Degradation and Efficacy of Deltamethrin + Chlorpyrifos-methyl and Cyfluthrin + Chlorpyrifos-methyl as Protectants of Wheat Stored in Southeast Georgia[1]

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ABSTRACT Soft red winter wheat (27.27 kg replicates) treated with combinations of deltamethrin + chlorpyrifos-methyl, with and without piperonyl butoxide, and cyfluthrin, applied alone or with either chlorpyrifos-methyl or piperonyl butoxide, was stored from 15 May 1992 to 9 February 1993 (6 chemical treatments and an untreated control). Each replicate was artificially infested with 50 adult lesser grain borers, *Rhyzopertha dominica* (Fab.), and 50 adult rice weevils, *Sitophilus oryzae* (L.), upon initial storage, sampled with probe traps at monthly intervals, and subsequently reinfested. Trap catch of lesser grain borer was always 0, except for two traps at month 4 that contained one adult in each trap. Maximum population levels of rice weevil and a natural infestation of the red flour beetle, *Tribolium castaneum* (Herbst), occurred at month 5. Trap catch of these two species in the chemical treatments averaged 2.2 to 34.0 and 0.0 to 19.5 live adults per trap, respectively. From months 4 to 9, the percentage of insect-damaged kernels averaged 4.0 to 5.5% in wheat treated with 0.25 ppm deltamethrin + 6.0 ppm chlorpyrifos-methyl + 4.0 ppm piperonyl butoxide. Maximum kernel damage in the other chemical treatments was 3.2%.

KEY WORDS Deltamethrin, cyfluthrin, chlorpyrifos-methyl, wheat, storage, insects.

Georgia is one of the leading producers of soft red winter wheat in the United States (U. S. Department of Agriculture 1994). Harvest occurs from mid-May to late June, with actual harvest date dependent on local conditions (Georgia Department of Agriculture 1994). Wheat can be stored on-farm for a short time before being transported to mills. Little extended storage occurs on-farm, but there are some commercial facilities that store wheat through the summer into the winter months.

Two of the most important beetle pests of stored wheat are the lesser grain borer, *Rhyzopertha dominica* (Fab.), and the rice weevil, *Sitophilus oryzae* (L.). Both of these species are internal feeders that cause serious economic damage in stored wheat. The organophosphate malathion is being removed from the post-harvest

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market as a result of reregistration requirements of the U. S. Environmental Protection Agency (Abramson 1991). When this process is completed the organophosphate insecticide chlorpyrifos-methyl will be the only labeled protectant of stored wheat.

Deltamethrin and cyfluthrin are two pyrethroids being evaluated for registration in the United States. Arthur (1994a) noted that application rates of 0.5 and 0.75 ppm deltamethrin on wheat killed all introduced lesser grain borer for 10 months, but the rice weevil survived exposure. Similar results were observed for tests with 0.5 and 1.0 ppm of cyfluthrin (Arthur 1994b). The objective of this study was to determine biological efficacy of deltamethrin applied with and without piperonyl butoxide and cyfluthrin applied alone or combined with either chlorpyrifos-methyl or piperonyl butoxide.

Materials and Methods

Mixed-variety soft red winter wheat purchased from a local granary was fumigated with phosphine to kill any hidden infestation, then held at 4°C until used for the experiment. Seven insecticide treatments were evaluated: (1) untreated controls, (2) 0.25 ppm deltamethrin + 4.0 ppm piperonyl butoxide + 6.0 ppm chlorpyrifos-methyl (the label rate for chlorpyrifos-methyl), (3) 0.5 ppm deltamethrin + 6.0 ppm chlorpyrifos-methyl, (4) 1.0 ppm cyfluthrin + 6.0 ppm chlopyrifos-methyl, (5) 1.0 ppm cyfluthrin + 4.0 ppm piperonyl butoxide, (6) 2.0 ppm cyfluthrin + 6.0 ppm chlorpyrifos-methyl, and (7) 2.0 ppm cyfluthrin. Insecticide spray solutions were prepared from emulsifiable concentrates of deltamethrin (60 mg AI/mL), cyfluthrin (240 mg AI/mL), piperonyl butoxide (960 mg AI per ml), and chlorpyrifos-methyl (480 mg AI/mL) obtained from Gustafson (Plano, TX).

The wheat was treated using an insecticide delivery system equipped with a Teejet nozzle # 650033 (Spraying Systems, Wheaton, IL). Each of four control replicates was sprayed with 18.9 mL distilled water per 27.27 kg of wheat (60 lbs. 1 bushel). Each of four treatment replicates was applied at the rate of 18.9 mL of formulated spray per 27.27 kg of wheat, which is equivalent to the field spray rate for chlorpyrifos-methyl. Each individual replicate was sprayed as wheat fell from a conveying chute into a metal container, and each replicate was in turn emptied into a 0.042 m^3 cardboard box.

Immediately after each treatment replicate was completed, a 400-ml beaker was used to remove approximately 320 g wheat from each box. The wheat was placed in a covered 0.95-liter jar (28 jars total) and a core sample was taken from the center of the jar using a 10.54 cm $\times$ 2.54 cm diameter cylinder. One hundred kernels from this core sample were examined for insect damage. The boxes of wheat were transported to an insulated metal shed and each box was infested with 50 1- to 2-week-old adult lesser grain borers and 50 1-to 2-week-old adult rice weevils obtained from pesticide-susceptible cultures maintained at the laboratory.

After approximately 1 month (8 June) 320 g wheat was removed from each box for damaged kernel estimates in the manner described above, and a Storegard WB Probe II plastic pitfall trap (Gustafson, Plano, TX) was placed in the center of each box to assess insect populations. After 1 wk the traps were removed, all live insects of each species were tabulated and returned to the box from which they were trapped, and each box was reinfested with 50 adult lesser grain borers and

50 adult rice weevils as described above. The entire sampling process was repeated at 2 months (9 July), 3 months (7 August), 4 months (8 September), 5 months (8 October), 6 months (9 November), and 9 months (9 February). Traps were always left in the box for 1 wk, and after the traps were removed the boxes were reinfested.

Daily temperature and relative humidity in the storage shed were plotted using Sigma Plot software. Data for trap catch and insect-damaged kernels were analyzed as a repeated measures test, with treatment as the main effect and month as the repeated measure using the General Linear Models (GLM) Procedure (SAS Institute 1987). The GLM Procedure also was used to determine model significance and estimate means and standard errors for trap catch for each species and the percentage of insect-damaged kernels on each sample date. After 1 month a natural infestation of red flour beetle, *Tribolium castaneum* (Herbst), was detected in the wheat. Data for the red flour beetle were included with the results for the lesser grain borer and the rice weevil.

Raw data for insect populations and the percentage of insect-damaged kernels in each treatment were transformed by taking the square root of each observation to stabilize variances. The GLM Procedure was used to perform contrast analyses on the following six treatment comparisons: untreated controls versus chemical treatments, 0.25 ppm deltamethrin + 4.0 ppm piperonyl butoxide + 6.0 ppm chlorpyrifos-methyl versus 0.50 ppm deltamethrin + 6.0 ppm chlorpyrifos-methyl, 1.0 ppm cyfluthrin + 4.0 ppm piperonyl butoxide versus 1.0 ppm cyfluthrin + 6.0 ppm chlorpyrifos-methyl, 1.0 ppm cyfluthrin + 6.0 ppm chlorpyrifos-methyl versus 2.0 ppm cyfluthrin + 6.0 ppm chlorpyrifos-methyl, 2.0 ppm cyfluthrin + 6.0 ppm chlorpyrifos-methyl versus 2.0 ppm cyfluthrin, and 0.50 ppm deltamethrin + 6.0 ppm chlorpyrifos-methyl versus 2.0 ppm cyfluthrin + 6.0 ppm chlorpyrifos-methyl.

Results and Discussion

Average daily temperature in the storage shed exceeded 25° C for the first 130 days of storage (15 May to 23 September) except for 4 days in May and 3 days in June (Fig. 1A). During October (day 138 to day 168) temperatures ranged from 16 to 25° C, but after 5 November (day 173) the average daily temperature exceeded 20° C on just 9 days. Average relative humidity fluctuated from day to day, with no consistent pattern during storage (Fig. 1B).

Main effect treatment and repeated measures month and treatment × month interaction were significant for trap catch of the lesser grain borer, the rice weevil, the natural infestation of the red flour beetle, and the percentage of insect-damaged kernels (Table 1). With one exception, trap catch for the lesser grain borer was always 0 at each sample date for each of the six chemical treatments (Table 2). Lesser grain borers in untreated controls increased after 2 months (July), declined then increased again at months 5 and 6 (Oct and Nov). Population levels declined again during the winter, possibly because the cooler weather limited insect movement and reduced trap catch. Contrasts were not reported because of the obvious significance between treatments and controls due to the 0 values in the treatments.

Trap catch of the rice weevil in untreated controls and chemical treatments increased to maximum levels at month 5 and month 6, then declined as

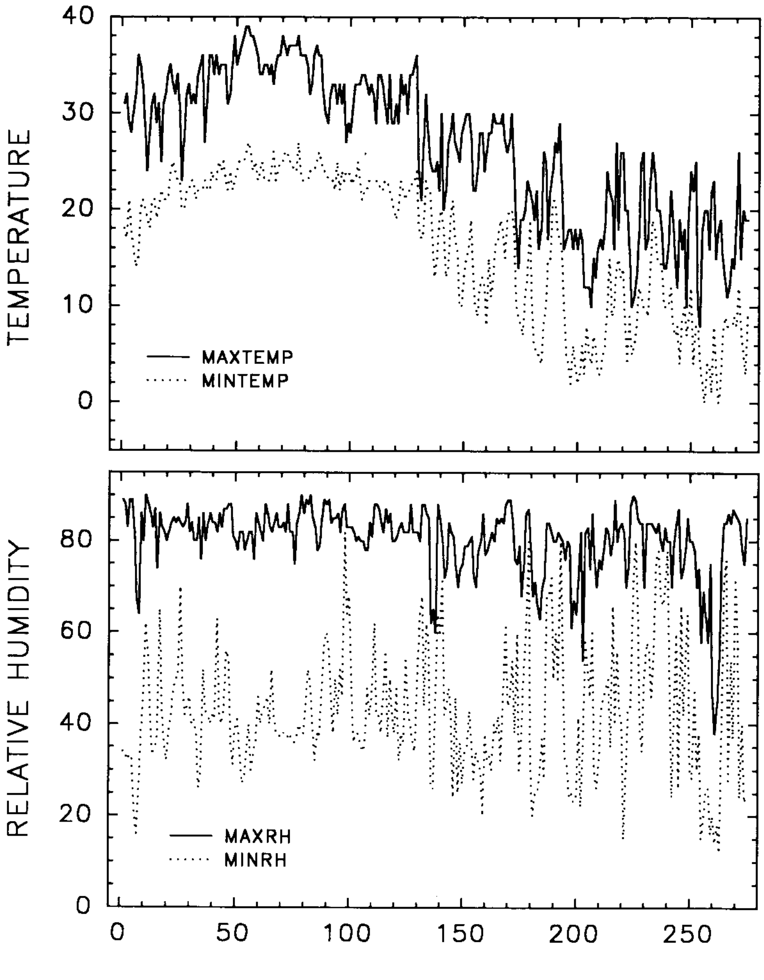

Fig. 1. Daily average temperatures (A) and relative humidity (B) in the storage facility.

temperatures dropped during late fall and winter (Table 2). Average trap catch in untreated controls at month 5 was 201.7 ± 122.7, while average trap catch in the chemical treatments ranged from 2.2 ± 1.6 in wheat treated with 2.0 ppm cyfluthrin + 6.0 ppm chlorpyrifos-methyl to 34.0 ± 17.6 in wheat treated with 1.0 ppm cyfluthrin + 6.0 ppm chlorpyrifos-methyl. Contrasts between untreated controls and chemical treatments were significant at each month (P = 0.0001). Significant contrasts in the chemical treatments occurred at month 4 between 0.25 ppm deltamethrin + 4.0 ppm piperonyl butoxide + 6.0 ppm chlorpyrifos-methyl versus 0.50 ppm deltamethrin + 6.0 ppm chlorpyrifos-methyl (P = 0.0026) and between 1.0 ppm cyfluthrin + 6.0 ppm chlorpyrifos-methyl versus 2.0 ppm

Table 1. Analyses of variance for trap catch of the lesser grain borer (LGB), the rice weevil (RW), the red flour beetle (RFB), and the percentage of insect-damaged kernels (IDK). Treatment and replicates are whole-plot treatments and time is a repeated measure.

Insect	Source	df	ms	F	$P > F$
LGB	replicate	3	3.1	1.1	0.3715
	Treatment	6	408.1	148.1	0.0001
	rep × treatment (a)	18	2.7		
	month	6	9.2	2.8	0.0149
	month × treatment	36	9.3	2.8	0.0001
	model residual (b)	126	3.3		
RW	replicate	3	827.2	1.5	0.8181
	Treatment	6	3419.6	637.4	0.0001
	rep × treatment (a)	18	535.7		
	month	6	79288.4	29.7	0.0001
	month × treatment	36	61699.0	23.1	0.0001
	model residual (b)	126	2667.6		
RFB	replicate	3	1.4	1.4	0.2457
	Treatment	6	896.4	896.4	0.0001
	rep × treatment (a)	18	1.0		
	month	6	179.6	128.2	0.0001
	month × treatment	36	116.3	83.8	0.0001
	model residual (b)	126	1.4		
%IDK	replicate	3	0.9	4.4	0.0056
	Treatment	6	201.9	1029.3	0.0001
	rep × treatment (a)	18	0.6		
	month	6	18.8	95.8	0.0001
	month × treatment	36	5.4	27.7	0.0001
	model residual (b)	126	0.2		

Table 2. Average trap catch (mean ± SEM) for the lesser grain borer (LGB), the rice weevil (RW), and the red flour beetle (RFB) in untreated wheat and chemical treatments (D = deltamethrin, PB = piperonyl butoxide, CM = chlorpyrifos-methyl, and CY = cyfluthrin, all numerical values are ppm calculated application rate)*.

		Storage Month						
Spp.	`Treatment	1	2	3	4	5	6	9
LGB	controls	22.5 ± 5.9	235 .2 ± 164.0	57.0 ± 14.5	78.5 ± 9.9	235.2 ± 21.3	244.0 ± 136.1	60.5 ± 15.1
	0.25 D + 4.0 PB + 6.0 CM	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
RW	controls	1.5 ± 0.5	7.0 ± 0.9	94.0 ± 20.0	169.7 ± 12.7	201.7 ± 122.7	573.0 ± 87.8	331.5 ± 69.3
	0.25 D + 4.0 PB + 6.0 CM	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	5.0 ± 1.3	23.7 ± 10.7	12.5 ± 7.3	1.5 ± 0.6
	0.50 D + 6.0 CM	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.2	8.5 ± 3.5	2.0 ± 1.1	0.0 ± 0.0
	1.0 CY + 4.0 PB	0.0 ± 0.0	0.2 ± 0.2	1.0 ± 0.6	5.5 ± 1.0	24.5 ± 9.9	8.2 ± 4.0	1.0 ± 0.7
	1.0 CY + 6.0 CM	0.0 ± 0.0	1.2 ± 0.7	1.5 ± 1.0	14.5 ± 5.5	34.0 ± 17.6	24.5 ± 14.1	1.2 ± 0.9
	2.0 CY + 6.0 CM	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.3	1.7 ± 0.7	2.2 ± 1.6	3.0 ± 1.2	0.5 ± 0.5
	2.0 CY	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	3.2 ± 1.9	12.0 ± 2.5	10.5 ± 2.5	0.2 ± 0.2
RFB	controls	0.0 ± 0.0	4.5 ± 1.5	52.2 ± 14.3	278.7 ± 9.3	1235.0 ± 73.5	1271.7 ± 179.5	162.7 ± 25.1
	0.25 D + 4.0 PB + 6.0 CM	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	5.5 ± 1.7	8.7 ± 4.8	1.0 ± 0.7	0.2 ± 0.2
	0.50 D + 6.0 CM	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.0 ± 0.7	1.2 ± 0.5	0.0 ± 0.0	0.0 ± 0.0
	1.0 CY + 4.0 PB	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	4.0 ± 1.1	4.0 ± 2.1	0.2 ± 0.2	0.2 ± 0.2
	1.0 CY + 6.0 CM	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	16.2 ± 8.7	19.5 ± 11.2	2.7 ± 1.9	0.2 ± 0.2
	2.0 CY + 6.0 CM	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.2 ± 0.7	0.0 ± 0.0	0.5 ± 0.3	0.0 ± 0.0
	2.0 CY	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.5 ± 1.0	0.2 ± 0.2	0.0 ± 0.0	1.5 ± 1.2

*Trap catch was always 0 in unreported chemical treatments.

cyfluthrin + 6.0 ppm chlorpyrifos-methyl were also significant (P = 0.0039). No other contrasts were significant ($P > 0.05$).

Even though the red flour beetle infestation was natural and not introduced with the other two species, trap catch in untreated controls increased to maximum levels at months 5 and 6, then apparently declined during the winter (Table 2). Trap catch in the 1.0 ppm cyfluthrin + 6.0 ppm chlorpyrifos-methyl treatment averaged 16.2 ± 8.4 and 19.5 ± 11.2 at months 4 and 5, respectively. Maximum trap catch in all other chemical treatments was 8.7 ± 4.8 (Table 2). Contrasts between untreated controls and chemical treatments were not significant at month 1 ($P > 0.05$) but were significant at each month thereafter (P = 0.0001). Significant contrasts among chemical treatments occurred at month 4 between 1.0 ppm cyfluthrin + 4.0 ppm piperonyl butoxide versus 1.0 ppm cyfluthrin + 6.0 ppm chlorpyrifos-methyl (P = 0.0164) and between 1.0 ppm cyfluthrin + 6.0 ppm chlorpyrifos-methyl versus 2.0 ppm cyfluthrin + 6.0 ppm chlorpyrifos-methyl (P = 0.0032). The contrast between 1.0 ppm cyfluthrin + 6.0 ppm chlorpyrifos-methyl versus 2.0 ppm cyfluthrin + 6.0 ppm chlorpyrifos-methyl was also significant at month 5 (P = 0.0035). No other contrasts were significant ($P > 0.05$).

Insect-damaged kernels in the untreated controls exceeded 50% by month 3 and leveled above 90% from months 5-9 (Table 3). No damaged kernels were detected in the chemical treatments for 3 months, except for one sample in the 1.0 ppm cyfluthrin + 6.0 ppm chlorpyrifos-methyl treatment. From months 4 to 9 insect-damaged kernels in wheat treated with 0.25 ppm deltamethrin + 4.0 ppm piperonyl butoxide + 6.0 ppm chlopyrifos-methyl ranged from 4.0 ± 2.0 to 5.5 ± 3.6%, while damage in the remaining treatments did not exceed 3.2%. Contrasts between controls and treatments were significant at each month (P = 0.0001). Contrasts between 0.25 ppm deltamethrin + 4.0 ppm piperonyl butoxide + 6.0 ppm chlorpyrifos-methyl versus 0.50 ppm deltamethrin + 6.0 ppm chlorpyrifos-methyl were significant at months 4, 5, 6, and 9 (P = 0.0092, 0.0348, 0.0176, and 0.0206, respectively). No other contrasts were significant ($P > 0.05$).

Once malathion is removed from the post-harvest market in the United States, chlorpyrifos-methyl will be the only labeled protectant for stored wheat. This insecticide breaks down rapidly on wheat stored at temperatures of 30° C or more (Desmarchelier and Bengston 1979, Arthur et al. 1992). Because daytime temperatures in this range are common in south Georgia from late May to early September, residual degradation during the summer months could limit the efficacy of chlorpyrifos-methyl. In addition, populations of the lesser grain borer in the midwestern United States have developed resistance to chlorpyrifos-methyl (Zettler and Cuperus 1990). The lesser grain borer has been removed from the list of species controlled by chlorpyrifos-methyl, as specified by the label on the formulation.

Pyrethroids may be more effective than chlorpyrifos-methyl as protectants for wheat stored in warm climates because they are more stable at high temperatures. However, the rice weevil apparently has some tolerance to pyrethroids. Application rates of bioresmethrin (Arthur 1992), resmethrin (Arthur 1992), tralomethrin (Halliday et al. 1992), deltamethrin (Arthur 1994a), and cyfluthrin (Arthur 1994b) that give residual control of the lesser grain borer will not control rice weevil. Combination treatments of pyrethroids + chlorpyrifos-methyl are an effective alternative to higher rates of pyrethroids for controlling both the lesser grain borer and the rice weevil in stored wheat.

Table 3. Average percentage insect-damaged kernels (mean ± SEM) in untreated wheat and chemical treatments (D = deltamethrin, PB = piperonyl butoxide, CM = chlorpyrifos-methyl, and CY = cyfluthrin, all numerical values are ppm calculated application rate).

	Storage Month						
`Treatment	1	2	3	4	5	6	9
controls	1.5 ± 0.3	27.5 ± 1.6	54.5 ± 3.2	83.5 ± 1.5	95.0 ± 0.9	98.5 ± 0.3	99.5 ± 0.3
0.25 D + 4.0 PB + 6.0 CM	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	4.0 ± 2.0	4.2 ± 2.6	5.0 ± 3.0	5.5 ± 3.6
0.5 D + 6.0 CM	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.5	0.2 ± 0.2	0.0 ± 0.0
1.0 CY + 4.0 PB	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.4	0.7 ± 0.2	1.5 ± 0.3	1.5 ± 0.3
1.0 CY + 6.0 CM	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.2	2.0 ± 1.4	2.2 ± 1.6
2.0 CY + 6.0 CM	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
4.0 CY	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.2	2,0 ± 0.7	2.0 ± 0.7	3.2 ± 1.0

Any insecticide or insecticide combination to be used on stored wheat in Georgia must control insects during the extended summer, when temperatures are conducive to rapid population development. Even though the combination with 0.25 ppm deltamethrin was sufficient to kill the majority of the introduced insect species, some feeding damage may have occurred before the insects died in the wheat. An application rate of 0.50 ppm deltamethrin combined with chlorpyrifos-methyl may be the minimum requirement for complete control of insects in wheat stored through the summer months in Georgia. An application rate of 1.0 ppm cyfluthrin combined with chlorpyrifos-methyl will also give sufficient control.

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