LABORATORY EVALUATION OF EMULSIFIABLE AND ENCAPSULATED FORMULATIONS OF MALATHION AND FENITROTHION ON SOFT RED WINTER WHEAT AGAINST STORED PRODUCT INSECTS

by

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INTRODUCTION

Present day practices in the storage and marketing of grain and grain products make it necessary to take rather drastic measures to protect such produce from stored product insects. The variety of conditions under which the food is usually stored increases the danger of damage and spoilage, which can be attributed to many species of insects.

Residual insecticides have an important role in the control and prevention of insect infestation in stored products. However, proper storage sanitation and good practices and handling are very important to obtain the greatest benefits from grain protectants. Malathion, O, O-dimethyl dithiophosphate of diethyle mercaptosuccinate, a well-known organophosphorous insecticide of relatively low mammalian toxicity coupled with high insecticidal activity is probably the most commonly used insecticide for the control of stored-product insects in grain. However, strains of some stored-product insects have developed resistance to the killing action of malathion residue. Parkin & Foster (1962) reported that a strain of *Tribolium castaneum* (Herbst) in North Nigeria has developed a resistance to malathion approximately 52 times greater than that of a standard laboratory strain. Others have reported resistant strains from locations of all parts of the world (Parkin 1965, Spiers et al. 1964, 1967, Champ and Campbell 1970, Dyte and Dorothy 1970). Consequently, the need for new insecticides or insecticidal formulations as grain protectants exists. Fenitrothion, O, O-dimethyl, O-(3-methyl 4-nitrophenyl) phosporothioate is one such candidate chemical (Tyler and Green 1968). Although fenitrothion is not yet recommended by FAO for grain protection, there have been many studies carried out to assess the effectiveness of this compound as a grain protectant (Strong and Sbur 1965, Lemon 1966, Green and Tyler 1966, Champ et al. 1969, Kane and Green 1969, Weaving 1975). It is an organophosphorous insecticide which exhibits a relatively low mammalian toxicity, compared to a generic relative, methyl parathion, accompanied with high insecticidal activity as a contact and stomach poison.

The objective of this study was to compare the effectiveness of sprays prepared from emulsifiable concentrates and encapsulated formulations of fenitrothion and malathion applied to soft red winter wheat as residual protectants against the attack by rice weevils, Sitophilus oryzae (L.); confused flour beetles, Tribolium confusum (Duval); red flour beetles, T. castaneum (Herbst); and lesser grain borers, Rhyzopertha dominica (F.). Residue analyses were determined by gas liquid chromatography (GLC) at regular intervals throughout the study to establish the degradation rates of the different formulations.

REVIEW OF LITERATURE

Many insecticides have been assessed as grain protectants both in laboratory and field scale trials. Malathion is the principal organophosphorus insecticide used in protective treatments on stored grain. Fenitrothion has been suggested as another protectant material. Strong and Sbur (1965) found that fenitrothion was more effective on wheat than malathion against rice weevils, granary weevils, *S. granarius* (L.), and confused flour beetles in studies where mortality of test insects was the only criterion used to measure the effectiveness of the deposits. Lemon (1966) found that fenitrothion was more effective than malathion against red flour beetles and confused flour beetles. Lemon (1967) also found fenitrothion to be considerably more toxic than malathion against ten species of stored-product insects, including *Sitophilus spp*. and *Tribolium spp*. Tyler and Green (1968) reported that the effectiveness of 2.0 ppm fenitrothion was similar to that of 10 ppm malathion when they compared the two chemicals on wheat and barley under severe practical conditions.

A field study by Green and Tyler (1966) compared malathion, dichlorvos and fenitrothion for the control of saw-toothed grain beetles, Oryzaephilus surinamensis (L.) infesting barley, indicated that fenitrothion was satisfactory when applied at 2.0 ppm. After 15 weeks of storage, they recovered .39 and .40 ppm of residues from barley that had been treated with 1.0 and 2.0 ppm, respectively. Kane and Tyler (1968) studied the protection of bagged wheat from insect infestation by using fenitrothion emulsion. The wheat (11% moisture content) was stored at 25°C and 60% RH under conditions of heavy infestation of saw-toothed grain beetles, granary weevils and red flour beetles. They found that red flour beetles were the most tolerant species and saw-toothed grain beetles were the most susceptible species. Kane and Tyler (1968) applied fenitrothion emulsion to the wheat at the rates of 1.0, 2.0 and 4.0 ppm. They reported that the residues recovered after 9 months of storage were .2, .4, and 1.1 ppm, respectively. Weaving (1975) reported that a dose of 8 ppm fenitrothion on maize (corn) was much more effective than an equal dose of malathion in controlling the maize weevil, S. zeamaiz (Motschulsky); however, there was a difference of only 12% in the reduction of the number of F_1 progeny after 12 months of storage.

Parkin and Horler (1967) reported that fenitrothion residues decreased when wheat freshly-treated with 5.0 ppm fenitrothion was subjected to milling and baking tests. Before milling

3.9 ppm of the applied dose was recovered and only .9 ppm was recovered from the milled flour. Fenitrothion was not detected in the loaf after baking. In comparing the effectiveness of malathion, diazinon, fenitrothion, and dichlorovos against rice weevils, and lesser grain borers, Champ et al. (1969) reported that fenitrothion was satisfactory as a residual material for control of both species. They also reported that fenitrothion was the outstanding residual material for reducing emergence of rice weevil adults from infested grain.

Strong and Sbur (1964) studied the effectiveness of an acetone solution of malathion applied to wheat internally infested with rice weevils and lesser grain borers, and found 10 and 29 percent reductions in the total numbers of rice weevil adults emerging from 10 and 20 ppm treatments respectively, and concluded that malathion treatments have little value in preventing emergence of rice weevil from internally infested kernels. The total number of lesser grain borer adults emerging from wheat infested prior to treatment was not reduced with 20.0 ppm treatments; but an 81 percent reduction in the population of live insects were recorded from this dosage.

The degradation rate of an insecticide on grain is influenced by many physical and enzymic factors and by the time the residues are exposed to these factors. Strong and Sbur (1961) studied the loss of effectiveness of malathion applied to wheat with moisture contents ranging from 10 to 20 percent. Reduction in mortalities of *S. granarius*, *S. oryzae* and *T. castaneum* was observed with increase in moisture content. They found that malathion remained effective for a considerable time on wheat with a 12 percent moisture content, but that the toxicity decreased very rapidly on grains containing more than 14 percent moisture content; which they considered to be the critical level of moisture in wheat. The decrease in effectiveness of malathion in grain with moisture content above the critical level is explained by the appearance of free water in the grain which is a necessary prerequisite for enzymic activity (Rowlands 1967, Kadoum and La Hue 1969). Rowlands (1966) reported that the moisture content of wheat affected the hydrolysis of malathion. He found that wheat with 18 percent moisture content showed the highest esterase and acid phosphatase activities. Grain at moisture levels of 11, 12 and 14 percent were roughly equal in activity, but significantly less than grain of 18 percent moisture content. He concluded that enzymic activity of grain has a great influence on the residual life of grain protectants. Rowland (1964) reported that the rate of degradation of malathion on living wheat was greater than that on dead wheat or living maize. Kadoum and La Hue (1972) in a 9-month study of the effect of viable and sterilized sorghum grain on malathion degradation found that more residues were retained by sterilized than by live sorghum grain. It was suggested that the biological activity of viable kernels greatly reduced the persistence of malathion. Rowlands (1965) determined by in vivo and in vitro methods that wheat grain oxidase systems were capable of activating malathion to malaoxon. Anti-cholinesterase metabolites other than malaoxon were identified as malaoxon monoacid and malaoxon diacid. Although these compounds are less potent inhibitors than malaoxon, it was noted that these compounds were probably present in greater quantities and resulted from hydrolysis of malaoxon. Rowland (1966) found that the oxidative activity was noted in the outer pericarp and germ and more was found in the starch endosperm. He also discovered that thioloxidase activity in wheat, capable of oxidizing malathion, is greatest immediately after harvest, but rapidly declines within a few weeks. Tyler et al. (1966) also observed more rapid degradation of malathion and fenitrothion on freshly-harvested wheat and barley than on grain which had been stored for sometime after harvest. Dissection of individual grains into pericarp, seed coat, starchy endosperm, and germ and subsequent in vitro study enabled Rowlands (1966) to locate the activity of different enzyme systems. The activity of malathion hydrolase in wheat grains was found to be greatest in the seed coat and germ; however, traces of slight activity were located in the outer pericarp and the starchy endosperm. He indicated that decarboxylase activity was predominant in the germ, although traces of activity were located in the seed coat. Degradation of insecticidal application to grain may also be affected by the penetration rate of insecticides into the kernels, which in turn is a function of many other factors such as: the nature of the insecticide, moisture content of the grain, method of application, and the type of formulation. Factors such as temperature and relative humidity are also important. Kadoum and La Hue (1972, 1974) measured the amounts of malathion that penetrated the kernels of corn, wheat and sorghum grains. They reported that all three grains showed more residues inside the kernels 1 month after treatment than they did at 24 hours, 3 and 6 months. It was suggested that malathion penetrated the kernels most rapidly during the first month after treatment. Thereafter, the degradation rate masked the rate of penetration. They concluded that the type of grain did not affect the movement of malathion residues into the kernels.

The type of formulation of an insecticide affects its stability and plays a major role in its biological effectiveness. Many reports have recorded that dust treatments have a longer effective life on stored grain than emulsion sprays. Lindgren et al. (1954) applied malathion as dusts and sprays to the whole kernels of wheat to test the effectiveness of the two formulations against rice weevils, granary weevils and lesser grain borer, and found that dust treatments appeared to be more effective than spray treatments. Similar results were obtained by La Hue (1969), who evaluated four formulations of malathion as a protectant of grain sorghum. La Hue (1969) reported that malathion dust treatment gave protection equal to that of a malathion concentrate, although the initial deposits were 12.8 and 19.74 ppm, respectively. He found that a malathion dust treatment was effective in toxicity tests using rice weevils and lesser grain borers and gave results comparable to that given by the malathion concentrate treatment. He also indicated that malathion dust treatment degraded to 2.12 ppm during the 12-month period of storage while malathion concentrate degraded to 3.14 ppm during the same period.

Among the risks involved in using the conventional formulations of insecticides is the possibility of irreversible injury to non-target organisms resulting from transport of the chemical away from its intended area of effectiveness. Pipper et al. (1948) tested a new formulation of DDT with selective properties in order to produce insecticides which could be toxic only to certain groups of insects and not to others. The formulation was prepared by coating the DDT with a degraded cellulose. They reported that this formulation eliminated the contact action of the DDT against dipterous and hymenopterous species, but retained its stomach-poisoning action against caterpillars.

Stockes et al. (1970) in chemical and biological evaluations of the release of aldicarb from granular formulations reported that certain compacted-carbon formulations prolonged the release of the chemical when compared to the standard corn cob formulations. Stockes et al. (1973) using controlled release granular formulations of aldicarb and dimethoate found that formulations prepared with selected plastics appeared to prolong the rate of release of the two toxicants when compared to the standard corn cob formulations. The authors reported also that the granular formulations extended the period for effective control of the boll weevil, *Anthonamus grandis* (Boheman), in the greenhouse. Greenhouse bioassays with cotton aphids, *Aphis gossypii* (Glover), and radioassays of plants grown in soil treated with selected granular formulations indicated that certain plastic and charcoal formulations of dimethoate extended the uptake from soil and prolonged biological activity.

Coppedge et al. (1974) pointed out that aldicarb, when applied in the greenhouse and in the field as a compacted-carbon slow release granular formulation, was less damaging to plants and was more effective against certain cotton pests than when applied in the conventional corn cob formulation. Coppedge et al. (1975) with three types of granular formulations of aldicarb, dimethoate, methomyl and disulfoton found that the slow-release formulations of aldicarb and dimethoate improved the systemic activity of these two chemicals against cotton aphids. They also pointed out that although the methomyl slow-release formulations was only slightly more effective than fast-release formulation, and that this slight difference may be due to the fact that methomyl has only limited effectiveness against aphids. They also suggested that different types of formulations other than the ones tested may be necessary for a low water soluble toxicant, such as disulfoton which was less effective in slow release formulation against cotton aphids than the fast release formulation. The authors concluded that the three types of formulations tested released the toxicant at three distinctly different rates.

Another approach for increasing specificity and controlling persistence is the microencapsulation of the pesticide. Gordon (1965) defined microencapsulation as a chemical process whereby droplets of particles are coated with a suitable material to form a uniform coating which is solidified or polymerized to form a wall around the particle and extremely small microcapsules can be produced. Phillips (1968) introduced microencapsulation as a method for increasing specificity and controlling persistence of particles and reported that kerosene solutions of DDT and BHC were enclosed in a hardened gelatin wall material in large (about 600 u diam.) and small (10-40 u diam.) capsules. When dry, the fresh capsules had no contact activity against adult houseflies (*Musca domestica*) or adult beetles (*T. castaneum*). Ruptured capsules killed these insects. Boiling in water did not cause the capsules to leak, and this water, when cooled, was harmless to houseflies. However, cabbage white butterflies and mustard beetle larvae which fed on leaf discs mixed with capsules died.

As indicated, there is a growing awareness that methods of using recommended insecticides can be found to decrease the number of applications required and the total amount needed which would probably reduce the cost of using insecticides. Recently, much interest has centered on new methods and formulations to slow the release of insecticides and thus extending the period of insecticidal activity. Slow release formulation, by retarding decomposition by sunlight, oxygen, and moisture, could make an insecticide more economical to use and possibly more effective (Sanders 1965). Research concerning the use of controlled released insecticides as grain protectants has not been reported at this date. Hence, the present study was initiated to demonstrate the degradation rate of encapsulated malathion and fenitrothion compared to emulsifiable concentrate of both compounds as grain protectants. The effectiveness of these formulations as protectants on wheat against adult rice weevils, lesser grain borers, red flour beetles and confused flour beetles, and the effect of preventing the reinfestation of these insects by F_1 progeny to the treated wheat were established.

MATERIALS AND METHODS

Wheat Preparation

Cleaned uninfested soft red winter wheat of approximately 13.8% moisture content was dried to 12.5 + .1% moisture using a forced-air laboratory dryer at 105-110°F. Moisture content was determined with Steinlite 512 RC moisture tester. Lots of 1.0 kilogram of tempered wheat were placed in 3.8-liter wide mouth glass jars for treatment.

Chemicals and Wheat Treatment

Water sprays prepared from fenitrothion EC (Sumithion(R) 1054.6g AI/l), encapsulated fenitrothion (Sumithion TD 2011, 317.6g AI/l), Malathion(R) EC 500g AI/l) and encapsulated malathion (Pennwalt 73-30, 310g AI/l) were applied at doses of 2.5, 5.0, 7.5, and 10.0 ppm. The sprays which were prepared immediately before use were kept in constant agitation at ca 25°C, the temperature of the grain when treated. Applications were made with a 1-ml volumetric pipette to the inside wall of the 3.8-liter glass jars above the grain level while the jars were turning on a 33-rpm turntable. Immediately after application, the jars were shaken by hand for 25-30 seconds and then rotated end-over-end for 15 minutes on a mechanical tumbler to mix the insecticides with the grain. The treated jars were maintained at 80°F and 60 ± 5% RH. Lots of untreated tempered wheat were placed in similar jars as controls. For Tribolium species tests, samples of all treatments were ground and maintained under the same conditions. Each application for each dosage was replicated four times.

Test Insects and Infestation of Treated Wheat

Test insects were reared in an incubator maintained at 26.7 ± 1.1°C and 60 ± 5% RH. The 14-day-old rice weevil, and lesser grain borer adults used in the test, were reared on hard winter wheat containing 12.5% moisture. The 21-day-old red flour beetles and confused flour beetles were reared on a standard laboratory culture medium containing 10 parts flour, 10 parts yellow cornmeal, and 1.5 parts brewer's yeast. After residue aging periods of 1, 3, 6, 9 and 12 months in the covered jars, 250-g samples of the wheat were removed and placed in 473-ml glass mason jars for the toxicity exposures. The test jars were fitted with rings, 40-mesh screens, and filter paper lids. About 50 unsexed adult insects were placed in individual samples and were exposed for 21 days to the deposits remaining on and in the wheat kernels. Live insects were placed back in the individual samples for progeny counts. The F_1 progeny counts of rice weevils, and lesser grain borers, were conducted 30 and 38 days respectively after the mortality readings, while 45 days were allowed for red and confused flour beetles. Each exposure was replicated 4 times.

Chemical residues determination

Samples drawn for chemical analysis 24 hours after application and after 1, 2, 3, 6, 9 and 12 months storage of the wheat were held in a deep freeze at -20°C until analyzed. Both chemical residues were determined using a modification of Kadoum's (1968) for GLC analysis. Each sample of 20g of treated wheat was blended after the required aging period with 100 ml of redistilled acetone in a covered omni-mixer at top speed for 1.5 minutes. The extract was then concentrated to about 2.0 ml under vacuum in a water bath at 40°C. The residues were transferred using 10 ml n-hexane to a 250 ml separatory funnel containing 100 ml distilled water. Funnels were vigorously shaken for 30 sec. and, after the two layers separated, the lower (aqueous) layer was drawn off and discarded. The upper layer (hexane) was partitioned with 80% acetonitrile in water for analysis. A flame photometric detector was used to analyze both chemicals under the following operating conditions: a 3-foot glass column of 2% DC-200, 2% QF1; nitrogen was used as a carrier gas, temperature of column, 185°C; detector cell, 200°C; and injector, 215°C. Volume injected was 4 ul of the extract in n-hexane.

Standards for the analyses were prepared by dissolving 95% analytical grade malathion and 99 percent analytical grade fenitrothion in redistilled n-hexane.

RESULTS AND DISCUSSION

Residues

Sufficient amounts of soft red winter wheat were treated for all residue and toxicity studies during the 12-month period of storage. The results of the residue analyses are listed in Table 1.

Residues recovered from malathion emulsion treatments after 24 hr. of application were 7.8, 6.0, 3.9 and 1.9 ppm from the applied dosages of 10, 7.5, 5.0 and 2.5 ppm, respectively. The residues degraded gradually during the 12-month storage period, and 1.0 ppm was recovered from wheat treated with 10 ppm at the end of the 12-month study. However, .2 ppm was recovered from the 2.5 treatment after 12 months.

Breakdown of encapsulated malathion was similar to that of emulsifiable concentrate. The residues recovered from wheat taken 24 hr. after treatment were 8.3, 5.9, 4.2 and 2.3 ppm from the rates of 10, 7.5, 5.0 and 2.5 ppm, respectively. All dosages degraded gradually with time and 1.2 ppm was recovered from 10-ppm treatment after 12 months. Residues recovered from encapsulated malathion treatments were significantly ($P \leq .05$) higher than that of emulsifiable concentrate during the 12-month study.

Fenitrothion emulsion residues recovered from wheat treated with 10, 7.5, 5.0 and 2.5 dosages were 8.8, 6.3, 4.4 and 2.2 ppm, while the residues recovered from encapsulated fenitrothion treatments were 8.6, 6.5, 3.8 and 2.0 ppm 24 hr. posttreatment. The subsequent determinations of fenitrothion residues during the 12-month storage period show that the deposits of the emulsifiable concentrate decreased gradually with time to 1.0, 0.8, 0.5 and 0.3 ppm at the end of 12 months. Kane and Green (1968) reported similar findings. The amounts recovered from fenitrothion encapsulated treatments at the end of the 12-month study were .90, 0.8, 0.4 and 0.3 ppm from the dosages of 10, 7.5, 5.0 and 2.5 respectively. Residues recovered from fenitrothion emulsion treatments were significantly ($P \leq .05$) higher than the residues recovered from encapsulated treatments during the 12-month study.

Under the conditions cited, similar patterns of degradation were obtained from both formulations throughout the storage period. There were no significant differences in the rates of breakdown of the two formulations of malathion and fenitrothion during the 12 months. Results showed that the breakdown rate of malathion was similar to that of fenitrothion. Tyler and Green (1968) reported that the persistence of fenitrothion on grain was similar to that of malathion.

Table 1

Average residues in ppm on soft red winter wheat during a 12-month storage period (a)

Dose (ppm)	24 hr	Months of storage 1	2	3	6	9	12
		Malathion emulsion					
10.0	7.8	5.5	3.4	2.9	2.7	1.7	1.0
7.5	6.0	3.8	2.6	2.4	2.0	1.5	.7
5.0	3.9	2.4	1.9	1.6	1.0	.8	.5
2.5	1.9	1.3	1.1	.7	.4	.4	.2
		Encapsulated malathion					
10.0	8.3	6.1	3.6	3.1	2.8	1.9	1.2
7.5	5.9	3.7	2.6	2.3	1.9	1.3	.8
5.0	4.2	2.5	2.0	1.7	1.2	.7	.5
2.5	2.3	1.5	.9	.6	.4	.4	.3
		Fenitrothion emulsion					
10.0	8.8	6.3	4.3	3.7	2.6	2.0	1.0
7.5	6.3	4.0	2.6	2.2	1.6	1.5	.8
5.0	4.4	2.9	2.2	1.8	1.2	1.1	.5
2.5	2.2	1.5	1.0	.9	.7	.5	.3
		Encapsulated fenitrothion					
10.0	8.6	6.1	4.4	3.9	2.4	2.0	0.9
7.5	6.5	4.3	3.0	2.4	1.6	1.6	.8
5.0	3.8	2.5	1.9	1.6	1.0	.9	.3
2.5	2.0	1.3	1.0	.8	.6	.4	.3

(a) average of four replicates.

PLATE 1

Malathion residues recovered from wheat treated with emulsifiable concentrate and encapsulated formulations during 12-month period.

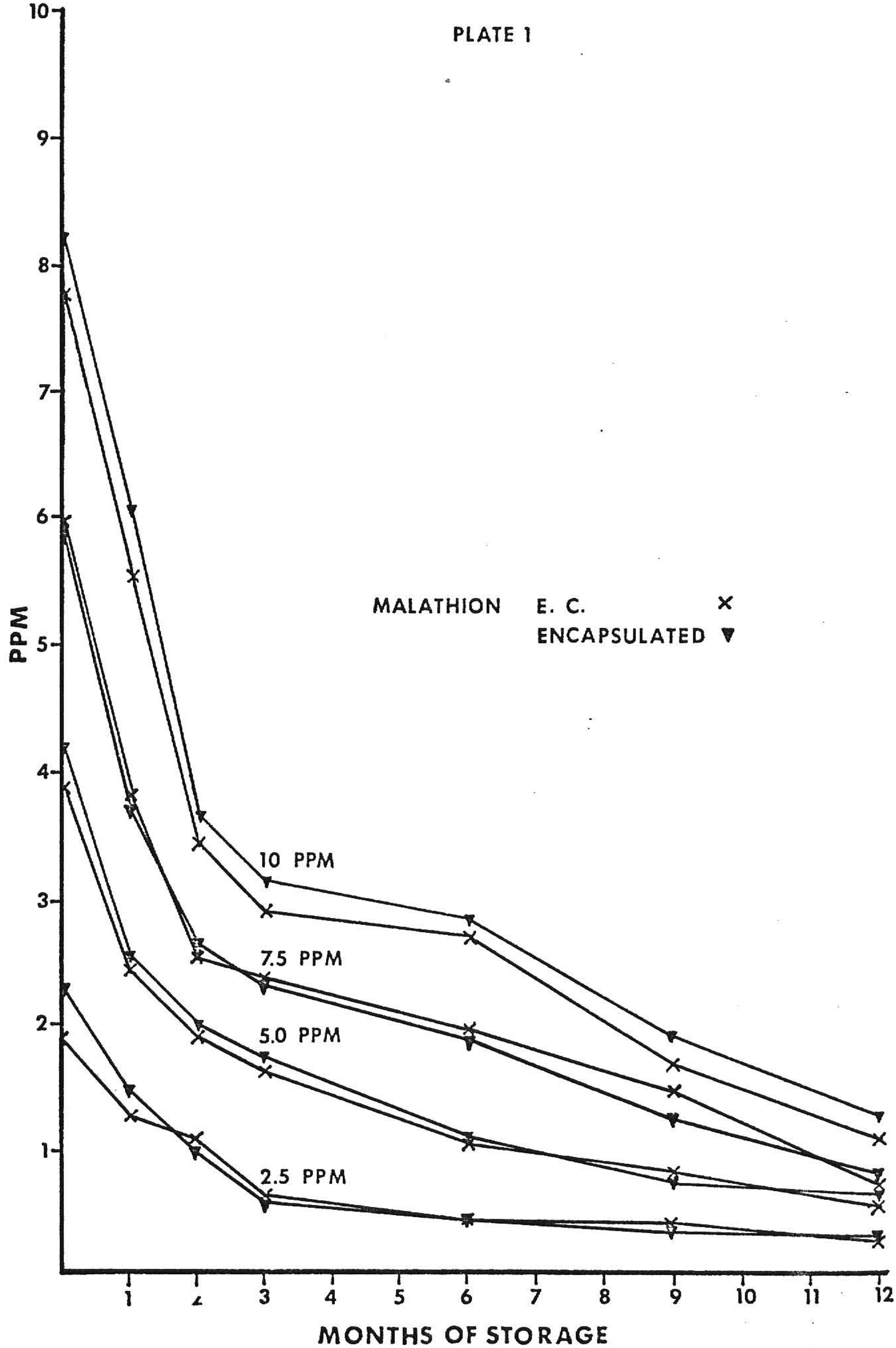
PLATE 1
PPM
10
9
8
7
6
5
4
3
2
1
MALATHION E. C. ×
ENCAPSULATED ▼
10 PPM
7.5 PPM
5.0 PPM
2.5 PPM
1
2
3
4
5
6
7
8
9
10
11
12
MONTHS OF STORAGE

PLATE 2

Fenitrothion residues recovered from wheat treated with emulsifiable concentrate and encapsulated formulations during 12-month period.

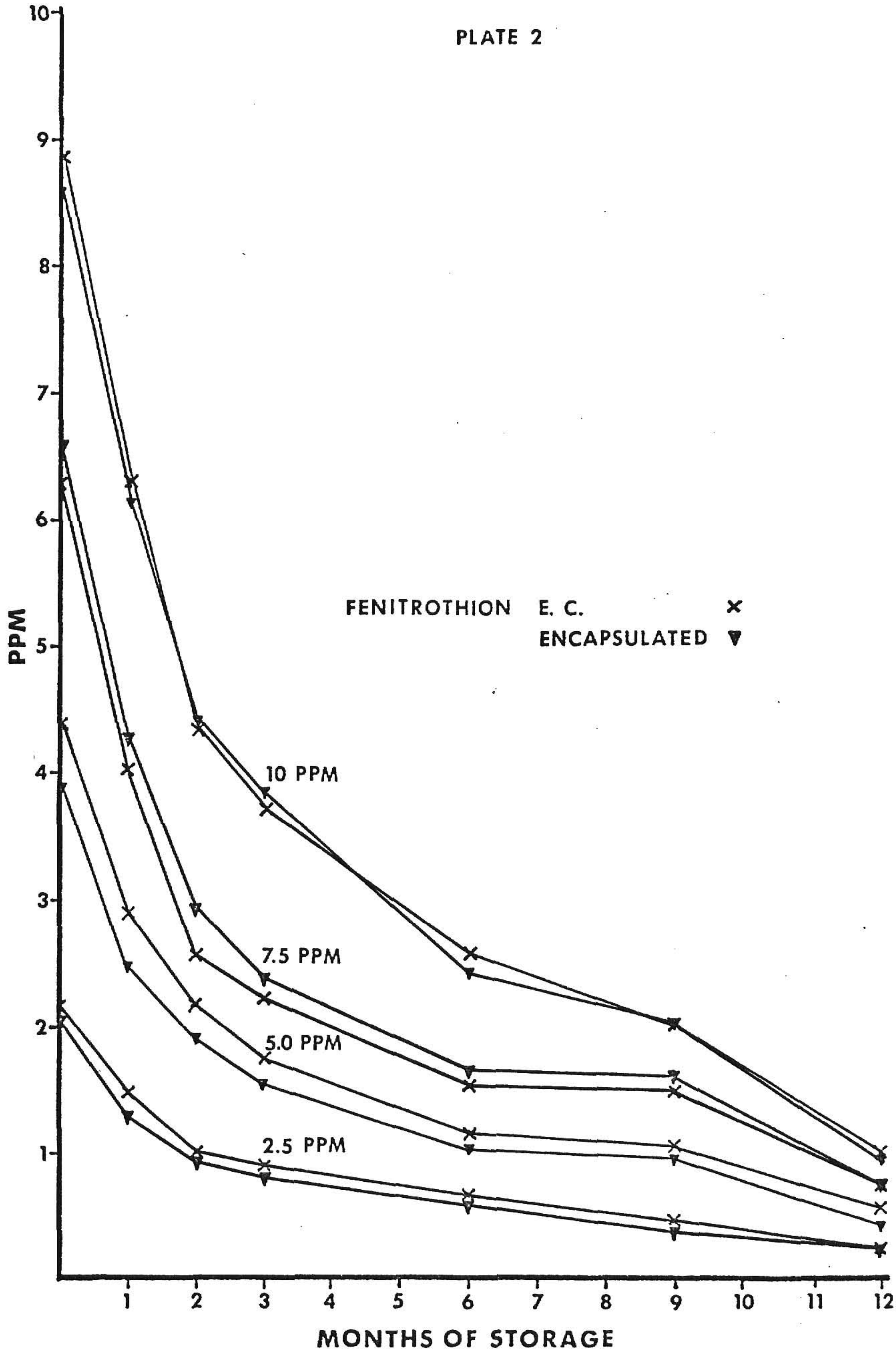
PLATE 2
FENITROTHION E. C. ×
ENCAPSULATED ▼
10 PPM
7.5 PPM
5.0 PPM
2.5 PPM
PPM
MONTHS OF STORAGE
0
1
2
3
4
5
6
7
8
9
10
11
12

Mortalities obtained from malathion treatments

Insects were considered dead if there was no indication of movement of any kind. There were no mortalities of the insects in the untreated (control) samples.

The results of toxicity tests obtained from wheat treated with malathion emulsion are presented in Table 2. The results show that the two highest rates of application gave complete kill of rice weevils throughout the 6-month period of storage, and a gradual loss of effectiveness occurred thereafter. Rapid loss of effectiveness of the 2.5-ppm dose was noticed during the first three months of storage and only 2.6% kill was achieved 9 months posttreatment.

Lesser grain borer adults were less susceptible to malathion emulsion treatments than rice weevil. The 10 and 7.5 ppm dosages gave complete kill only for the first month of storage. The effectiveness of 10 ppm decreased gradually thereafter and only an average of 9.1% kill was recorded 12 months after treatment. The two lowest dosages failed to achieve complete kill during the first month of storage. The effectiveness of the 2.5 ppm dose was diminished completely after 12 months of storage.

All dosages failed to give complete kill of red flour beetle adults 3 months after treatment. The 10 ppm dosage gave

94.1% kill 3 months posttreatment, but its effectiveness dropped rapidly thereafter. The effectiveness of the 2.5 ppm dose diminished completely during the first six months of storage.

Confused flour beetles were the least susceptible species to malathion treatments; only 38% were killed when exposed to 2.5 ppm dosage after one month. The 10 ppm level gave 2.0% kill after 12 months, while the effectiveness of the other three dosages was nil.

Results of encapsulated malathion are presented in Table 3. There were no significant differences ($P \leq .05$) observed between the two formulations against all insects tested.

<u>Mortalities obtained from fenitrothion treatments</u>

Results of fenitrothion emulsion treatments are presented in Table 4. The mortalities from all dosages show that fenitrothion emulsion was more effective against rice weevil than was malathion. The highest three dosages of fenitrothion emulsion treatments resulted in 100% mortalities of rice weevils throughout the 12-month period. The 2.5 ppm dosage gave a complete kill up to 9 months after treatment and 93.5% mortality from the tests conducted 12 months posttreatment. All dosages of fenitrothion emulsion were much less effective against lesser grain borers than against rice weevils. The 10 ppm dosage gave complete kill for the first month and the effectiveness decreased gradually thereafter to give only 30.4% mortality after 12 months. The 2.5 ppm gave 91.3% kill for the first month, but only 27% after 3 months.

Fenitrothion emulsion treatments were more effective against red flour beetles than against lesser grain borers. Complete mortalities were obtained with all dosages after 1 month. The 10 ppm dosage maintained 100% kill up to 6 months after treatment, and 98 and 49.5% after 9 and 12 months. The 2.5 ppm rate gave 75.6, 17.0, 10.9 and 6.0% mortalities after 3, 6, 9 and 12 months, respectively.

All dosages of fenitrothion emulsion gave complete kill of adult confused flour beetles for the first month. The 2.5 ppm had lost its effectiveness 6 months posttreatment, and gave only 9.5% kill. The 10 ppm level maintained complete kill up to 3 months, but its effectiveness decreased thereafter until only 6.9 mortality was achieved 12 months posttreatment. Results were similar for all dosages of fenitrothion encapsulation as for the emulsion formulation against rice weevils and lesser grain borers. However, fenitrothion emulsion treatments were significantly ($P \leq .05$) more effective than encapsulated fenitrothion treatments against red and confused flour beetles. The difference in effectiveness is probably due to the difference in the initial deposits of each formulation when applied to wheat.

Table 2

Average percentage mortality of adult insects exposed for 21 days to soft winter wheat treated with malathion emulsion sprays (a)

Dosage (ppm)	Months in storage after treatment				
	1	3	6	9	12
			Rice weevil		
10.0	100.0	100.0	100.0	89.0	78.0
7.5	100.0	100.0	100.0	69.6	50.5
5.0	100.0	100.0	80.0	26.5	13.4
2.5	100.0	71.9	18.8	2.6	2.0
			Lesser grain borer		
10.0	100.0	95.2	59.0	43.8	9.1
7.5	100.0	87.9	37.5	28.1	1.9
5.0	97.0	61.5	29.1	20.0	1.2
2.5	87.0	33.5	20.1	2.8	0
			Red flour beetle		
10.0	100.0	94.1	28.0	8.0	2.0
7.5	100.0	93.4	16.3	4.9	1.4
5.0	100.0	52.4	7.5	1.0	0
2.5	97.5	9.5	0	0	0
			Confused flour beetle		
10.0	100.0	75.5	30.2	4.0	2.0
7.5	100.0	71.5	26.0	4.7	0
5.0	99.0	18.5	2.0	.5	0
2.5	38.0	1.5	0	0	0

(a) average of four replicates.

Table 3

Average percentage mortality of adult insects exposed for 21 days to soft winter wheat treated with malathion encapsulated sprays (Pennwalt Batch 73-30) (a)

Dosage (ppm)	Months in storage after treatment 1	3	6	9	12
	Rice weevil				
10.0	100.0	100.0	100.0	97.0	79.2
7.5	100.0	100.0	100.0	52.0	47.0
5.0	100.0	100.0	82.0	23.2	12.2
2.5	100.0	64.5	18.3	2.5	2.3
	Lesser grain borer				
10.0	100.0	95.0	69.3	62.1	9.0
7.5	100.0	82.3	38.2	25.1	1.9
5.0	94.1	50.3	24.6	22.1	1.9
2.5	90.0	35.8	15.7	2.6	0
	Red flour beetle				
10.0	100.0	100.0	39.0	13.0	1.4
7.5	100.0	84.8	12.5	5.6	1.6
5.0	100.0	55.4	7.0	1.5	0
2.5	95.5	9.3	.3	0	0
	Confused flour beetle				
10.0	100.0	95.5	36.3	6.4	1.8
7.5	100.0	73.7	28.2	2.5	0
5.0	99.0	13.5	2.5	0	0
2.5	41.5	.9	0	0	0

(a) average of four replicates.

Table 4

Average percentage mortality of adult insects exposed for 21 days to soft red winter wheat treated with fenitrothion emulsion sprays (Sumithion(R) EC) (a)

Dosage (ppm)	Months in storage after treatment				
	1	3	6	9	12
			Rice weevil		
10.00	100.0	100.0	100.0	100.0	100.0
7.5	100.0	100.0	100.0	100.0	100.0
5.0	100.0	100.0	100.0	100.0	100.0
2.5	100.0	100.0	100.0	100.0	93.5
			Lesser grain borer		
10.0	100.0	98.0	75.8	61.7	30.4
7.5	100.0	86.3	59.7	34.2	29.6
5.0	99.0	51.1	28.4	15.0	10.5
2.5	91.3	27.0	16.8	11.6	8.6
			Red flour beetle		
10.0	100.0	100.0	100.0	98.0	49.5
7.5	100.0	100.0	84.4	67.4	33.6
5.0	100.0	99.0	69.8	59.4	9.3
2.5	100.0	75.6	17.0	10.9	6.0
			Confused flour beetle		
10.0	100.0	100.0	54.1	21.0	6.9
7.5	100.0	93.2	15.9	8.3	3.5
5.0	100.0	57.7	12.5	3.5	1.0
2.5	100.0	9.4	0	0	0

(a) average of four replicates.

Table 5

Average percentage mortality of adult insects exposed for 21 days to soft winter wheat treated with fenitrothion encapsulated sprays (Sumithion TD 2011) (a)

Dosage	Months in storage after treatment				
(ppm)	1	3	6	9	12
			Rice weevil		
10.0	100.0	100.0	100.0	100.0	100.0
7.5	100.0	100.0	100.0	100.0	100.0
5.0	100.0	100.0	100.0	100.0	100.0
2.5	100.0	100.0	100.0	100.0	87.9
			Lesser grain borer		
10.0	100.0	98.0	88.3	58.7	32.9
7.5	100.0	96.7	69.2	42.7	31.0
5.0	99.5	44.9	24.2	18.3	12.0
2.5	86.0	27.7	17.2	10.2	6.9
			Red flour beetle		
10.0	100.0	100.0	100.0	92.3	36.0
7.5	100.0	100.0	79.5	59.3	34.8
5.0	100.0	98.0	58.0	38.2	10.2
2.5	100.0	62.7	15.2	9.8	6.7
			Confused flour beetle		
10.0	100.0	100.0	59.5	17.1	7.5
7.5	100.0	90.5	12.1	10.1	1.9
5.0	100.0	46.0	10.5	1.0	1.0
2.5	98.5	4.3	0	0	0

(a) average of four replicates.

Rice Weevil

The average total percentage mortality indicates that rice weevil adults were the most susceptible species to both chemicals. Both emulsifiable concentrate and encapsulated malathion, at 10.0 ppm treatments, gave complete kill up to 6 months posttreatment, and 78 and 79.2% mortalities, respectively, after 12 months of storage. Fenitrothion treatments of both formulations also gave comparable results. The 2.5 ppm of emulsion and encapsulated fenitrothion gave complete kill up to 9 months posttreatment and 93.5 and 87.9% mortalities after 12 months, respectively. The highest three dosages gave excellent control and accomplished 100% kill in the tests conducted after 12 months of storage. Fenitrothion was much more effective than malathion against rice weevils. These findings agree with those obtained by Strong and Sbur (1961), Lemon (1966, 1967) and Champ et al. (1969).

The progeny counts were conducted 30 days after the mortality readings. Average number of progeny produced from wheat treated with malathion emulsion sprays during the 12-month period are listed in Table 6, and those from encapsulated malathion treatments in Table 7. Malathion treatments of 2.5 ppm of both formulations gave 97% reduction of rice weevil progeny produced from weevils exposed to the wheat 1-month posttreatment. After

12 months of storage, the 2.5 ppm treatments of both formulations did not cause any reduction in the number of rice weevils produced compared to the control treatments, while at 10 ppm dosages, there was about 64 and 52% reduction in emerging progeny from malathion EC and encapsulated treatments, respectively. Fenitrothion was much more effective in suppressing the progeny production of rice weevils than was malathion. Tests conducted 12 months posttreatment showed that 2.5 ppm emulsifiable concentrate and encapsulated gave 68.5 and 60% reduction, respectively, in the numbers of progeny rice weevil adults emerged from treated wheat. These findings support Champ et al. (1969), who reported that fenitrothion was the outstanding residual material for reducing emergence of S. oryzae adults from infested grain. They also reported that death of unemerged adults was the major cause of reduction in emergence totals with fenitrothion treatments. On the other hand, in this study, there was a significant difference ($P \leq .05$) in the numbers of adult progeny emerged from fenitrothion EC and encapsulated treatments, which was not clear with malathion. All fenitrothion EC treatments were more effective in reducing the total number of adults emerged than were encapsulated treatments. These findings are probably due to the availability of the insecticide inside the kernels. Perhaps the encapsulated formulation, as suspension, left the chemical residues outside the

kernel surface while the water absorbed into the kernel while the water in EC formulation carried some of the bounding chemical into the kernel in amounts sufficient to kill insects before emergence. The difference in fenitrothion treatments was clear, probably because fenitrothion exhibits high toxicity against rice weevils.

Lesser Grain Borer

Fenitrothion and malathion residues were very much less effective against lesser grain borer adults than they were against rice weevils. Both insecticides at 5.0 ppm dosages or less failed to give complete kill after 1-month posttreatment. The 10 ppm of both formulations of malathion gave only 9.0% mortality 12 months after treatment. The effectiveness of the 2.5 ppm dosage of both formulations diminished completely at the end of the storage period. Fenitrothion treatments were more effective than malathion treatments. These findings agree with the results of Champ et al. (1969).

The progeny counts were made 38 days after the toxicity readings. The residual activity of fenitrothion was very effective against emergence of adult lesser grain borers. There were no progeny produced from all dosages of fenitrothion treatments after 12 months of storage. The 10 and 7.5 ppm dosages of malathion suppressed progeny of development completely. The 5.0 ppm malathion EC and encapsulated accomplished 87.7 and 88.5% reduction in the total number of progeny from tests conducted 12 months after treatment. There was 44 and 59.4% reduction, respectively, in the total number of progeny developed from 2.5 EC and encapsulated malathion treatments exposed to adults 12 months after treatment. Strong et al. (1967) reported that good protection against *R. dominica* was obtained by malathion treatments. It may be concluded that the susceptibility of free living first instar larvae of *R. dominica* is probably an important factor in the use of grain protectants for prevention of infestation of this species.

Red Flour Beetle

In tests 1 month after treatment, complete kill of the red flour beetle adults were obtained from all malathion dosages except 2.5 ppm. The effectiveness of the 2.5 ppm residues were nil 6 months after treatment, and only 9% kill was recorded after 3 months posttreatment. All dosages of malathion gave less than 2% mortality 12 months after treatment. Fenitrothion treatments were more effective. The 10 ppm dosage of both formulations of fenitrothion treatments gave complete kill up to 6 months after treatments. The 5.0 ppm fenitrothion treatment was more effective than the 10 ppm dosage of malathion. This agrees with Lemon (1966, 1967) and Kane and Green (1968), who reported that fenitrothion was more toxic than malathion against red flour beetles. Progeny production in fenitrothion treatments were completely suppressed with the highest three dosages during the 12-month period of storage. Few progeny were produced by the adults placed on the 2.5 ppm treated wheat 12 months posttreatment. The 2.5 ppm dosages of EC and encapsulated malathion gave 67.5 and 69.9% reduction in total numbers of progeny adults produced by parent insects exposed to the treated wheat 12 months posttreatment.

Confused Flour Beetle

Confused flour beetle was the most tolerant species to both insecticides. The 2.5 ppm dosage of malathion produced no mortality after 6 months of storage and less than 2% kill 3 months after treatment. The 5.0 ppm dosage caused less than 3.0% mortality 6 months after treatment. Fenitrothion residues were more effective in controlling adults of confused flour beetles than those of malathion residues. These results concur with those of Strong and Sbur (1965), Lemon (1966, 1967). The highest three dosages of fenitrothion treatments gave good protection and prevented progeny production within 45 days after the toxicity readings. The 2.5 ppm dosage caused about 80% reduction in the total number of adult progeny when parents were exposed to wheat 12 months after treatment. Results of 2.5 dosage of EC and encapsulated malathion treatments showed that only 40.8 and 33.5% progeny reduction, respectively, occurred in the 12 months posttreatment tests.

Table 6

Average number of F_1 progeny produced from 50 adults placed on wheat treated with malathion emulsion spray (Malathion(R) EC).

Dosage (ppm)	Months of storage after treatment 1	3	*6	9	12
			Rice weevil (b)		
2.5	13.5	232.0	620.0	475.5	427.0
5.0	0.0	34.0	430.3	418.3	405.0
7.5	0.0	1.5	250.0	319.8	253.8
10.0	0.0	0.0	98.5	146.0	145.5
Control	434.0	514.0	880.0	541.0	406.0
			Lesser grain borer (c)		
2.5	0.0	7.5	21.3	26.3	66.0
5.0	0.0	1.5	6.3	11.5	14.5
7.5	0.0	0.0	0.0	0.0	0.0
10.0	0.0	0.0	0.0	0.0	0.0
Control	101.5	111.8	163.8	102.0	117.5
			Confused flour beetle (d)		
2.5	0.0	5.5	8.0	20.8	28.3
5.0	0.0	.8	1.3	3.8	9.0
7.5	0.0	0.0	0.0	0.0	0.0
10.0	0.0	0.0	0.0	0.0	0.0
Control	54.3	58.0	68.3	48.3	47.8
			Red flour beetle (d)		
2.5	0.0	6.0	7.8	13.8	15.8
5.0	0.0	.8	2.3	3.5	7.0
7.5	0.0	0.0	0.0	0.0	0.0
10.0	0.0	0.0	0.0	0.0	0.0
Control	46.8	54.8	68.5	58.0	58.5

(a) average of four replicates.
(b) adults produced during 30-day period after mortality reading
(c) adults produced during 38-day period after mortality reading
(d) adults produced during 45-day period after mortality reading
* counts were made 5 days late

Table 7

Average number of F_1 progeny produced from 50 adults placed on wheat treated with encapsulated malathion spray (Pennwalt Batch (73-30). (a)

Dosage (ppm)	Months of storage after treatment 1	3	*6	9	12
			Rice weevil (b)		
2.5	14.0	298.8	699.5	469.0	435.0
5.0	0.0	36.0	365.3	399.5	411.0
7.5	0.0	6.2	219.3	336.0	269.0
10.0	0.0	0.0	75.8	132.5	194.5
Control	434.0	514.5	880.0	541.0	406.0
			Lesser grain borer (c)		
2.5	0.0	6.5	20.8	25.5	43.8
5.0	0.0	3.8	7.5	10.0	13.5
7.5	0.0	0.0	0.0	0.0	0.0
10.0	0.0	0.0	0.0	0.0	0.0
Control	101.5	111.8	163.8	102.0	117.5
			Confused flour beetle (d)		
2.5	0.0	2.8	10.5	23.8	31.8
5.0	0.0	.5	1.8	5.5	11.0
7.5	0.0	0.0	0.0	0.0	0.0
10.0	0.0	0.0	0.0	0.0	0.0
Control	54.3	58.0	68.3	48.3	47.8
			Red flour beetle (d)		
2.5	0.0	4.0	7.0	13.3	14.8
5.0	0.0	1.5	2.8	4.8	7.8
7.5	0.0	0.0	0.0	0.0	0.0
10.0	0.0	0.0	0.0	0.0	0.0
Control	46.8	54.8	68.5	58.0	58.5

(a) average of four replicates
(b) adults produced during 30-day period after mortality reading
(c) adults produced during 38-day period after mortality reading
(d) adults produced during 45-day period after mortality reading
* counts were made 5 days late

Table 8

Average number of F_1 progeny produced from 50 adults placed on wheat treated with fenitrothion emulsion spray (Sumithion$^{(R)}$ EC). (a)

Dosage (ppm)	Months of storage after treatment				
	1	3	6	9	12
			Rice weevil (b)		
2.5	0.0	10.3	58.0	83.8	161.0
5.0	0.0	6.3	22.3	24.5	39.0
7.5	0.0	2.5	10.0	11.7	19.3
10.0	0.0	0.0	7.3	7.3	11.8
Control	586.0	576.0	605.0	403.0	495.0

Table 9

Average number of F_1 progeny produced from 50 adults placed on wheat treated with encapsulated fenitrothion spray (Sumithion TD 2001) (a)

Dosage (ppm)	Months of storage after treatment				
	1	3	6	9	12
			Rice weevil (b)		
2.5	0.0	17.8	64.8	99.3	198.0
5.0	0.0	4.8	27.0	35.8	60.8
7.5	0.0	3.8	14.3	14.9	24.3
10.0	0.0	0.0	11.5	8.0	18.8
Control	586.0	576.0	605.0	403.0	495.0

(a) average of four replicates
(b) adults produced during 30-day period after mortality reading

SUMMARY AND CONCLUSION

Clean uninfested soft red winter wheat was treated with emulsifiable and encapsulated formulations of malathion and fenitrothion at doses of 2.5, 5.0, 7.5 and 10 ppm Al. Samples of the wheat were stored for 1, 3, 6, 9 and 12 months to determine the degradation rate and the relative effectiveness of the residues against adult rice weevils, lesser grain borers, red flour beetles and confused flour beetles.

The residues deposited on wheat by fenitrothion emulsion sprays were much more effective against rice weevils than residues from the malathion. Complete control was obtained with a dosage of 5 ppm fenitrothion for 12 months, but a dosage of 10 ppm malathion emulsion resulted in an average mortality of only 78%.

Fenitrothion emulsifiable concentrate was more effective in reducing adult progeny production of rice weevil in treated wheat than was encapsulated fenitrothion throughout the 12-month period.

The control of lesser grain borers with fenitrothion was only slightly better than with malathion; both insecticides gave high initial kills, but gradually they lost effectiveness as doses decreased and storage time increased. Fenitrothion was more effective in reducing progeny production of lesser grain borers than malathion. No adult F_1 progeny of less grain borers were produced in any fenitrothion treatments throughout the 12-month period. Progeny produced in malathion emulsion treatments are listed in Tables 6 and 7.

Fenitrothion imparted greater protection to wheat against red and confused flour beetles than did malathion, by reducing the number of adult progeny produced. No significant difference ($P \leq .05$) was observed in the effectiveness of emulsifiable and encapsulated formulations of malathion throughout the 12-month study. Confused flour beetle adults were the least susceptible species, while rice weevil adults were the most susceptible ones to both compounds.

No significant difference was noted in the rates of degradation of the encapsulated and emulsifiable formulations of either compound during the 12-month study.

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LITERATURE CITED

Champ, B. R., R. W. Steele, G. Green and K. D. Elms. A Comparison of malathion, diazinon, fenitrothion and dichlorvos for control of Sitophulus orzvae (L.) and Rhyzopertha dominica (F.) in wheat. J. Stored Prod. Res. 5, 21-48, (1969).

Champ, B. R. and M. J. Campbell-brown. Insecticide resistance in Australian T. castaneum (Herbst.), (Coleoptera, Tenebrionidue) 11, Malathion resistance in Eastern Australia. J. Stored Prod. Res. 6, 111-131, (1970).

Coppedge, J. R., R. A. stokes, R. E. Kinzor and R. L. Ridgway. Biological Evaluations of slow release formulations of aldicarb. J. Econ. Entomol. 67, 292-294, (1974).

Cramer, R. D. III. Controlled release pesticides making the most benefits. Inter. Pest Control. (March/April, 1976).

Cramer, R. D. III. Controlled release pesticides making the most benefits. Inter. Pest Control. (May/June, 1976).

Dyte, C. E. and G. B. Dorothy. The spread of insecticide resistance in Tribolium castaneum. J. Stored Prod. Res. 6, 255-261, (1970).

Gordon, T. T. Big future for "micro-eggs." New Scientist, 597-598, (Nov. 25, 1965).

Green, A. A. and P. S. Tyler. A field comparison of malathion, dichlorovos, and fenitrothion for the control of Oryzaephilus surinamensis (L.), (Coleoptera, Silvanidae), infesting stored barley. J. Stored Prod. Res. 1, 273-285, (1966).

Kadoum, A. M. Extraction and cleanup methods to determine malathion and its hydrolytic products in stored grains by gas-liquid chromatography. J. Agr. Food Chem. 17, 1178-1180, (1969).

Kadoum, A. M. and D. W. La Hue. Effect of hybrid, moisture content, foreign materials, and storage temperature on the degradation of malathion residues in grain sorghum. J. Econ. Entomol. 62, 1161-1164, (1969).

Kadoum, A. M. and D. W. La Hue. Degradation of malathion on viable and sterilized sorghum grain. J. Econ. Entomol. 65, 497-500, (1972).

Kadoum, A. M. and D. W. La Hue. Penetration of malathion in stored corn, wheat and sorghum grain. J. Econ. Entomol. 67, 477-478, (1974).

Kane, J. and A. A. Green. The protection of bagged grain from insect infestation using fenitrothion. J. Stored Prod. Res. 4, 59-68, (1968).

King, D. R., E. O. Morrison and J. A. Sundman. Bioassay of chemical protectants and surface treatments for the control of insects in stored sorghum grain. J. Econ. Entomol. 55, 506-510, (1962).

La Hue, D. W. Evaluation of several formulations of malathion as a protectant of grain sorghum against insects in small bins. USDA Marketing Research Report. 828, 1-19, (1969).

Lemon, R. W. Laboratory evaluation of some organophosphorous insecticides against Tribolium confusum (Duval.) and T. Castaneum (Herbst.), (Coleoptera, Tenebrionidae). J. Stored Prod. Res. 1, 247-253, (1966).

Nishizawa, Y. Chemistry of Sumithion. Residue Reviews. 60, 1-10, (1976).

Parkin, E. A. The onset of insecticide resistance among field population of stored product insects. J. Stored Prod. Res. 1, 3-8, (1965).

Phillips, F. T. Microencapsulation: A method for increasing specificity and controlling persistance of pesticides. PANS, 14, 407-410, (1968).

Ripper, W. E., R. N. Greenslade, J. Health and K. Barker. "New formulation of DDT with selective properties." Nature Lond. 161, 484, (1948).

Rowlands, D. G. The activation and detoxification of three organic phosphorothionate insecticides applied to stored wheat grains. J. Stored Prod. Res. 2, 105-116, (1966).

Rowlands, D. G. The metabolism of contact insecticides in stored grains. Residue Reviews. 17, 105-177, (1966).

Rowlands, D. G. and J. E. Clements. The degradation of malathion in rice brans. J. Stored Prod. Res. 1, 101-103, (1965).

Sanders, H. J. New weapons against insects. Special report. Chem. and Eng. News. 18-31, (July 29, 1975).

Spiers, R. D., H. P. Boles, J. H. Lang and L. M. Redlinger. Malathion resistance in red flour beetles collected from stored peanuts. Bull. Entomol. Soc. Amer. 10, 157-176, (1964).

Spiers, R. D., L. M. Redlinger and H. P. Boles. Malathion resistance in the red flour beetle. J. Econ. Entomol. 60, 1373-1374, (1967).

Stokes, R. A., J. R. Coppedge, D. L. Bull and R. L. Ridgway. Use of selected plastics in controlled release of granular formulations of aldicarb and dimethoate. J. Agr. Food Chem. 21, 103-108, (1973).

Stokes, R. A., J. R. Coppedge, and R. L. Ridgway. Chemical and biological evaluations of the release of aldicarb from granular formulations. J. Agr. Food Chem. 18, 195-198, (1970).

Strong, R. G. Relative toxicity of confused flour beetle and red flour beetle to twelve organophosphorous insecticides with notes on adequacy of the test method. J. Econ. Entomol. 63, 258-263, (1969).

Strong, R. G. and D. E. Sbur. Influence of grain moisture and storage temperature on the effectiveness of malathion as a grain protectant. J. Econ. Entomol. 53, 341-349, (1960).

Strong, R. G. and D. E. Sbur and G. T. Partida. The Toxicity and residual effectiveness of malathion and diazinon used for protection of stored wheat. J. Econ. Entomol. 60, 500-505, (1967).

Strong, R. G. and D. E. Sbur. Protective sprays against internal infestation of grain beetles in wheat. J. Econ. Entomol. 57, 544-548, (1964).

Strong, R. G. and D. E. Sbur. Evaluation of insecticides as protectants against pests of stored grain and seeds. J. Econ. Entomol. 58, 18-22, (1965).

Tyler, P. S. and A. A. Green. The effectiveness of fenitrothion and malathion as grain protectants under severe practical conditions. J. Stored Prod. Res. 4, 119-126, (1968).

Tyler, P. S., S. G. Bristow, D. F. Horler and J. E. Clements. Protective treatment of grain, laboratory experiments. Pest Infestation Res. 26, (1966).

Weaving, A. J. S. Grain protectants for use under tribal storage conditions and comparative toxicities of some insecticides on maize and sorghum. J. Stored Prod. Res. 11, 65-70, (1975).

LABORATORY EVALUATION OF EMULSIFIABLE AND ENCAPSULATED FORMULATIONS OF MALATHION AND FENITROTHION ON SOFT RED WINTER WHEAT AGAINST STORED PRODUCT INSECTS

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AN ABSTRACT OF A MASTER'S THESIS

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ABSTRACT

Emulsifiable and encapsulated formulations of malathion and fenitrothion were applied to soft red winter wheat at doses of 2.5, 5.0, 7.5, and 10 ppm Al. The wheat then was stored 12 months to determine the relative effectiveness of the residues against adult rice weevils, *Sitophilus oryzae* (L.); lesser grain borers, *Rhyzopertha dominica* (F.); red flour beetles, *Tribolium castaneum* (Herbst.); and confused flour beetles, *Tribolium confusum* (Jacquelin duVal). Fenitrothion was more effective than malathion against all species tested. No significant differences in relative effectiveness against adults were found between the encapsulated and emulsifiable formulations of either compound. Emulsifiable concentrate of fenitrothion was more effective in reducing adult progeny production of rice weevils than was encapsulated fenitrothion throughout the 12-month study. However, confused flour beetle adults were the least susceptible ones to both compounds.

Residues were determined by GLC analysis. There were no significant differences in the percentage of residue remained on and in wheat by the encapsulated and emulsifiable applications.