Present Use of Pest Management Practices in Wheat, Corn, and Oats Stored on the Farm

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ABSTRACT Preventive and remedial actions reported by producers to maintain the quality of grain during storage on the farm was minimal. Application of malathion when the grain was binned was the most frequent action reported in wheat, aeration the most frequent in corn, and fumigation the principal action in oats. Less than 10% of the grain was reported as fumigated during storage periods of 1 to 4 years and high numbers of dead adult insects observed in fumigated grain indicate that damaging populations were already present when the decision to fumigate was made. Liquid fumigant mixtures were the principal type used in corn and oats; phosphine-producing fumigants were the predominant types used in wheat. Malathion was found on only 14.6% of the wheat, 8.2% of the corn, and 4.2% of the oats from more than 8,000 farm bins across 27 states. When malathion was present the incidence, number of different species, and density of most species were generally less than in untreated grain. The effectiveness of malathion decreased significantly at grain moisture levels above 12%. The most frequent species found in malathion-treated grain were *Plodia interpunctella* (Hübner), *Cryptolestes* spp., *Tribolium* spp., *Rhyzopertha dominica* (F.), and *Oryzaephilus surinamenis* (L.). Nearly two-thirds of the insects found in malathion-treated grain occurred in grain containing residues of 2 ppm or less.

THE APPLICATION of proper pest management practices is essential to maintaining the quality of grain stored on the farm. Insect control measures used on the farm may be classified into two categories: chemical treatments and nonchemical or physical actions. Chemical treatments include preventive applications of a residual insecticide that are designed to limit the invasion and development of damaging insect infestations and remedial fumigations that provide rapid control of existing insect populations. Nonchemical control measures include cooling grain by aeration to retard insect development and reproduction, turning or stirring grain to stop crusting and moisture accumulation, and drying grain to prevent molding and heating, which attracts insect species that prefer high-moisture conditions or feed on molds or decaying vegetable matter. These insect control measures have been part of the general grain management guidelines recommended by many state, federal, and industry groups for more than 20 years, yet relatively little information is available on the extent to which these control measures are actually used in farm storage and how effectively they control insects infesting stored grain.

Previous data, developed by Storey et al. 1982, showed that only 11.6% of the wheat and 7.7% of the corn arriving at port terminals in the United States contained biologically active deposits of malathion, the only readily available chemical grain protectant presently approved for direct application to grain (Storey et al. 1979). Barak and Harein (1981) found that only 2 of 35 corn bins and none of 13 wheat bins surveyed in west-central Minnesota in 1978 had been treated with a grain protectant when the bins were filled. They also reported only 2.8% of the corn and 8.2% of the wheat examined in a survey of postharvest pesticide use in Minnesota had received treatment (P. Harein, H. Deer, and A. Barak, unpublished data). A 1980 survey of pesticide use in stored grain in Ohio (Waldron et al. 1981) reported that only 10.6% of producers who store corn on the farm in Ohio treated the grain for pest control.

Studies presented here were developed to show a national overview of actions taken by producers to maintain the quality of grain stored on the farm with special emphasis placed on determining the use and effectiveness of malathion treatments. These data were further related to the incidence of insects in the grain, length of storage period, fumigation, geographic area, and moisture content of the grain. This study was conducted in conjunction with a national survey of over 8,000 farm bins across 27 states to determine the incidence of insect infestation in wheat, corn, and oats stored for 1 to 4 years on the farm (Storey et al. 1983).

Materials and Methods

Grain Samples. Grain samples for analysis were obtained by Agricultural Stabilization and Conservation Service (ASCS) personnel from bins of wheat, corn, and oats stored under the farmer-owned grain reserve program of the U.S. Dept. of Agriculture from crop years 1976, 1977, 1978, and

1979. A total of 8,139 samples (4,171 wheat; 2,918 corn; and 1,050 oats) from 628 counties across 27 states were examined. Bins selected for sampling were based on random sample procedures developed by the Economics, Statistics, and Cooperative Service (ESCS) for use by ASCS in performing periodic quality checks of farm-stored reserve grain. County ASCS employees were directed to obtain a representative sample from each bin selected, using a probe to draw the sample. Approximately 2,000 g of grain was drawn from each bin and divided into two equal parts. One-half of the grain together with identifying sample information was sent directly to the U.S. Grain Marketing Res. Lab. (USGMRL) for processing. The wheat and oat bins were sampled during June and July and the corn was sampled from September to October.

The moisture content of each grain sample was measured on a Dickey-John GACII grain tester.

Insect Analysis. Procedures used for processing and examining the grain samples for insects are described in Storey et al. 1983. These procedures were designated to maximize the survivial and maturation of all insect species present in the grain at the time the samples were collected. Estimates of the density of insects in the samples were standardized by multiplying the number of insects detected in each sample by 1,000 divided by the actual weight of the infested sample to provide a density number per 1,000 g of grain. These figures were combined to calculate average densities for all species combined in the pooled groups of samples involving malathion-treated versus untreated grain.

Supplemental Data. Additional sample information was supplied by ASCS (Form CCC-682, Request for Quality Analysis) that indicated the approximate date the grain was placed in storage, volume stored, type of storage structure, and when possible, a brief history obtained from the producer on actions taken to maintain the quality of the grain during storage.

Malathion Incidence and Residue Analysis. The incidence of malathion on the grain samples obtained from farm storage was estimated using a bioassay technique (Storey et al. 1982) involving adult rice weevils *Sitophilus oryzae* (L.); a species and stage of development particularly susceptible to low concentrations of malathion. Grain samples in which the mortality of the adult weevils was 30% or greater were considered treated and placed in sealed jars held in cold storage (ca. −10°C) for residue analysis. Residues of malathion were extracted from the samples and prepared for analysis in a Tracor M.T. (Microtec) gas chromatograph by an unpublished procedure (L. Davidson, Physical Science Technician, USGMRL) from that of Storrherr et al. (1964) and reported by Quinlan et al. (1979). The lower detectable limit was 0.1 ppm. Not all of the samples in which the bioassay mortality was greater than 30% were analyzed. Samples selected for residue analysis were based on the bioassay response, geographic location, and the presence or absence of insects in that portion of the grain sample used for determining the incidence of insects. A few samples in which bioassay mortality was less than 30% were also analyzed for possible malathion residues. A total of 184 samples of wheat, 110 of corn, and 15 of oats was analyzed for malathion content.

Data Processing. Information associated with individual grain samples was combined and summarized by computer to provide a listing of the type and frequency of use of actions taken by producers to maintain quality during storage and to characterize relationships between specific insect populations and such factors as prior treatment of the grain with malathion, fumigation of the grain, length of storage, and moisture content.

Results

Producer Responses. Preventive and remedial actions reported by producers to maintain the quality of grain during storage on the farm from 1976 through 1979 was minimal (Table 1). Application of the grain protectant, malathion, when the grain was binned was the quality action most frequently reported taken in farm-stored wheat, aeration the most frequent action in corn, and fumigation the principal action in oats. Relatively little use of dichlorvos impregnated polyvinyl chloride strips was indicated and use of the biological agent *Bacillus thuringiensis*, a bacterium formulation labeled in 1979 for control of moth larvae, was reported only in corn.

The percentage of producers reporting the use of malathion was fairly similar from one crop year to another within the same commodity (Table 2). Producers storing grain the longest (crop year 1976) generally reported the most frequent use of grain fumigants. Aeration was reported more frequently in newer grain (crop year 1979) than in grain stored for longer periods of time.

Table 1. Control measures reported by producers to maintain the quality of grain stored on the farm for 1 to 4 years (1976–1979)

Quality action indicated	% Responses of		
	Wheat	Corn	Oats
Chemical controls			
Malathion	12.1	5.4	3.5
Fumigation	9.5	4.3	8.8
Dichlorvos (pest strip)	0.1	0.4	0
Nonchemical			
Bacillus thuringiensis (moth control)	0	0.3	0
Physical actions			
Aeration			
Turning of grain	6.2	21.3	1.4
Raking or stirring grain surface	2.1	8.0	5.5

Table 2. Percentage of frequency of use of malathion treatments, fumigation, and aeration reported by producers to maintain the quality of grain stored on the farm

Action/ commodity	Crop year			
	1976	1977	1978	1979
Malathion				
Wheat	9.8	13.9	11.7	14.4
Corn	6.1	5.6	4.8	5.9
Oats	0	4.5	1.1	2.6
Fumigation				
Wheat	10.8	12.1	8.5	5.9
Corn	7.0	5.4	4.4	2.1
Oats	31.3	9.4	5.6	5.2
Aeration				
Wheat	3.8	7.6	4.1	10.1
Corn	10.6	17.7	23.3	26.6
Oats	0	0.9	2.2	3.2

Fumigation responses show that liquid fumigants containing mixtures of carbon tetrachloride, carbon disulfide, ethylene dibromide, ethylene dichloride, and sulfur dioxide were the predominant materials used in corn and oats and phosphine-producing fumigants the principal type used in wheat (Table 3). Extensive use of phosphine in place of liquid fumigant mixtures was particularly evident in more recently stored grain (crop years 1978 and 1979) than in older grain. Most fumigations occurred during the 2nd year of storage and more than one treatment of the same grain was rarely indicated. Response data were insufficient to estimate the percentage of grain storages treated professionally. However, those identified as commercially treated were generally large bins with capacities of 272 metric ton (10,000 bu) or more. Fumigations were reported most often (18.2%) by wheat producers in the lower North Central States (Colorado, Kansas, Nebraska) and least often (7.5%) by producers in the upper North Central States (North Dakota, South Dakota, Minnesota).

Among all grain samples examined for insect infestation, one or more live stored-product insects were found in 25.1% of the wheat, 56.4% of the oats, and 79.7% of the corn (Storey et al. 1983). The average numbers of insects per 1,000 g in these infested samples were 105 for wheat, 26 for corn, and 39 for oats. The frequency of insects in

Table 3. Types of fumigants used in the treatment of wheat, corn, and oats stored on the farm

Type of fumigant	% Responses of		
	Wheat	Corn	Oats
Liquids (carbon tetrachloride, carbon disulfide, ethylene dibromide, ethylene dichloride, sulfur dioxide)	29.9	43.2	69.4
Phosphine	59.9	13.5	22.4
Methyl bromide	0	5.5	0
Chloropicrin	10.2	37.8	8.2

Table 4. Average numbers of dead adult insects found in grain samples from fumigated bins

Commodity	Avg. density (range) of dead adult insects	Principal species
Wheat	890 (32–2,283)	*Tribolium* spp. and lesser grain borer
Corn	290 (106–428)	*Tribolium* spp. and *Sitophilus* spp.
Oats	1,449 (157–2,923)	*Tribolium* spp. and sawtoothed grain beetle

bins identified as having been fumigated was essentially the same as for all bins with live insects found in 25% of the fumigated wheat bins, 53% of the oats, and 75% of the corn. Most of the grain samples from fumigated bins also contained high densities of dead adult insects, especially *Tribolium* spp. (red and confused flour beetle) (Table 4).

Malathion Incidence and Residue Analysis. Biologically active deposits of malathion were detected on only 14.6% of the wheat samples, 8.2% of the corn, and 4.2% of the oats (Table 5). The limited use of malathion observed in farm-stored grain was consistent with the incidence of malathion found on grain arriving at export terminals—i.e., of 11.6% for wheat and 7.7% for corn (Storey et al. 1982). Among states from which more than 25 samples were analyzed, the incidence of malathion was most frequent on wheat from Washington, Kansas, Oregon, Colorado, and Nebraska (51.9–34.8%) and least frequent on wheat from North Dakota, Minnesota, and South Dakota (6.1–10.5%). Malathion occurred most often on corn from Kansas, Illinois, Missouri, and Nebraska (19.0–10%) and least often on corn from Wisconsin, South Dakota, North Dakota, and Michigan (1.0–4.7%). Malathion treatments in oats ranged from 9.0% of the samples from North Dakota to only 2.8% of the oats from Minnesota.

Concentrations of malthion detected in the grain samples ranged from trace levels (less than 0.1 ppm) to a few samples containing in excess of 50 ppm. Nearly half of the samples in which malathion residues were analyzed contained concentrations of 2 ppm or less, a level generally considered only marginally effective. Nevertheless, when malathion was present, the incidence, number of different species, and density of most species were generally less (Table 5). This was particularly evident in wheat in which the incidence of insects was nearly 4-fold greater in untreated wheat (28.2%) than in treated wheat (7.5%) and both density and number of different species was about twice as high in untreated as in treated wheat.

One species not materially affected by malathion treatments was *Plodia interpunctella* (Hübner) (Indianmeal moth). This species was detected nearly twice as often in malathion-treated corn (47.3%) as in untreated corn (25.9%) and also occurred in slightly more of the malathion-treated wheat (1.0%) than in untreated wheat (0.7%). If

Table 5. Incidence and density of insects in malathion-treated grain versus untreated grain stored on the farm

Factor	Wheat (4,171 samples)	Corn (2,918 samples)	Oats (1,050 samples)
Malathion-treated grain (% of all samples)	14.6	8.2	4.2
% Infested	7.5	67.8	25.0
Avg. density/1,000 g	58	20	64
No. of species/groups of species	7	12	4
Untreated grain (% of all samples)	85.4	91.8	95.8
% Infested	28.2	80.8	57.8
Avg. density/1,000 g	96	35	39
No. of species/groups of species	15	24	12

this species is omitted from comparisons of treated and untreated grain the incidence of insects in treated corn drops from 67.8 to 31.8% and the average density declines from 20 to only 5 insects per 1,000 g. Omitting Indianmeal moth from comparisons in wheat has little impact on insect incidence, because this species occurred in less than 1% of the samples. However, because they were frequently present in great numbers, their omission reduces the average density in malathion-treated wheat from 58 to 21 per 1,000 g for all other species.

Although species other than Indianmeal moths were found in treated grain, nearly two-thirds of these insects were present in samples containing malathion residues of only 2 ppm or less. The most frequent species found in malathion-treated wheat were *Cryptolestes* spp. (2.5%), *Tribolium* spp. (2.1%), and *Rhyzopertha dominica* (F.) (2.0%). The most frequent species other than Indianmeal moth found in malathion-treated corn were *Cryptolestes* spp. (20.1%) and *Tribolium* spp. (14.6%). *Oryzaephilus surinamenis* (L.) (15.9%) and *Cryptolestes* spp. (9.1%) were the most frequent species found in malathion-treated oats.

Species generally associated with damp or moldy grain were seldom found in malathion-treated grain. However, increased grain moisture did have an adverse effect on the protection provided by malathion treatments (Table 6). The incidence of live insects was consistently less in treated than in untreated wheat and corn throughout all moisture levels from <10 to 13%, but the effectiveness of malathion decreased substantially at moisture levels above 12%.

Discussion

Data obtained in producer responses together with the biological information developed during analyses of farm-stored grain suggest the following characteristics:

(1) Actions taken by producers to maintain the quality of grain during storage on the farm are minimal; once grain is placed in storage, it is left relatively undisturbed.

(2) Except for wheat stored in Kansas, Colorado, Nebraska, Washington, and Oregon, malathion treatment is not a common management practice in grain stored on the farm.

(3) Less than 10% of the grain stored on the farm is fumigated during storage periods of 1 to 4 years.

(4) Carbon tetrachloride-based, liquid fumigants are still the principal type used in oats and corn, but have declined in use in wheat in favor of phosphine-producing fumigants.

(5) High densities of dead insects present in grain reported as fumigated suggest that decisions to fumigate are often delayed until damaging levels of infestation have developed.

When responses obtained from producer interviews and our own assessments of malathion use are compared with the overall incidence and density of insects found in farm-stored grain, it is evident that actions currently taken by producers to maintain the quality of grain during storage are inadequate to effectively reduce losses caused by insect attack. No pretreatment of bins before loading was reported by producers, nor was any regularly scheduled inspection program in evidence.

Table 6. Effect of moisture content on the incidence of insects in malathion-treated grain stored on the farm

Commodity/factor	No. of samples	Moisture range (% of samples with live insects)				
		<10	10–10.9	11–11.9	12–12.0	>13
Wheat						
Untreated	3,560	13.8	17.2	26.5	41.1	55.0
Malathion treated	611	6.4	5.3	8.0	9.4	21.7
Corn (without Indianmeal moth)						
Untreated	2,679	57.6	67.5	73.8	79.4	78.9
Malathion treated	239	22.2	20.8	28.9	38.6	50.0

Fumigation does not appear to be a commonly used action to control insects in farm-stored grain. The high numbers of dead adult insects in "fumigated" grain indicate that damaging insect populations were usually present when grain was fumigated. Therefore, the remedial action served mainly to halt further destruction of the grain, but did not prevent reinfestation of the treated grain at nearly the same frequency as nonfumigated grain.

It is difficult to understand why malathion, the only readily available chemical grain protectant presently approved for direct application to grain, is used so infrequently. With application expense generally less than 1 cent per bushel, cost should not be a major deterrent. Furthermore, data obtained in this study suggest that malathion is still sufficiently effective in limiting insect development to warrant its continued use.

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