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Evaluation of Fenoxycarb, *Bacillus thuringiensis*, and Malathion as Grain Protectants in Small Bins[1]

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ABSTRACT Treatment of wheat placed in 3-bu bins with 10 ppm fenoxycarb controlled the rice weevil, *Sitophilus oryzae* (L.), confused flour beetle, *Tribolium confusum* Jacquelin du Val, and Indianmeal moth, *Plodia interpunctella* (Hübner), for two grain storage seasons in Kansas. Malathion (10 ppm) and *Bacillus thuringiensis* (Dipel, 125 ppm in 10 cm surface layer) were inadequate in controlling the moth and beetle species, respectively. The lesser grain borer, *Rhyzopertha dominica* (F.), was controlled, based on a laboratory bioassay of wheat that had been treated with fenoxycarb 1 year earlier. None of the insecticide treatments reduced the ability of the seed to germinate. Residue analysis showed no loss of fenoxycarb after 1 year of storage and approximate distribution in milled fractions as follows: bran, 25 ppm; red dog, 5 ppm; shorts, 3 ppm, and flour, 1 ppm.

MALATHION often is used to prevent infestation of stored products by insects (Storey et al. 1982). Its effectiveness is becoming limited due to the incidence of malathion resistance appearing in strains of both stored product Coleoptera (Haliscak and Beeman 1983) and Lepidoptera (Zettler et al. 1973, Beeman et al. 1982). This study was undertaken as part of a program to develop insecticidal materials that are more effective than malathion as a grain protectant.

Fenoxycarb is a non-neurotoxic carbamate insecticide that exhibits juvenile hormone activity against adults and larvae of numerous insect species representing various orders (Dorn et al. 1981, Anonymous 1983). Previously we evaluated this insect growth regulator in the laboratory against 12 species of stored product beetles and moths (Kramer et al. 1981). Fenoxycarb suppressed F_1 progeny of nine coleopteran and three lepidopteran species at 10 ppm or lower levels, when applied to wheat based media. In the present study we mixed fenoxycarb with whole kernel wheat and compared its protectant activity to that of malathion and *Bacillus thuringiensis* (Dipel) in small bins for a storage period of 2 years. The latter material also was tested because it is registered for use as a grain and soybean protectant against stored product Lepidoptera (McGaughey 1980).

Materials and Methods

Cylindrical 3-bu capacity metal bins with removable lids were used to hold the grain. Twenty-eight bins (40 cm diam at grain surface) each containing 2 bu of 12.6% moisture hard red winter Newton wheat harvested in 1981 were placed randomly in a larger bin (800-bu capacity) situated on the U.S. Grain Marketing Research Laboratory (USGMRL) grounds in October 1981. The wheat was treated with either 50 ml water (carrier), 10 ppm fenoxycarb (ethyl [2-(p-phenoxyphenoxy) ethyl] carbamate, [Maag Agrochemicals], 125 g [AI] per liter EC) or 10 ppm malathion (*O,O*-dimethyl *S*-(1,2-dicarbethoxyethyl) phosphorodithioate, Cythion 57% EC [American Cyanamid]) in a small electric cement mixer and placed in small bins. After 20 days Dipel dust (*Bacillus thuringiensis*, var. Berliner, 16,000 IU per mg [Abbott Lab.], 7.3 g) was raked into the top four inches of some of the bins. Combinations of treatments, including fenoxycarb plus malathion, fenoxycarb plus Dipel, and malathion plus Dipel also were tested. Four replicates of each treatment were run.

The onset of cold weather reduced the likelihood that infestations would develop before the following spring. Therefore, infestation was delayed until May 1982. In May, each bin was infested with 200 each, confused flour beetle adults, *Tribolium confusum* Jacquelin du Val, and rice weevil adults, *Sitophilus oryzae* (L.), obtained from cultures maintained at the USGMRL. Beginning in August 1982, the bins were sampled monthly with a probe (3 cm diam, 100 cm long) that removed ca. 150 g of wheat. During 1982, the temperature of the grain varied from −2°C in January to 49°C in July while in 1983, the temperature extremes were −3°C in January and 47°C in July. The bins also were sampled in August and November 1983. Indianmeal moth eggs (250), *Plodia interpunctella* (Hübner), obtained from the laboratory culture, were added to each bin in April 1983 and populations present were recorded in August 1983. The lesser grain borer, *Rhyzopertha dominica* (F.), was bioassayed in the laboratory using

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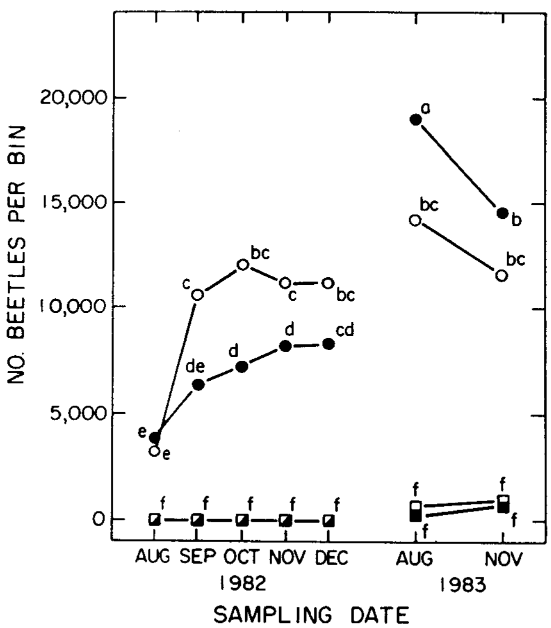

Fig. 1. Monthly rice weevil counts in wheat treated with water (●), Dipel (○), fenoxycarb (■), and malathion (□). Points denoted by the same letter do not differ significantly ($P = 0.05$; Duncan's multiple range test).

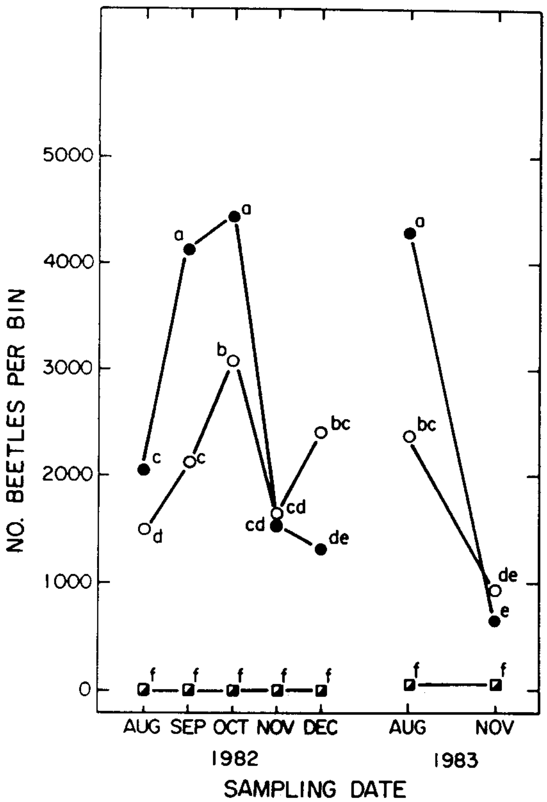

Fig. 2. Monthly confused flour beetle counts in wheat treated with water (●), Dipel (○), fenoxycarb (■), and malathion (□). Points denoted by the same letter do not differ significantly ($P = 0.05$; Duncan's multiple range test).

wheat that had been treated one year previously (Kramer et al. 1981). The effect of insecticide treatment on seed germination was determined after placing four replicates of 100 seeds each in moist paper toweling at 27°C for 5 days. Moisture content and test weight were measured using a Dickey-John Grain Analysis Computer II.

For fenoxycarb residue analysis 2-bu of wheat were treated with 10 ppm fenoxycarb and stored at 25°C in the laboratory for 1 year. The uninfested wheat was sampled and milled into bran, shorts, red dog, and flour fractions at 0, 1, 6, and 12 months for determination of residue (Anonymous 1984). The mean recovery of residue from wheat treated at 1.0 ppm was about 84% and the limit of detection was ca. 0.05 ppm. Data were subjected to Duncan's multiple range test (SAS Institute Inc. 1982).

Results

Effect on Insect Populations. The level of insecticides used were those recommended by the label (malathion and Dipel) or that which prevented progeny development in a laboratory study (fenoxycarb; Kramer et al. 1981). Both malathion and fenoxycarb were applied homogeneously at 10 ppm to the entire grain mass, while the bacterium was applied only to a 10 cm surface layer at 125 ppm. In Fig. 1, monthly rice weevil counts in treated and untreated bins of wheat are presented. Large populations were present in both the check and in the Dipel-treated bins during 1982 and 1983. No weevils were found in the fenoxycarb- and malathion-treated wheat the first year. Very low levels of infestation occurred in 1983 with slightly fewer weevils in the fenoxycarb-treated grain compared with numbers in the malathion treatments. The small population buildup during 1983 in the fenoxycarb- and malathion-treated wheat indicated that the effectiveness of both compounds had diminished slightly 1 year after insecticide application.

Counts of numbers of confused flour beetles as a function of sampling date are shown in Fig. 2. As observed with the rice weevil, the largest populations occurred in both the check and Dipel-treated bins. Only fenoxycarb and malathion were effective in suppressing beetle populations in stored wheat for 2 years. The effect of the insecticide treatments on a third beetle species, the lesser grain borer, *Rhyzopertha dominica* (F.), was assessed in bioassay tests of 250-g samples removed from the surface layer of grain in the bins. Fenoxycarb and malathion suppressed progeny >99%, while Dipel exhibited <10% suppression (unpublished data).

A sampling of Indianmeal moth populations was

Table 1. Moisture content, test weight, and grade of wheat samples

Treatment	Moisture (%)	Test wt (lb/bu)	Grade[a]
Check (water)	12.9 ± 0.4a	58.1 ± 0.8a	2, weevily
Dipel	13.0 ± 0.5a	57.9 ± 0.8a	Sample
Malathion	12.0 ± 0.1b	60.8 ± 0.2b	2, damaged kernels
Fenoxycarb	12.0 ± 0.1b	61.1 ± 0.2b	1
Fenoxycarb + malathion	12.0 ± 0.1b	61.1 ± 0.1b	1
Fenoxycarb + dipel	12.2 ± 0.4b	60.8 ± 0.3b	1
Malathion + dipel	11.8 ± 0.1b	61.0 ± 0.2b	1

Before infestation moisture content and test weight were 12.4 ± 0.1% and 61.3 ± 0.1 lb/bu, respectively. Means within a column followed by the same letter are not significantly different ($P = 0.05$; Duncan's multiple range test).

[a] Grading performed by Federal Grain Inspection Service, Grandview, Mo.

taken in August 1983. The check and malathion-treated bins exhibited dense deposits of silk webbing at the grain surface and contained large moth populations of 2,503 ± 1,460 and 3,813 ± 2,090, respectively, while fenoxycarb- and Dipel-treated wheat did not allow moth development. Thus, in our tests only the latter two insecticides appeared effective at this date in suppressing moth populations in stored wheat. In August 1983, when the beetle and moth infestations were the heaviest overall, fenoxycarb suppressed 98% of the population, malathion 83%, and Dipel 36%. The rice weevil and confused flour beetle were not controlled by Dipel, while malathion did not suppress the Indianmeal moth.

Several combinations of insecticides also were tested. No significant population of either rice weevil, confused flour beetle, or Indianmeal moth occurred in bins treated with fenoxycarb plus malathion, fenoxycarb plus Dipel, or malathion plus Dipel. The malathion plus Dipel combination exhibited an additive effect with the former insecticide controlling the beetles and the latter, the moth.

At the end of the test (November 1983), sample moisture contents and test weights were determined (Table 1). The most heavily infested samples (check and Dipel) had significantly higher moisture contents and lower test weights. All of the other samples were essentially identical in those two parameters. The loss in test weight and increase in moisture are reflections of the relatively poor condition of grain samples infested with insects compared to uninfested wheat (Storey et al. 1983). Additionally, when test samples were graded by the Federal Grain Inspection Service (Table 1), the fenoxycarb-treated wheat was evaluated as U.S. No. 1 grade (United States Government, 1974). Malathion-treated wheat was rated U.S. No. 2, because many kernels were damaged by Indianmeal moth larvae. Low ratings were given to the check wheat (U.S. No. 2, weevily) and Dipel-treated

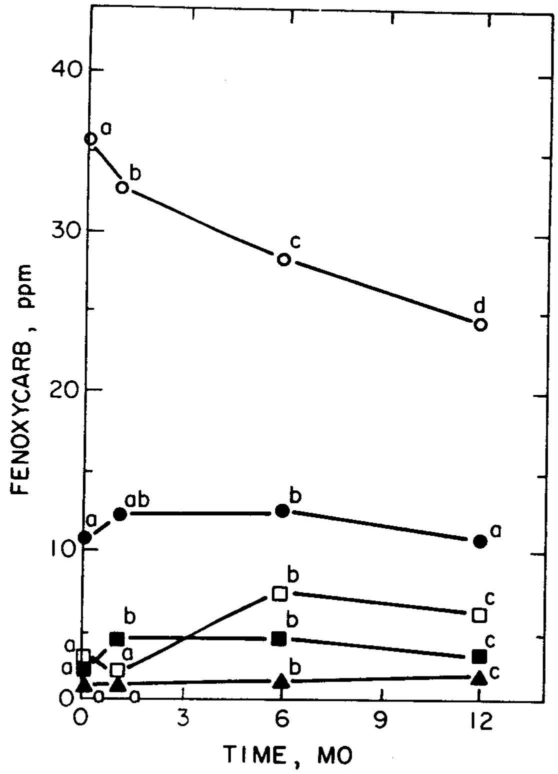

Fig. 3. Residue analysis of wheat treated with 10 ppm fenoxycarb and its milled fractions during storage for one year. Whole wheat (●), bran (○), red dog (□), shorts (■), and flour (▲). For each sample, points denoted by the same letter do not differ significantly ($P = 0.05$; Duncan's multiple range test).

wheat (sample grade, weevily). All combined insecticide-treated grain samples were graded as U.S. No. 1.

Effect on Seed Germination. None of the insecticide treatments adversely affected wheat seed germination; 97.5% of the control (water-treated) seeds germinated, while 97.5 to 99% of the fenoxycarb- (10 ppm), malathion- (10 ppm), or Dipel- (125 ppm) treated seeds successfully germinated. Fenoxycarb, thus, appears a more suitable new candidate insecticide for seed grains compared to other insect growth regulators, such as methoprene, diflubenzuron, and BAY SIR 8514, which reduce wheat germination at 1 month after treatment by 13, 18, and 24%, respectively, when applied at 10 ppm (Mian and Mulla 1983).

Residue Analyses. Fenoxycarb residue and its distribution in the wheat kernel was monitored for 1 year following application. Results revealed that the insect growth regulator is very stable with no loss of active ingredient from uninfested whole wheat after 1 year of storage (Fig. 3). Analyses of the fractions showed that migration from external to internal portions of the kernel occurred. There was a significant decrease in the amount of fenoxycarb present in the bran fraction and generally there were only small increases in residues associated with shorts, red dog, and flour fractions. Flour exhibited a slight increase in residue (from 0.8 ppm to 1.3 ppm) after 12 months.

Discussion

Chemical protectants are essential for preventing insect pest damage to agricultural commodities while in storage and during marketing. Stringent requirements of safety to humans and the environment have been mandated for candidate chemicals that are tested for efficacy in control of post-harvest insects. A qualified chemical pesticide should be extremely toxic to the target pests, nontoxic to plants and nontarget animals, harmless to commodities, inexpensive to produce, and convenient to use. Although malathion, synergized pyrethrins, and *B. thuringiensis* are approved for direct application to grain for the purpose of controlling or limiting insect populations, none of these satisfies all of the above criteria. Malathion is effective against most insect species, but it loses activity rapidly, especially when the moisture content and grain temperature are high. In addition, resistance to malathion is already acute and particularly widespread in Indianmeal moth and red flour beetle populations, while even the lesser grain borer has exhibited a measurable tolerance to this insecticide (Haliscak and Beeman 1983). Pyrethrins are more limited in their effectiveness and relatively expensive to use. The bacterium is generally inactive towards Coleoptera.

Thus, there is a need for alternative protectants for harvested cereal grains. Although many chemical insecticides have been screened as potential grain protectants, none have been registered since malathion was in 1958. Several insecticidal chemicals for application to stored grains are presently in the process of development including organophosphates, fenitrothion, pirimphos-methyl, and chloropyriphos-methyl, as well as the insect growth regulators, methoprene and fenoxycarb.

Fenoxycarb and methoprene show excellent potential as protectants of stored grain. Both exhibit lower vertebrate toxicities (acute oral LD_{50} for the rat >10 g/kg) and higher biological activity against most target pest species than do the residual protectants. However, an apparent problem with methoprene is that it exhibits relatively poor activity against *Sitophilus* species (McGregor and Kramer 1975, Mian and Mulla 1982a,b, Edwards and Short 1984), which diminishes somewhat its potential use as a grain protectant. Fenoxycarb, however, is very effective against *Sitophilus* sp. and other stored product insects. Results from bioassay experiments are in agreement with residue analyses. When whole grain is treated with 10 ppm fenoxycarb, the endosperm accumulates about 1 ppm of active material, which is sufficient for suppressing development of internal feeding Coleoptera, such as the weevil species (Kramer et al. 1981).

Of the three materials evaluated in this study, it would appear that fenoxycarb is the compound that comes closest to satisfying the criteria for an ideal grain protectant. It is very active as a population suppressant of stored grain insects, is relatively nontoxic to humans and other animals, does not reduce the ability of the treated seed to germinate, and is just as convenient to use as other chemical protectants. However, its full potential as a grain protectant must await the results of additional field trials and long-term toxicological studies.

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