Pirimiphos-Methyl and Thiabendazole Impact on the Quality of On-Farm Stored Shelled Corn[1]

Bryan D. Price, John D. Sedlacek and Paul A. Weston

Community Research Service, Kentucky State University, Frankfort, KY 40601 USA

J. Entomol. Sci. 34(2): 225-238 (April 1999)

Abstract A study was conducted to examine the ability of Actellic® (pirimiphos-methyl, ICI Americas, Wilmington, DE), an organophosphorous insecticide, and Mertect® 340-F (thiabendazole, Merck and Co., Inc., Rahway, NJ), a benzimidazole fungicide, to preserve the quality of shelled corn stored for an extended duration in metal grain bins. Treatments included application of pirimiphos-methyl, thiabendazole, pirimiphos-methyl and thiabendazole combined, and untreated control. Corn samples of 0.3 liter were taken bi-monthly with a deep-bin cup probe and kept frozen until processed. Quality parameters examined included total insect contaminants (numbers of insects and insect fragments), numbers of insect-damaged kernels, percent fines, and numbers of kernels with visible fungal growth. Suppression of insects and fungi by Actellic or Mertect was evident, but the overall quality of the corn was not consistently improved by their application.

Key Words Insecta, stored grain, pirimiphos-methyl, thiabendazole.

In Kentucky, corn (*Zea mays* L.) not sold soon after harvest is normally stored on-farm for a period of months or even years (Barney et al. 1989). During storage, the grain may sustain damage and deteriorate due to the presence of a complex of various insect and fungal pests. In addition to damaging the kernels, insect infestation and fungal infection may create foul odors, a loss in nutritive value, or result in the production of mycotoxins, a health hazard to livestock and humans (Sanchis et al. 1982). As a means of preserving the quality of stored corn destined for sale, growers often use insecticides to control insect infestation and maintain moisture contents <15% (w/w) to manage fungal contamination.

Mertect® 340-F (thiabendazole) is a benzimidazole fungicide produced by Merck and Co. (Rahway, NJ). Thiabendazole was first described as an antihelminthic (Brown et al. 1961) and has been used to protect various fruits and vegetables from fungal damage (Eckert and Sommer 1967). It has been very effective in preventing post-harvest damage in oranges (El-Refai et al. 1982, Gutter 1970), potatoes (Cayley et al. 1979), apples (Monico-Pifarre and Xirau-Vayreda 1987), and even in controlling Sclerotinia dollar spot in turfgrass (Goldberg et al. 1970). In a previous laboratory study (Gabal 1987), the fungicidal effect of thiabendazole varied from complete suppression to variable growth inhibition when screened against several species of mycotoxigenic fungi commonly found in stored feeds and grain. Although not labeled for protection of stored grain, Mertect 340-F has been tested in the laboratory for its ability to protect

[1]Received 11 September 1997; accepted 19 July 1998.

high moisture bin-stored corn. Emergency use permits were granted for Mertect 340-F in Illinois and Missouri (Smith 1986).

Actellic® 5E (pirimiphos-methyl, ICI Americas, Wilmington, DE) is an organophosphorous insecticide that is registered for use against stored-product insects of corn and grain sorghum (Anon 1996) and has been proven to successfully control these pests (LaHue 1975, LaHue and Dicke 1977a, b, Arthur 1995). Despite increasing consumer concern about presence of pesticide residues in foods and evidence documenting insect resistance (Arthur et al. 1988), pirimiphos-methyl is perceived to be a replacement for malathion and will continue to be used as a grain protectant. Used widely for many years, malathion has a well-documented history of resistance development (Zettler 1982, Horton 1984) and will not be re-registered for use in stored grains.

The quality of corn is measured by several parameters. These parameters include, but are not limited to, percentage of fines, broken kernels and foreign material, percentage of insect and fungal damaged kernels and weight per cubic meter (Manis 1992). The objective of this study was to determine the effects of pirimiphos-methyl and thiabendazole on the numbers of insects and insect parts present in a given sample, insect-damaged kernels, fines, and kernels with visible fungal growth in stored corn.

Materials and Methods

Binning and treatment. The corn used in the study, 'Dekalb 689', was grown at the Kentucky State University Agricultural Research Farm, Franklin Co., KY, and harvested in November 1989 at approximately 20% moisture content. Seven m^3 (i.e., 200 bu) of corn were placed into each of 12 bins (10.6 m^3 capacity). Treatments were applied at the time of binning using a loading auger fitted with injection ports equipped with disc-core nozzles and a spray metering system consisting of a peristaltic squeeze pump and conventional hydraulic sprayer (Paul's Machining and Welding, Villa Grove, IL). One-fourth of the corn was treated with thiabendazole at a rate of 0.12 liter per 3.5 m^3 (19 ppm), one-fourth was treated with pirimiphos-methyl at a rate of 0.36 liter per 35.2 m^3 (8.6 ppm), one-fourth was treated with both pesticides, and the remaining one-fourth was treated with water only. Treatments were arranged in a randomized complete block design. The corn was dried in the bins to approximately 15% moisture content using standard aeration fans to push ambient air through the grain masses.

Sampling procedures. Corn was sampled bi-monthly using a deep-bin cup probe 35.6 cm in length. Samples, 0.3 liters in volume, were taken 30 cm from the top and bottom of the grain masses 15 cm from the north and south bin walls, as well as from the center of the grain masses. North and south samples were combined for quality analyses, resulting in three samples per bin. Temperatures were recorded at five locations (0.3 and 1.5 m deep north and south, 0.9 m deep center) in each grain mass at the time of sampling using Type T thermocouples and a hand-held reader (Omega Engineering Inc., Stamford, CT.)

Each corn sample was sifted through a No. A round commercial sieve (0.48 cm); fines were collected in a pan. The fines and the remainder of each sample were weighed, and fines were examined for insect contaminants (whole insects and insect parts). Percent fines were calculated based on the ratio of fine weight to the weight of the whole sample. One hundred kernels were randomly selected from each sample, and the number of insect-damaged kernels and kernels with visible fungal growth were quantified. Subsamples were removed for pesticide residue analyses and moisture content determination. Prior to pesticide residue analyses, corn was ground to pass through a number 20 mesh. Pirimiphos-methyl residues were isolated by extracting ground corn (50 g) with 1:4 acetone:hexane (150 ml), partitioning the extractant (combined with 100 ml of additional solvent used to wash the extracted corn) against water (150 ml), and then partitioning the hexane layer against acetonitrile (2 × 150 ml). After reducing the volume of acetonitrile to 30 ml, 5% Na_2SO_4 (100 ml) was added; this mixture was partitioned against hexane (2 × 100 ml). The hexane was then reduced to 10 ml, and pirimiphos-methyl was quantified using gas chromatography (GC) (HP Model 5890 Series II GC equipped with a 30m × 0.25mm HP-5 column, carrier gas He @ 2 ml/min, FID detection at 250°C, oven programmed from 80°C [1 min initial hold] up to 240°C @ 15/min). Thiabendazole residues were determined by mixing ground corn (25 g) with water (150 ml), 1N H_2SO_4 (25 ml), and 0.1N HCl (20 ml), and digesting them on a steam bath for 2 h. After cooling, pH was adjusted to 4.0 to 4.5 with 2N sodium acetate, and a diastase suspension (0.15 g diastase in 2 ml water) was added. Following incubation overnight at 45°C, a portion of each sample (15 g) was combined with NaCl (3 g), 2N sodium acetate (5 ml), and ethyl acetate (10 ml). After shaking for 10 min, samples were centrifuged and the ethyl acetate layer was removed. The sample was extracted twice more with ethyl acetate (2 × 10 ml), and the three ethyl acetate portions were combined. The combined ethyl acetate was cleaned up by successively partitioning against 2N NaOH (10 ml) and water (10 ml) plus NaCl (3 g), then partitioned against 0.1N HCl (2 × 10 ml). The combined acid layers were then mixed with 2N NaOH (1 ml), 2N sodium acetate (3 ml) and ethyl acetate (20 ml), shaken, and centrifuged. Finally, the ethyl acetate layer (5 ml) was shaken with 0.1N HCl (5 ml), and the thiabendazole concentration in the acid layer was determined with a Turner Model 430 spectrofluorometer (excitation wavelength = 300 nm, emission wavelength = 360 nm [G. K. Turner Associates, Palo Alto, CA]). Moisture contents were obtained by drying samples in an oven at 100°C for 3 d and calculating the dry weight/wet weight ratio.

Statistical analyses. Data were analyzed with repeated measures analysis of variance (ANOVA) and least significant difference (LSD) tests by the general linear models procedure of the Statistical Analysis System (SAS Institute 1988). Analyses were performed to determine differences among treatment combinations and among different locations within the bins. Insect, insect damaged kernels, and fungal infection data were log transformed [log (x + 1)] before analysis, but means presented are untransformed.

Results and Discussion

Grain temperature remained consistent among treatments (Fig. 1a), as well as at different sampling depths during the study (Fig. 1b). Moisture content also was consistent among treatments except in April 1991, when corn in bins treated with pirimiphos-methyl and pirimiphos-methyl + thiabendazole had moisture contents 1 to 2 percentage points higher than the other treatments (Fig. 2a). Moisture content at the top of the bins was approximately 3 percentage points higher than at the bottom of the bins at the beginning of the study (Fig. 2b). The moisture contents converged during the middle of the period, although the top of the grain mass always had a higher moisture content. Between April and December 1991, moisture contents again di-

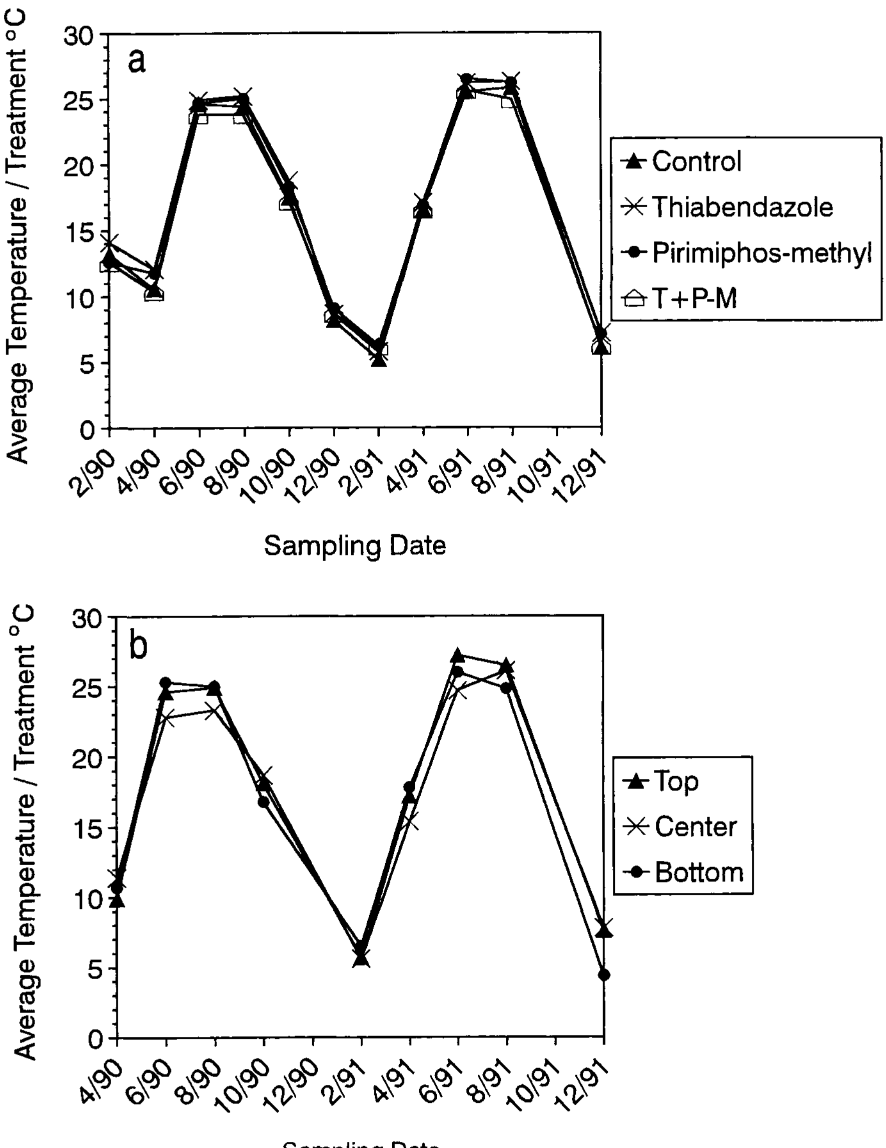

Fig. 1. Mean temperature (°C) for treatments (a) and depths (b) in bin-stored corn treated with pirimiphos-methyl, thiabendazole, both pesticides combined, or control.

verged to a point where the top was about 2 percentage points higher in December (Fig. 2b).

Initial residues of pirimiphos-methyl were within recommended rates (6 to 8 ppm) for use in shelled corn in the pirimiphos-methyl-treated bins, but slightly lower (5.2

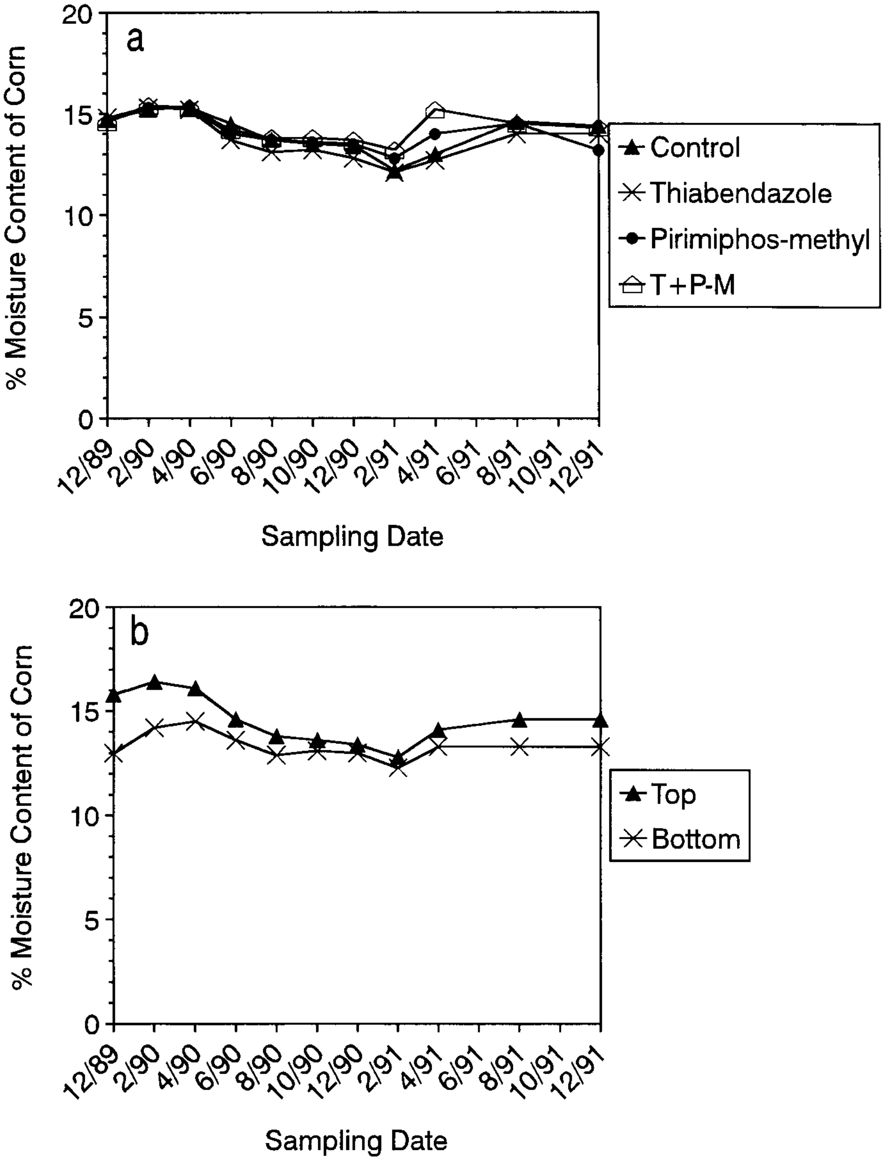

Fig. 2. Mean grain moisture content (%) for treatments (a) and sample depths (b) in bin-stored corn treated with pirimiphos-methyl, thiabendazole, both pesticides combined, or control.

ppm) in the bins treated with pirimiphos-methyl and thiabendazole. Residues were below recommended levels by August 1990. Thiabendazole residues were somewhat lower than the recommended rate of 19 ppm (13 to 16 ppm), but has been found to inhibit fungal growth at rates as low as 10 ppm (Gabal 1987).

Variability of parameters related to presence of insects was large, which resulted in detection of only a limited number of statistically significant differences among grain treatments (Table 1). However, the trend for insect contamination or damage followed the expected pattern after the fourth sampling date (June 1990). Grain treated with pirimiphos-methyl or pirimiphos-methyl and thiabendazole frequently had the lowest values for number of insect contaminants (Table 2), and insect-damaged kernels (Table 3), whereas control grain typically had the highest values. The number of insect contaminants increased substantially after the fourth sampling date. Some minor deviations from this pattern were observed (e.g., June and August, 1991), but were probably the result of low numbers of samples. Fines, which would be expected to increase during the storage period, primarily as a result of insect feeding, were relatively consistent among treatments throughout the study (Table 4). The only significant difference in percentage of fines occurred in August 1991 ($F = 3.08$; df = 3, 28; $P = 0.04$), when grain treated with pirimiphos-methyl plus thiabendazole had the lowest percentage.

Visible fungal growth consisted almost entirely of either *Penicillium* spp. and/or *Aspergillus glaucus* Link:Fr., both of which cause "blue-eye" in kernels, but incidence was almost uniformly contrary to expectation. From the tenth month of storage (October 1990) onward, except for June 1991, grain treated with pirimiphos-methyl plus thiabendazole was most often contaminated with visible fungal growth (Table 5). Surprisingly, control grain had very low levels of visible fungal growth, similar to levels observed in grain treated with thiabendazole alone.

More consistent differences were detected in grain quality parameters as a function of location within bins. The number of insect contaminants was highest in the center of the grain mass for the first 16 mo of storage (Table 2), consistent with documented distribution patterns of several stored-product insect species in bins of stored wheat (Hagstrum et al. 1985). By the end of the storage period, the greatest number of insect contaminants was observed in the top grain stratum (Table 2), likely because many insects that infest stored grain in bins spend much of their time near the surface of the grain (Arbogast and Throne 1997). Fines were highest in the center of the grain mass ($F = 19.72$; df = 2, 22; $P < 0.0001$; Table 1, Table 4), which was not initially a result of insect feeding but rather the phenomenon of particle settling that occurs during bin filling (Loewer et al. 1981). The modest increase in fines that occurred over the course of the study was probably a result of insect feeding. Insect-damaged kernels remained very low throughout the study, increasing sharply only for grain in the topmost portion of the grain masses during the last 4 mo of storage. The nature of the feeding damage was diagnostic of Angoumois grain moth, which is not able to penetrate deeply into the grain (Simmons and Ellington 1933).

Large changes in visible fungal growth by location within bins began after 8 mo in storage (Table 5). Not surprisingly, most fungal growth occurred in grain taken from the top grain stratum, though only statistically significantly ($P \leq 0.05$) more than other strata on four sampling dates. This difference is likely explained by differences in moisture content. Although not statistically different, moisture content was consistently numerically higher in grain samples from the top of the grain mass than those from the bottom (Fig. 2b).

United States grading standards for corn assign the commodity a grade ranging from 1 to 5, or define it as sample grade if it does not meet those quality standards (Giler and Eustrom 1995). In addition, corn is considered "weevily" if 2 live weevils, 1 live weevil and 7 other insects, or 14 other insects are found in a 1,000 g sample

Table 1. Repeated measures ANOVA for effect of treatment and sample depth in stored corn treated with pirimiphos-methyl, thiabendazole, both pesticides combined, or control

		Total Insects		Insect Damaged Kernels		Percent Fines		Visible Fungal Colonies	
Source	df	MS	*F*	MS	*F*	MS	*F*	MS	*F*
TRT	3	0.69	1.83	1.87	6.12**	0.15	0.98	8.40	6.34**
DEP	2	6.40	16.97****	11.76	38.51****	2.99	19.72****	4.09	3.09
TRT*DEP	6	1.23	3.27*	0.61	1.99	0.11	0.70	0.56	0.42
Error 1	22	0.38		0.31		0.15		1.32	
(S)ample (D)ate	11	17.67	77.10****	2.81	12.07****	0.38	15.49****	4.39	19.96****
SD*TRT	33	0.37	1.60*	0.28	1.20	0.02	1.00	0.73	3.32****
SD*DEP	22	0.56	2.44***	2.39	10.27****	0.03	1.14	0.35	1.61*
SD*TRT*DEP	66	2.39	1.46*	0.23	0.98	0.03	1.02	0.23	1.04
Error 2	242	0.23		0.23		0.02		0.22	

*, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$; ****, $P < 0.0001$.

Table 2. Effect of treatment and sample location on number of total insect contaminants (mean #/100 kernels ± SE) sampled from stored corn treated with pirimiphos-methyl, thiabendazole, both pesticides combined, or control

	Treatment*				Sample Location**		
Date	P-M†	T‡	P-M + T	C§	Top	Center	Bottom
DEC 89	0.4 ± 0.2a	0.1 ± 0.1a	0.6 ± 0.2a	0.4 ± 0.1a	0.5 ± 0.2A	0.3 ± 0.1A	0.3 ± 0.1A
FEB 90	0.9 ± 0.3a	0.8 ± 0.3a	0.7 ± 0.3a	0.6 ± 0.2a	0.7 ± 0.2A	1.2 ± 0.3A	0.4 ± 0.1A
APR 90	0.6 ± 0.2a	0.3 ± 0.2a	0.9 ± 0.4a	0.5 ± 0.2a	0.5 ± 0.2A	0.9 ± 0.3A	0.3 ± 0.1A
JUN 90	1.3 ± 0.5a	0.7 ± 0.3a	1.4 ± 0.5a	1.3 ± 0.3a	1.2 ± 0.2A	1.5 ± 0.5A	0.9 ± 0.3A
AUG 90	4.6 ± 1.0a	4.1 ± 1.0a	3.8 ± 0.8a	6.5 ± 2.9a	5.0 ± 0.8A	6.7 ± 2.2A	2.6 ± 0.6B
OCT 90	8.9 ± 4.4a	8.4 ± 2.9a	5.7 ± 1.7a	14.0 ± 7.1a	5.5 ± 1.4B	18.8 ± 5.6A	3.4 ± 0.7B
DEC 90	4.3 ± 1.2b	4.6 ± 1.1ab	3.1 ± 0.5b	11.1 ± 3.7a	5.7 ± 1.7A	7.8 ± 2.8A	4.0 ± 0.6A
FEB 91	7.8 ± 2.7a	6.1 ± 2.0a	3.6 ± 0.7a	7.8 ± 2.0a	5.8 ± 1.4A	8.1 ± 1.9A	5.1 ± 1.8A
APR 91	5.8 ± 2.6a	8.5 ± 2.3a	3.9 ± 1.2a	9.9 ± 3.8a	6.1 ± 1.7AB	10.8 ± 3.1A	4.1 ± 1.3B
JUN 91	8.2 ± 3.1a	5.5 ± 0.9ab	3.0 ± 0.5bc	3.6 ± 1.7c	4.9 ± 1.1A	5.1 ± 1.0A	5.4 ± 2.4A
AUG 91	10.6 ± 2.6a	7.6 ± 1.1a	7.3 ± 2.4a	6.9 ± 1.5a	10.3 ± 1.9A	9.3 ± 1.7A	4.8 ± 1.0B
DEC 91	10.2 ± 2.7a	12.8 ± 2.5a	15.7 ± 8.4a	18.8 ± 4.1a	25.5 ± 5.9A	11.3 ± 2.1B	6.4 ± 0.8B

* means followed by the same lower case letter in a row are not significantly different ($P \geq 0.05$).
** means followed by the same capital letter in a row are not significantly different ($P \geq 0.05$).
† pirimiphos-methyl.
‡ thiabendazole.
§ control.

Table 3. Effect of treatment and sample location on the occurrence of insect damaged kernels (mean #/100 kernels ± SE) in stored corn treated with pirimiphos-methyl, thiabendazole, both pesticides combined, or control

	Treatment*				Sample Location**		
Date	P-M†	T‡	P-M + T	C§	Top	Center	Bottom
DEC 89	0.2 ± 0.2a	0.1 ± 0.1a	0.3 ± 0.2a	0.8 ± 0.3a	0.4 ± 0.2A	0.3 ± 0.2A	0.4 ± 0.2A
FEB 90	0.3 ± 0.2a	0.4 ± 0.2a	0.2 ± 0.2a	0.6 ± 0.3a	0.5 ± 0.2A	0.2 ± 0.2A	0.5 ± 0.2A
APR 90	0.4 ± 0.2a	0.6 ± 0.2a	0.6 ± 0.2a	0.3 ± 0.2a	0.5 ± 0.2A	0.6 ± 0.2A	0.3 ± 0.2A
JUN 90	0.3 ± 0.2a	0.2 ± 0.2a	0.1 ± 0.1a	0.4 ± 0.2a	0.3 ± 0.2A	0.2 ± 0.1A	0.3 ± 0.2A
AUG 90	0.2 ± 0.2a	0.3 ± 0.2a	1.0 ± 0.3a	0.7 ± 0.3a	0.8 ± 0.3A	0.7 ± 0.3A	0.3 ± 0.1A
OCT 90	0.3 ± 0.2a	0.9 ± 0.4a	0.0 ± 0.0a	0.6 ± 0.2a	0.5 ± 0.2A	0.6 ± 0.3A	0.3 ± 0.1A
DEC 90	0.4 ± 0.2a	0.9 ± 0.6a	0.6 ± 0.2a	0.6 ± 0.2a	1.1 ± 0.4A	0.6 ± 0.2A	0.2 ± 0.1A
FEB 91	0.3 ± 0.2a	1.0 ± 0.3a	0.2 ± 0.2a	0.6 ± 0.2a	0.7 ± 0.2A	0.7 ± 0.2A	0.3 ± 0.2A
APR 91	0.4 ± 0.2a	2.7 ± 1.3a	1.0 ± 0.4a	1.1 ± 0.4a	2.9 ± 0.9A	0.4 ± 0.2B	0.6 ± 0.3B
JUN 91	0.3 ± 0.2a	1.2 ± 0.7a	0.8 ± 0.4a	1.7 ± 0.5a	2.1 ± 0.6A	0.3 ± 0.1B	0.7 ± 0.3B
AUG 91	1.1 ± 0.9b	3.1 ± 1.2a	1.1 ± 0.9b	1.8 ± 0.6ab	3.7 ± 1.0A	1.2 ± 0.7B	0.5 ± 0.2B
DEC 91	6.9 ± 4.5a	9.7 ± 4.5a	9.1 ± 5.9a	15.2 ± 7.6a	29.7 ± 4.8A	0.6 ± 0.3B	0.4 ± 0.3B

* means followed by the same lower case letter in a row are not significantly different ($P \geq 0.05$).
** means followed by the same capital letter in a row are not significantly different ($P \geq 0.05$).
† pirimiphos-methyl.
‡ thiabendazole.
§ control.

Table 4. Effect of treatment and sample location on percent fines (mean percentage/sample ± SE) sifted from stored corn treated with pirimiphos-methyl, thiabendazole, both pesticides combined or control

	Treatment*				Sample Location**		
Date	P-M†	T‡	P-M + T	C§	Top	Center	Bottom
DEC 89	0.5 ± 0.1a	0.5 ± 0.1a	0.5 ± 0.1a	0.4 ± 0.1a	0.5 ± 0.0AB	0.6 ± 0.1A	0.4 ± 0.0B
FEB 90	0.6 ± 0.1a	0.6 ± 0.0a	0.6 ± 0.1a	0.5 ± 0.0a	0.6 ± 0.0B	0.8 ± 0.1A	0.5 ± 0.0B
APR 90	0.8 ± 0.1a	0.7 ± 0.1a	0.7 ± 0.1a	0.7 ± 0.1a	0.7 ± 0.0B	1.0 ± 0.1A	0.6 ± 0.1B
JUN 90	0.6 ± 0.1a	0.5 ± 0.0a	0.5 ± 0.1a	0.5 ± 0.1a	0.5 ± 0.0B	0.6 ± 0.1A	0.4 ± 0.0B
AUG 90	0.8 ± 0.1a	0.8 ± 0.1a	0.7 ± 0.1a	0.7 ± 0.1a	0.6 ± 0.0B	1.0 ± 0.1A	0.7 ± 0.1B
OCT 90	0.7 ± 0.1a	0.8 ± 0.1a	0.6 ± 0.1a	0.8 ± 0.1a	0.7 ± 0.0B	1.0 ± 0.1A	0.6 ± 0.0B
DEC 90	0.7 ± 0.1a	0.8 ± 0.1a	0.7 ± 0.0a	0.7 ± 0.6a	0.7 ± 0.0B	0.8 ± 0.1A	0.7 ± 0.0B
FEB 91	0.8 ± 0.1a	0.8 ± 0.1a	0.7 ± 0.1a	0.7 ± 0.1a	0.7 ± 0.1B	1.0 ± 0.1A	0.6 ± 0.0B
APR 91	0.6 ± 0.1a	0.7 ± 0.1a	0.7 ± 0.1a	0.7 ± 0.1a	0.6 ± 0.0B	0.9 ± 0.1A	0.5 ± 0.0B
JUN 91	0.7 ± 0.1a	0.8 ± 0.1a	0.7 ± 0.1a	0.7 ± 0.1a	0.6 ± 0.1B	0.9 ± 0.1A	0.6 ± 0.1B
AUG 91	0.7 ± 0.1ab	0.8 ± 0.0a	0.6 ± 0.0b	0.8 ± 0.1a	0.7 ± 0.1AB	0.8 ± 0.1A	0.7 ± 0.0B
DEC 91	0.8 ± 0.1a	1.0 ± 0.1a	0.8 ± 0.1a	0.8 ± 0.1a	0.8 ± 0.1B	1.0 ± 0.1A	0.7 ± 0.0B

* means followed by the same lower case letter in a row are not significantly different ($P \geq 0.05$).
** means followed by the same capital letter in a row are not significantly different ($P \geq 0.05$).
† pirimiphos-methyl.
‡ thiabendazole.
§ control.

Table 5. Effect of treatment and sample location on the occurrence of visible fungal colonies (mean #/100 kernels ± SE) in stored corn treated with pirimiphos-methyl, thiabendazole, both pesticides combined, or control

	Treatment*				Sample Location**		
Date	P-M†	T‡	P-M + T	C§	Top	Center	Bottom
DEC 89	0.1 ± 0.1a	0.0 ± 0.0a	0.0 ± 0.0a	0.1 ± 0.1a	0.2 ± 0.1A	0.0 ± 0.0A	0.0 ± 0.0A
FEB 90	0.0 ± 0.0a	0.0 ± 0.0a	0.3 ± 0.2a	0.0 ± 0.0a	0.1 ± 0.1A	0.0 ± 0.0A	0.2 ± 0.1A
APR 90	0.0 ± 0.0a	0.1 ± 0.1a	0.0 ± 0.0a	0.2 ± 0.2a	0.2 ± 0.1A	0.1 ± 0.1A	0.0 ± 0.0A
JUN 90	0.0 ± 0.0a	0.1 ± 0.1a	0.6 ± 0.6a	0.6 ± 0.4a	0.9 ± 0.5A	0.0 ± 0.0B	0.0 ± 0.0B
AUG 90	1.0 ± 0.6a	0.6 ± 0.6a	1.3 ± 0.7a	1.2 ± 0.9a	2.2 ± 0.8A	0.6 ± 0.4B	0.3 ± 0.2B
OCT 90	3.1 ± 1.2a	0.2 ± 0.2b	3.2 ± 1.3a	0.7 ± 0.7b	3.2 ± 1.2A	1.0 ± 0.4A	1.3 ± 0.8A
DEC 90	1.9 ± 1.1ab	0.0 ± 0.0c	3.8 ± 1.5a	1.1 ± 0.9bc	3.1 ± 1.3A	1.7 ± 0.9AB	0.3 ± 0.2B
FEB 91	2.2 ± 1.0ab	0.0 ± 0.0c	6.3 ± 2.7a	0.7 ± 0.6bc	4.3 ± 1.9A	2.3 ± 1.3AB	0.3 ± 0.3B
APR 91	2.7 ± 1.1a	0.6 ± 0.2a	3.0 ± 1.5a	0.9 ± 0.9a	3.2 ± 1.3A	1.2 ± 0.6A	1.0 ± 0.6A
JUN 91	6.2 ± 2.5a	2.1 ± 0.8ab	2.8 ± 0.8ab	1.1 ± 0.5b	3.8 ± 1.6A	2.7 ± 1.4A	2.8 ± 0.8A
AUG 91	3.7 ± 1.5b	1.7 ± 0.7bc	5.9 ± 0.7a	0.8 ± 0.5c	3.4 ± 1.1A	2.9 ± 1.1A	2.7 ± 0.7A
DEC 91	2.6 ± 1.2ab	0.2 ± 0.2c	5.3 ± 1.5a	0.8 ± 0.7bc	2.5 ± 1.1A	1.6 ± 1.0A	2.6 ± 1.0A

* means followed by the same lower case letter in a row are not significantly different ($P \geq 0.05$).
** means followed by the same capital letter in a row are not significantly different ($P \geq 0.05$).
† pirimiphos-methyl.
‡ thiabendazole.
§ control.

(Manis 1992). The limits for damaged kernels (insect damaged + visible fungal growth) range from 3% to 15% for Grades 1 through 5, respectively, and the amount of fines allowed ranges from 2% for Grade 1 to 7% for Grade 5 (Giler and Eustrom 1995). Samples taken at the last sampling date were graded according to these standards, assigning the minimal grade based on these three grading criteria (presence of live insects, percent damaged kernels and percent fines). Consistent with the data presented to this point, pirimiphos-methyl and thiabendazole had only modest benefits for preserving grain quality. Control corn was graded as U.S. No. 5, corn treated with pirimiphos-methyl alone graded as U.S. No. 3, corn treated with thiabendazole alone graded as U.S. No. 4, and corn treated with both materials graded between 3 and 4.

Our results suggest that neither pirimiphos-methyl nor thiabendazole, alone or in combination, are strong candidates for long-term (i.e., >1 year) preservation of quality of stored corn. Thiabendazole has been shown to have varying degrees of success in controlling storage fungi in bins with either ambient or high temperature drying, with the intent of protecting the grain until the moisture content dropped below 13.5%, the threshold of growth of most fungi (Smith 1986, White et al. 1993, White and Toman 1994). The goal of those studies was to protect the corn for a shorter time (ranging from 8 to 40 wks), not a year or more. In a laboratory study conducted for 150 d, Moreno-Martinez and Ramirez (1985) found that combinations of thiabendazole with either Captan, Carbendazim M, Captafol, or Chlorothanonil provided better protection from storage fungi than thiabendazole alone. White and Toman (1994) found that adding soybean or mineral oil to thiabendazole as a carrier gave better control of storage fungi than a water/thiabendazole mixture. Thus, a greater reduction of kernels with visible fungi may have been achieved if any of these methods had been used.

Protection from insect damage with pirimiphos-methyl for shorter durations has been well-documented. White et al. (1997) found that on maize treated with pirimiphos-methyl, greater than 90% of stored-product insects were killed for a period of 8 mo post treatment. The percentage kill however, decreased significantly over an 18 month period. In another study on maize, La Hue (1975) observed that 100% of *Sitophilus oryzae, Tribolium* spp., and *Rhyzopertha dominica* were killed at 24 h and one month after treatment of grain with pirimiphos-methyl. However, 3 mo after treatment, *Tribolium* spp. exhibited some adult survival with no progeny production while *R. dominica* exhibited some adult survival, progeny production, and grain damage. In another study examining the effect of pirimiphos-methyl on *Typhaea stercorea* (L.), the hairy fungus beetle, it was determined that 12-wk-old residues of the insecticide killed only 61% of the beetles compared with 100% for fresh and 4-wk-old residues (Tigar and Pinniger 1996). Protection of grain by pirimiphos-methyl may be feasible for longer durations if reapplications are made to grain in the topmost (e.g., 0-10 cm deep) portion of the grain mass. This is because most insect damage occurs in this region. Likewise, reapplication of thiabendazole to grain in this stratum might also help reduce fungal contamination for extended periods because this portion of the grain mass typically has the highest moisture content within a bin. Precision application of insecticides and fungicides could become important components of integrated pest management in stored grains, and should be further investigated.

Acknowledgments

We thank R. J. Barney and G. Antonius for reviewing an earlier draft of this manuscript. N. Lapp of MSD AGVET provided the Mertect 340-F, the application auger, and assistance during corn treatment, and ICI Americas provided the Actellic 5E. This study was funded by a grant awarded to Kentucky State University by USDA/CSREES under project number KYX-10-91-18P and by MSD AGVET.

References Cited

Anonymous. 1996. Farm Chemicals Handbook '96. Meister, Willoughby, OH.

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

Arthur, F. H. 1995. Efficacy of three insecticides to control insect pests of stored seed corn. J. Agric. Entomol. 12: 45-53.

Arthur, F. J., J. L. Zettler and W. R. Halliday. 1988. Insecticide resistance among populations of almond moth and Indianmeal moth (Lepidoptera: Pyralidae) in stored peanuts. J. Econ. Entomol. 81: 1283-1287.

Barney, R. J., D. E. Legg and J. D. Sedlacek. 1989. On-farm storage facilities and management practices in Kentucky. Bull. Entomol. Soc. Amer. 35: 26-33.

Brown, H. D., A. R. Matzuk, I. R. Ilves, L. H. Peterson, S. A. Harris, L. H. Sarett, J. R. Egerton, J. J. Yakstis, W. C. Campbell and A. C. Cuckler. 1961. Antiparasitic drugs. IV. 2-(4'-thiazolyl)-benzimidazole, a new anthelmintic. J. Am. Chem. Soc. 83: 1764-1765.

Cayley, G. R., G. A. Hide, K. A. Lord, D. J. Austin and A. R. Davies. 1979. Control of potato storage diseases with formulations of thiabendazole. Potato Res. 22: 177-190.

Eckert, J. W. and N. F. Sommer. 1967. Control of diseases of fruits and vegetables by post-harvest treatment. Ann. Rev. Phytopath. 5: 391-432.

El-Refai, A. M., M. Baimi, N. Rofael and A. Hana. 1982. Relationship between mode of application of thiabendazole and its effectiveness in inhibiting green mould sporulation on oranges. Int. Pest Control. Sept/Oct. 1982. Pp 128-131.

Gabal, M. A. 1987. Preliminary study on the use of thiabendazole in the control of common toxigenic fungi in grain feed. Vet. Hum. Toxicol. 29: 217-221.

Giler, J. and M. Eustrom. 1995. The FGIS' role in grain inspection, Pg. 35-43. *In* V. Krischik, G. Cuperus, and D. Galliart (eds.), Stored product management. 2nd ed. CES, USDA, FGIS, APHIS.

Goldberg, C. W., H. Cole and J. Duich. 1970. Comparative effectiveness of thiabendazole and benomyl for control of Helminthosporium leafspot and crown rot, red thread, Sclerotinia dollar spot, and Rhizoctonia brown patch of turfgrass. Pl. Dis. Reptr. 54: 1080-1084.

Gutter, Y. 1970. Effectiveness of thiabendazole and benomyl in controlling green mold of Shamouti and Valencia oranges. Israel J. Agric. Res. 20: 91-95.

Hagstrum, D. W., G. A. Milliken and M. S. Waddell. 1985. Insect distribution in bulk-stored wheat in relation to detection or estimation of abundance. Environ. Entomol. 14: 655-661.

Horton, P. M. 1984. Evaluation of South Carolina field strains of certain stored-product coleoptera for malathion resistance and pirimiphos-methyl susceptibility. J. Agric. Entomol. 1: 1-5.

LaHue, D. W. 1975. Pirimiphos-methyl as a short term protectant of grain against stored-product insects. J. Econ. Entomol. 68: 235-236.

LaHue, D. W. and E. B. Dicke. 1977a. Evaluating selected protectants for shelled corn against stored-grain insects. U.S. Dep. Agr. Marketing Res. Rept. No. 1058.

1977b. Evaluation of selected insecticides applied to high moisture sorghum grain to prevent stored grain insect attack. U.S. Dep. Agr. Marketing Res. Rept. No. 1063.

Loewer, O. J., I. J. Ross and G. M. White. 1981. Aeration, inspection, and sampling of grain in storage bins. Univ. Kentucky Cooperative Ext. Ser. Publ. AEN-45. Lexington, KY. 16 pp.

Manis, J. M. 1992. Sampling, inspecting, and grading, Pg. 563-588. *In* D. B. Sauer (ed.), Storage of cereal grains and their products. 4th ed., Am. Assoc. Cereal Chemists. St. Paul, MN.

Monico-Pifarre, A. and M. Xirau-Vayreda. 1987. Monitoring residues of carbendazim (applied as benomyl) and thiabendazole in Wellspur apples. J. Assoc. Off. Anal. Chem. 70: 596-597.

Moreno-Martinez, E. and J. Ramirez. 1985. Protective effect of fungicides on corn seed stored with low and high moisture contents. Seed Sci. and Tech. 13: 285-290.

SAS Institute. 1988. SAS/STAT Users Guide. SAS Institute. Cary, NC.

Sanchis, V. I., I. Vinas, M. Jimenez, M. A. Calvo and E. Hernandez. 1982. Mycotoxin-producing fungi isolated from bin-stored corn. Mycopathologia 80: 89-93.

Simmons, P. and G. W. Ellington. 1933. Life history of the Angoumois grain moth in Maryland. U.S. Dep. Agr. Tech. Bull. 351: 1-34.

Smith, D. 1986. Store 16% corn. Farm Journal vol. 110: 14-15 (Sept.).

Tigar, B. J. and D. B. Pinniger. 1996. A comparison of the toxicity of pirimiphos-methyl and malathion to *Typhaea stercorea* (L.) when applied to stored maize. J. Stored Prod. Res. 32: 307-313.

White, D. G., J. Toman, D. C. Burnette and B. J. Jacobsen. 1993. The effect of postharvest fungicide application on storage fungi of corn during ambient air drying and storage. Pl. Dis. 77: 562-568.

White, D. G. and J. Toman, Jr. 1994. Effects of postharvest oil and fungicide application on storage fungi in corn following high-temperature grain drying. Pl. Dis. 78: 38-43.

White, N. D. G., D. S. Jayas and C. J. Demianyk. 1997. Degradation and biological impact of chlorpyriphos-methyl on stored wheat and pirimiphos-methyl on stored maize in western Canada. J. Stored Prod. Res. 33: 125-135.

Zettler, J. L. 1982. Insecticide resistance in selected stored-product insects infesting peanuts in the southeastern United States. J. Econ. Entomol. 75: 359-362.