitage, D. M., and L. M. Stables. 1984. Effects of aeration on established insect infestations in bins of wheat. Prot. Ecology 6: 63–76.

Armitage, D. M., and B. E. Llewellin. 1987. The survival of *Oryzaephilus surinamensis* (L.) (Coleoptera: Curculionidae) in aerated bins of wheat during British winters. Bull. Entomol. Res. 77: 457–466.

Arthur, F. H. 1994a. Efficacy of unsynergised deltamethrin and deltamethrin + chlorpyrifos-methyl combinations as protectants of stored wheat. J. Stored Prod. Res. 30: 87–94.

1994b. Feasibility of using aeration to control insect pests of corn stored in southeast Georgia: simulated field test. J. Econ. Entomol. 87: 1359–1365.

1994c. Efficacy of cyfluthrin applied with and without piperonyl butoxide and piperonyl butoxide + chlorpyrifos-methyl for protection of stored wheat. J. Econ. Entomol. 87: 1707–1713.

Arthur, F. H., and J. E. Throne. 1994. Pirimiphos-methyl degradation and insect population growth in aerated and unaerated corn stored in southeast Georgia: small bin tests. J. Econ. Entomol. 87: 810–816.

Arthur, F. H., L. M. Redlinger, and R. A. Simonaitis. 1988. Chlorpyrifos-methyl as a protectant of farmers stock peanuts. Peanut Sci. 15: 15–18.

Arthur, F. H., J. E. Throne, and R. A. Simonaitis. 1991. Chlorpyrifos-methyl degradation and biological efficacy toward maize weevils (Coleoptera: Curculionidae) on corn stored at four temperatures and three moisture contents. J. Econ. Entomol. 84: 1926–1932.

1992. Degradation and biological efficacy of chlorpyrifos-methyl on wheat stored at five temperatures and three moisture contents. J. Econ. Entomol. 85: 1994–2002.

Burrell, N. J. 1967. Grain cooling studies II: effect of aeration on infested grain bulks. J. Stored Prod. Res. 3: 145–154.

Cuperus, G. W., C. K. Prickett, P. D. Bloome, and J. T. Pitts. 1986. Insect populations in aerated and unaerated stored wheat in Oklahoma. J. Kans. Entomol. Soc. 59: 620-626.

Desmarchelier, J. M., and M. Bengston. 1979. The residual behaviour of chemicals on stored grain, pp. 138–151. *In* Proceedings, 2nd International Working Conference on Stored-Product Entomology, Ibadan, Nigeria. USDA, Savannah, GA.

[GAF] Georgia Agricultural Facts. 1983. Georgia Agricultural Statistics Service, Athens, GA.

SAS Institute. 1987. SAS statistics guide for personal computers, 6th ed. SAS Institute, Cary, NC.

Received for publication 13 March 1995; accepted 14 June 1995.