THE UNIVERSITY OF MANITOBA

PERSISTENCE ON STRUCTURAL SURFACES OF RESIDUES OF ORGANOPHOSPHORUS AND PYRETHROID INSECTICIDES AGAINST FIVE SPECIES OF STORED-PRODUCT INSECTS

by

Somsak Tauthong

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ABSTRACT

The persistence of three organophosphorus and three pyrethroid insecticides applied to fir plywood surfaces were evaluated at dosages considered to be appropriate for the control of five species of stored-product insects. The organophosphorus insecticides, bromophos, iodofenphos and malathion were applied as water-base emulsions at 0.5, 1.0, and 2.5 g/m^2 (actual insecticide); the pyrethroid insecticides, pyrethrins-piperonyl butoxide (1:10), S-bioallethrin and bioethanomethrin were applied as oil-base sprays at 0.5, 1.0 and 2.5 g/m^2 (actual insecticide). The residual effectiveness of each insecticide was compared at 25$\pm$ 2°C and 30 to 50% R.H. against the confused flour beetle, *Tribolium confusum* (Jacquelin du Val.); the red flour beelte, *Tribolium castaneum* (Herbst); the saw-toothed grain beetle, *Oryzaephilus surinamensis* (Linnaeus); the merchant grain beetle, *Oryzaephilus mercator* (Fauvel); and the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens). Beetles were exposed on fir plywood surfaces treated with pyrethroid insecticides for 5 hours and on surfaces treated with organophosphorus insecticides for 3, 5, 8, 16 and 24 hours; mortality was assessed 3 days after the beetles were removed to crush wheat at 27.5°C and 70% R.H.

Bromophos was the least effective compound against all species except *C. ferrugineus*. Malathion was more toxic than iodofenphos and bromophos to all species exposed on surfaces for 5 hours at 0.5 g/m^2 except *C. ferrugineus* but it was less toxic than iodofenphos against all species at 1.0 g/m^2. In general, iodofenphos was slightly more toxic than malathion and bromophos against *C. ferrugineus* but it was as effective as malathion against *O. surinamensis* and *O. mercator* at an exposure period of 5 hours; there was no significant difference between these compounds. Malathion was significantly more effective than iodofenphos and bromophos

against *Tribolium* spp. Malathion was the most effective insecticide against all species at an exposure period of 5 hours and at all dosages employed, whereas iodofenphos was the most effective insecticide at 1.0 g/m^2. Iodofenphos was also found to be the most persistent insecticide against all species tested.

Of the pyrethrins and pyrethroids that were tested, bioethanomethrin was the most effective insecticide against *O. surinamensis*, *O. mercator* and *C. ferrugineus*. S-bioallethrin was the most effective insecticide against *Tribolium* spp., whereas pyrethrins-piperonyl butoxide (1:10) was the least effective among insecticides tested against most of the species. Although bioethanomethrin was less toxic against *T. castaneum* than S-bioallethrin, it provided adequate control against this insect.

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CHAPTER I

INTRODUCTION

This thesis is a study of the persistence and effectiveness on wood surfaces of several synthetic pyrethroid and organophosphorus insecticides in the control of five major species of stored-product insects.

The control of stored-product pests is of importance because it is during the storage and processing stage that grains and food materials have their greatest value in terms of time and effort spent on production. Chemical control is, and perhaps always will be essential, but it must be closely integrated with all other aspects of food handling and processing to achieve maximum protection of the product.

Malathion and pyrethrins are the major contact insecticide used to protect stored cereals and cereal products against infestation of stored-product insects. They are used to treat stored grain as well as premises in which food products are stored (Watters, 1973; Harein and Las Casas, 1974).

Surface treatments with contact insecticides can be used effectively to protect insect-free commodities against infestation or to supplement other treatments in the control of insect infestations. During the preparation of grain bins, elevators, and warehouses for storage, all interior structural surfaces of the facilities may be treated to eliminate insects not removed by routine sanitation procedures.

Statement of the Problem

The objectives of this study were firstly to determine the persistence of the organophosphorus insecticides, bromophos, iodofenphos, and malathion on wood surfaces against the confused flour beetle, Tribolium confusum (Jacquelin du Val.); the red flour beetle, Tribolium castaneum (Herbst); the saw-toothed grain beetle, Oryzaephilus surinamensis (Linnaeus); the merchant grain beetle, Oryzaephilus mercator (Fauvel.); and the rusty grain beetle, Cryptolestes ferrugineus (Stephens); and secondly to investigate the persistence of the pyrethroid insecticides, bioethanomethrin, pyrethrins-piperonyl butoxide (1:10), and S-bioallethrin on wood surfaces against the same species of stored-product insects.

Importance of the Study

At least 10% of the harvested food crops are destroyed by insects, rodents and fungi in the absence of control measures during storage and transport; and current losses of 30% apparently are common in large areas of the world (Hall, 1970), particularly in tropical and subtropical countries where the need for increased food is greatest. Although the loss in the Canadian grain industry due to storage pests is singularly low, insect, mite and mold infestations cause grain heating, spoilage, and grade losses, and buyer complaints can have serious consequences for individual grain producers (Gray and Watters, 1953).

The main objective, therefore, in the use of insecticides is to reduce or to eradicate insect pest populations. In surface treatments, treated surfaces form toxic barriers which kill, repel, or inactivate insects (Watters, unpublished data 1975). Residual insecticidal activity is desirable to prolong the period of protection as long as possible after treatment to avoid the need for frequent reapplication. Any environmental factor that affects the effectiveness of insecticide used for insect control or adversely affects the biology of the insect must be considered in any insect control program.

Surface treatments are commonly employed in the control of stored-product insects. Malathion is most widely used as a residual protectant to spray storage premises as well as to protect stored grain. Although malathion loses its toxicity almost immediately on concrete surfaces (Parkin, 1966; Lemon, 1967), it has proven to be persistent on neutral pH surfaces such as filter paper, wood, and sacking (Parkin , 1966).

The increasing use of malathion will undoubtedly result in the incidence and spread of its resistance to stored grain pests which are moved from country to country and commodity to commodity through normal trade channels. Resistance to this insecticide has resulted in control failures under field conditions, and in countries where this has not yet occurred it is likely to happen quite soon if this insecticide continues to be used (Dyte, 1970).

Pyrethroids, which possess repellent characteristics useful in industrial treatments, have been used for many years to control stored-product insects. Bromophos and iodofenphos have been shown to be the effective substitutes for malathion (Green et al., 1970; Watters, 1970). Pyrethroid compounds, bioallethrin and S-bioallethrin, which possess improved biological activity, were among the most effective to control pests (Briggs et al., 1974; Rauch and Lhoste, 1974). There is, however, no adequate information available on the persistence of these insecticides on wood surfaces. Further investigation on the persistence of these alternative compounds on surface treatment is needed.

Information provided by this investigation, as far as the persistence and effectiveness of these insecticides are concerned, may suggest the substitution of one compound or another for the control of a certain species or group of species of stored-product insects. This may result in more effective and economical control on certain structural surfaces.

The results of this investigation will also provide information on the type of structural surface of a treated granary, elevator or warehouse, that favors maximum persistence of a given insecticide against a certain species. However, more investigation of these compounds is needed for other structural surfaces, such as concrete and metal, that are commonly used in many permanent-type storages.

CHAPTER II

REVIEW OF THE LITERATURE

Persistence on Structural Surfaces of Organophosphorus Insecticides, Bromophos, Iodofenphos, and Malathion Against Stored-Product Insects

The persistence and effectiveness of grain protectants are governed by many factors. Under a wide range of environmental conditions where grain protectants are applied, the effects of grain moisture and temperature are well known, but other variable factors are not so well understood (Minett , 1974).

In farm buildings or warehourses, environmental temperature and the type of surface on which an insecticide is applied will affect the persistence and effectiveness of insecticide deposits. Concrete and other alkaline surfaces, which commonly comprise the interior surfaces of storage buildings, often reduce the toxicity of insecticides. Malathion, although highly effective against many species of stored-product insects, loses its toxicity almost immediately on concrete surfaces (Parkin, 1966; Lemon, 1967). However, Watters (1970) showed that malathion may not break down on concrete floors impregnated with grain dust in a terminal elevator as rapidly as on fresh concrete prepared in the laboratory. Cogburn (1972) also reported that at 1.26 g/m^2, malathion was over 90 percent effective for 2 weeks and at 2.5 g/m^2 it was over 95 percent effective for 5 weeks against T. confusum on concrete floors in a Gulf of Mexico port warehouse.

Malathion appears to be stable on surfaces that are near neutral. High mortalities of T. confusum were obtained for 16 weeks on filter papers treated with malathion at 0.75 g/m^2 (Lemon, 1967). Similarly, at a rate of 0.86 g/m^2, it was proved to be persistent on filter paper for 16 months against the granary weevil, *Sitophilus granarius* (L.), *T. castaneum* and *O. surinamensis* (Parkin and Scott, 1960). Parkin (1966) found that malathion applied on wood and sacking at 0.43 g/m^2 persisted for 2-4 months.

The residual effectivenss of malathion was much reduced by high grain moisture and storage temperatures (Watters, 1959, Strong and Sbur, 1960). Watters (1959) found that malathion applied at 2 ppm to wheat of 13.5% moisture content was as effective as when applied at 16 ppm on wheat of 15.5% moisture content against *C. ferrugineus*, and malathion at 16 ppm on wheat of 19% moisture content was ineffective against this insect. The residual effectiveness of malathion applied to wheat at 10 ppm was higher at 10°C than 50°C, and it remained effective against insect infestations for at least 12 months when storage temperature was not higher than 15.6°C and the moisture content of wheat did not exceed 14% at this dosage (Strong and Sbur, 1960).

In evaluation studies, malathion, being the principal contact insecticide for the control of stored-product insects, is often used as the standard compound for assessment of new candidates under test. The development of insecticide resistance in stored-product insects has limited the effectiveness of malathion at the most useful stored-product insecticide (Parkin *et al.*, 1962; LaHue, 1969 a, b; Dyte, 1970; Watters, 1973).

Bromophos, although less effective than fenitrothion and malathion against *Tribolium* spp. and *Sitophilus* spp. when applied topically or admixed on wheat (Lemon, 1967), is of considerable interest as a grain protectant due to its stability under conditions of high alkalinity. It could be suitable for treating concrete surfaces on which malathion breaks down very rapidly (Parkin, 1966; Lemon, 1967). Good control was obtained by using bromophos water dispersible powder, applied at 0.54g/m^2

to an infested wooden floor in a farm building against S. granarius; O. surinamensis; the waste grain beetle, Alphitophagus bifasciatus; and Cryptolestes spp. Protection lasted at least 46 weeks except for T. Cast - aneum when only 54 percent kill occurred at 10 weeks after treatment (Tyler et al., 1969; Hope et al., 1970).

The efficacy of bromophos as a protectant of bagged wheat and barley was proved, when applied as water-based emulsion at 24 ppm, to be fully effective against O. surinamensis for 36 weeks and against S. granarius for 24 weeks. It was indicated that 9.3 ppm of bromophos will likely provide adequate control of O. surinamensis for up to 12 months (Green et al., 1970). At 0.5 g/m^2, bromophos sprayed on bags or on hessian sheets, which covered the stack of bagged maize, gave less effective protection than that obtained with the routine lindane and malathion sprayings against the tropical warehouse moth, Ephestia cautella Walker in Malawi (Schulten, 1973).

Bromophos is relatively stable on damp grain. At 16.5 percent moisture content, the residual life of bromophos is longer than that of malathion and fenitrothion (Rowlands, 1967).

Although bromophos is a useful insecticide for the protection of grain, its slow action detracts from its potential value as a treatment for high alkalinity premises and as a treatment for infested grain and clean grain. Bromophos is considered to be a possible alternative to malathion as a grain protectant only if insect resistance to malathion becomes a problem and there is no better alternative (Green et al., 1970; Lemon 1967). Dyte and Rowlands (1968) found that the malathion resistant strain of T. castaneum from Nigeria had no cross-tolerance to bromophos.

Iodofenphos is currently one of the new organophosphorus insecticides of potentially high importance for stored grain protection. It was proved to be more toxic to T. castaneum adults than malathion (Blackman, 1969), and more effective against the Indian-meal moth, Plodia interpunctella (Hübner), larvae than malathion and Gardona (McDonald and Speirs, 1971), when applied topically. It was also reported to be more toxic to the black carpet beetle, Attagenus piceus (Olivier), but less toxic to T. confusum than malathion. In a preliminary assessment on filter paper (Gradidge, 1970), it was generally more effective than malathion when applied as an emulsion at 0.8 g/m^2 to various surfaces including brick, concrete, asbestos and galvanized metal of a clean modern granary which was lightly infested with O. surinamensis (Gradridge et al., 1970).

Although 10 parts per million of iodofenphos gave complete protection of bagged wheat and barley for about 20 weeks against both O. surinamensis and S. granarius (Kane et al., 1973), iodofenphos sprayed directly at 0.5 g/m^2 on bags or hessian sheets which covered stacks of bagged maize did not seem to be very effective against E. cautella in Malawi (Schulten, 1973). Green (1973) reported that iodofenphos gave as good control as malathion both in laboratory and field trials when applied either as an admixture or as a surface treatment to unshelled groundnuts against a lindane-resistant Gambian strain, the groundnut bruchid, Caryedon serratus (Olivier). Both compounds appear to be satisfactory replacements for lindane.

In several incidences from both laboratory and field experiments iodofenphos has proved to be more effective and has persisted longer than malathion against most of the stored grain insects. In particular, Wilkin et al. (1973 a, b) demonstrated its effectiveness was longer than that of malathion when applied to warm and moist wheat against O. surinamensis which is the species most susceptible to malathion. An experiment by Dyte and Rowlands (1968) also demonstrated that the malathion resistant strain of T. castaneum from Nigeria had no cross-tolerance to iodofenphos.

Persistence on Structural Surfaces of Pyrethroid Insecticides, Pyrethrins-Piperonyl butoxide, S-bioallethrin, and Bioethanomethrin Against Stored- Product Insects

Natural pyrethrins are valued for their remarkably lethal action against a wide range of insect species (Gnadinger, 1936-1945). The insecticide activity of the pyrethrins is enhanced by the addition of less expensive compounds called synergists which suppress detoxification of pyrethrins and enable them to persist longer in the insect (Casida, 1970; Yamamota, 1973). Pyrethroids vary greatly in the extent to which they are synergized. Allethrin, bioallethrin, S-bioallethrin, and tetramethrin are much more effective when synergized by piperonyl butoxide (Lloyd et al., 1970; Lloyd, 1973; Davies, 1974). Although tetramethrin was much less toxic than pyrethrins against both T. castaneum and S. granarius, in combination with the synergist, piperonyl butoxide, tetramethrin was slightly more toxic than pyrethrins plus piperonyl butoxide against T. castaneum (Lloyd et al., 1970). Piperonyl butoxide has received extensive use as a synergist in formulation with pyrethroids. The commercial formulations most widely accepted for treatments against stored-product insects contain pyrethrins synergized with piperonyl butoxide in a 1:10 ratio (Gillenwater and Burden, 1973).

Pyrethrins plus piperonyl butoxide are used as a surface spray applied over the top of bulk-stored peanuts, to the outside surface of stocked bagged peanuts, and to burlap bags containing dried citrus pulp animal feed to prevent infestations of stored-product insects (Anonymous, 1966; Luadani et al., 1959). Watters (1961) found that a deposit of 0.05 g pyrethrins and 0.5 g piperonyl butoxide per m^2 applied as a spray on the country warehouse floor gave good control of the hairy spider beetle, Ptinus villiger (Reitter), for 4 to 6 weeks. Plywood floor targets and groved plywood wall targets remained effective for 11 months against C. ferrugineus when pyrethrins plus piperonyl butoxide (1:10), at 240 g/1,000 m^3, were applied as a fog in an empty grain bin (Watters, 1968).

The persistence of pyrethrins has been shown to be inferior to resmethrin as a surface treatment against adult mosquitoes (Hadaway et al., 1970). However, the formulations of synergized pyrethrins used for surface treatments should be applied to produce a deposit of about 0.05 g of pyrethrins and 0.5 g of piperonyl butoxide per square meter of the surface (Gillenwater and Burden, 1973).

The value of repellency versus toxicity for protecting flour in paper bags treated with synergized pyrethrins was demonstrated by Laudani and Davis (1955). Further studies by Davis and Laudani (1956) and Highland et al. (1964, 1966) led to development of an insect-resistant treatment (IRT) for multiwall paper bags. The IRT was also proved to be safe and effective for raisins packaged in 2-lb bags and a use label for this treatment has been approved (Yarington, 1972). Similarly, pyrethrins and piperonyl butoxide are incorporated into the adhesive layer of a bag waterproofed with cellophane laminated with 0.0005 inch-thick polyethylene, at concentrations of 0.054 g/m^2 and 0.54 g/m^2, respectively. The treated bags completely protected raisins and mixed fruit for at least 6 months in areas with high infestation of *Oryzaephilus* spp., *Tribolium* spp., the maize weevil, *Sitophilus zeamais* (Mots.), *P. interpunctella*, and three species of the dermestid beetles, *Trogoderma glabrum*, *T. inclusum*, and *T. variable* (Anonymous, 1975). However, most of the researchers agree that the toxic effectsof pyrethroids are lost rapidly when applied to stored grain, whereas the repellent actions remain the primary factor for insect protection from 6 to 12 months (Harein and Las Casas, 1974).

Allethrin, resmethrin, and tetramethrin are the major synthetic pyrethroids presently available commercially (Head, 1973) that could be blended with natural pyrethrins. These are all esters of chrysanthemic and pyrethric acid that may be in the (±)-*cis*, *trans* isomer such as allethrin, resmethrin, pyremethrin etc. or for improved biological activity, (+)-*trans* structure, such as bioallethrin, S-bioallethrin, bioresmethrin etc. (Elliott *et al.*, 1967; Davies, 1974).

The allethrolonyl chrysanthemates, allethrin, bioallethrin and S-bioallethrin, are particularly suitable for mosquito coils used in Japan and Southeast Asia and because of their heat stability they are well dispersed in the smoke during the burning of coils (Nishizawa, 1971; Rauch and Lhost, 1974). S-bioallethrin was the most effective (Rauch and Lhoste, 1974). Bioallethrin is 1.5 and 2 times more toxic to *S. granarius* and *T. castaneum* than allethrin respectively, whether synergized or not (Lloyd *et al.*, 1970; Lloyd, 1973). However, allethrin and bioallethrin were inferior to natural pyrethrins, especially when unsynergized (Lloyd, 1973).

Since bioethanomethrin and S-bioallethrin are relatively new, there is no information available on the persistence of these compounds on any structural surface against stored-product insects. However, bioethanomethrin, the ethanochrysanthemate RU 11 679, is more lethal than bioresmethrin and it is less polar than most of the other highly lethal pyrethroids, epoxidation still produces a good knockdown agent, which also retains some killing action (Briggs et al., 1974).

CHAPTER III

MATERIALS AND METHODS

I. MATERIALS

The present study was undertaken at the Research Station, Canada Department of Agriculture, Winnipeg, Manitoba.

Experimental Insects

Five species of stored-products of the order Coleoptera; the confused flour beetle, *Tribolium confusum* (Jacquelin du Val.), Tenebrionidae; the red flour beetle, *Tribolium castaneum* (Herbst), Tenebrionidae; the saw-toothed grain beetle, *Oryzaephilus surinamensis* (linnaeus), Silvanidae; the merchant grain beetle, *Oryzaephilus mercator* (Fauvel), Silvanidae; and the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens), Cucujidae; were selected for the test insects.

Biology of Experimental Insects

The confused flour beetle and red flour beetle

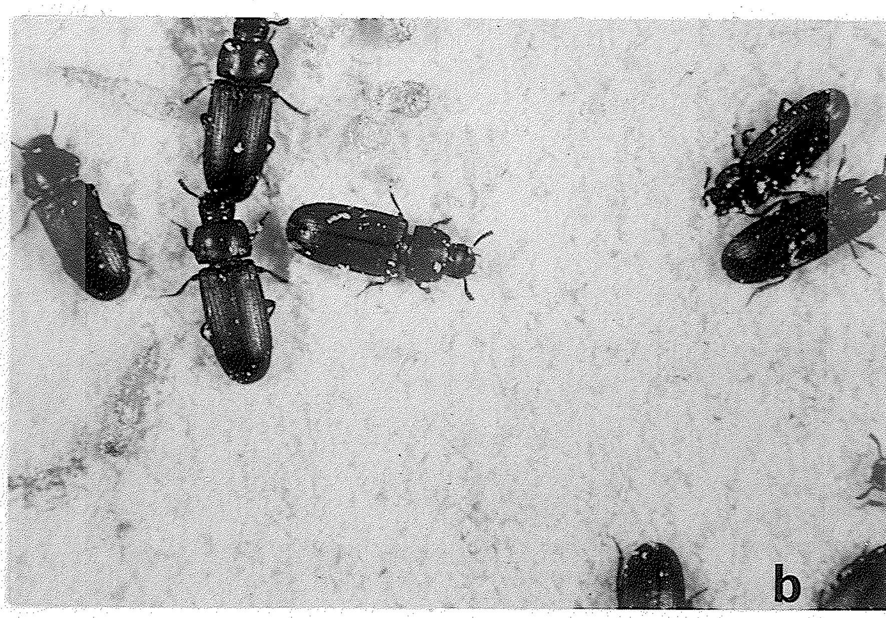
The adults of *T. confusum* and T. *castaneum* are flat, about 3 to 4 mm long, and reddish-brown. They are distinguished by the following characteristics (Figure 1.a, b) (Cotton and Wilbur, 1974).

Figure 1. Insects used in insecticidal persistence and effectiness on wood surfaces.

(a) The confused flour beetle, Tribolium confusum (Jacquelin du Val.), (Tenebrionidae, Coleoptera).

(b) The red flour beetle, Tribolium castaneum (Herbst), (Tenebrionidae, Coleptera).

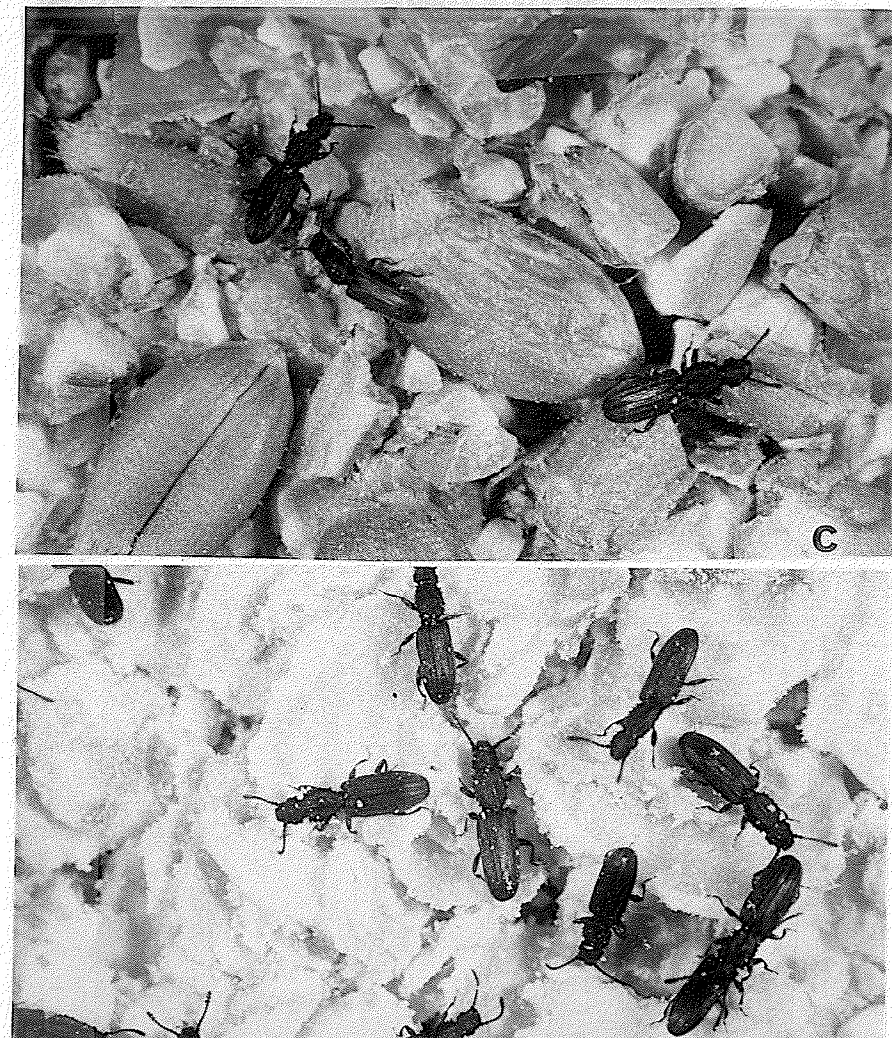

a


b

(c) The saw-toothed grain beetle, *Oryzaephilus surinamensis* (Linnaeus), (Silvanidae, Coleptera).

(d) The merchant grain beetle, *Oryzaephilus mercator* (Fauvel), (Silvanidae, Coleoptera).

(e) The rusty grain beetle, *Cryptolestes ferrugineus* (Stephens), (Cucujidae, Coleoptera).


c
d
e

T. confusum	*T. castaneum*
a) Slightly larger than, 3.5mm	a) Slightly smaller than, 3.3mm
b) Antennae gradually enlarged toward the tip	b) Antennae with the last three segments abruptly enlarged
c) Eyes smaller	c) Eyes larger
d) Underneath, the width of each eye is about 1/3 the distance separating them	d) Underneath, the width of each eye is equal to the distance separating them
e) Wings not functional	e) Wings functional

These species are serious pests of flour and other prepared cereal products. They live in grain storages and are particularly abundant in dead flour stock and nutritious foods in protected places throughout mills and cereal processing plants (Cotton, 1963; Cotton and Wilbur, 1974).

Females of these species lay up to 400 or more eggs loosely on flour or on grain kernels. The larvae are yellowish and feed extensively on flour and or on the germ of wheat kernels. The development period from egg to adult may be as short as 4 weeks under favorable environmental conditions (Cotton, 1963; Watters, 1967). The length of the developmental period varies widely, depending on temperatures, type of food, available moisture and other factors. The optimum temperature conditions for the rapid development of *T. castaneum* from egg to adult, in 20 days, was between 35° and 37.5°C at above 70% R.H. At 70% R.H. and 22°C development from egg to adult took 75 days (Howe, 1956b).

In general, *T. castaneum* develops more rapidly than *T. confusum* and has higher fecundity. The developmental period for the two species were equal at temperatures between 23° and 27°C, depending on humidity. At lower temperatures, *T. confusum* developed faster than at higher temperatures (Howe, 1960).

T. confusum and T. castaneum occur together in hot and dry climates (over 22°C and less than 60% R.H.) or in hot and damp climates (over 22°C and 70% R.H.). In Canada, T. confusum is the major species since the climatic conditions are moderate (less than 22°C and over 55% R.H.) (Freeman, 1962). However, a survey of these insect species in the Prairie Provinces of Canada was made by Liscombe and Watters (1962), showed that T. confusum and T. castaneum were present in 4 percent and 25 percent, respectively, of granaries examined. Sinha (1971) also listed T. castaneum to be one of the three chief insects that cause heating in bulk grain storage in Canada.

The saw-toothed grain beetle and merchant grain beetle

O. surinamensis and O. mercator have similar habits. The adults of both species are small, 2.4-3.5 mm long, slender, flat, reddish brown to dark brown beetle with six sawtoothed-like projections on each side of the pronotum (Cotton and Wilbur, 1974) (Figure 1. c, d). It has been clearly established in cross-breeding experiments, by Howe (1956 a) that they are distinct species. The two species can be separated by the relative length of the temple and the vertical diameter of the eye (Howe, 1956 a; Loschiavo and Smith, 1970) and by the male genitalia (Howe, 1956 a).

O. surinamensis infests both stored grain and processed cereal products. O. mercator has become firmly established as a household pest of processed cereal products especially those of high oil content, but it has not been reported from stored grain in Canada (Liscombe and Watters, 1962; Loschiavo and Smith, 1970).

The beetles live from 6 to 10 months. The females lay from 50 to

300 eggs. The time required for development from egg to adult may vary from 20 to 75 days depending on food, temperature and relative humidity. Lowering the temperature and humidity slows larval development. The optimum temperature for O. surinamensis was about 30-35°C and that for O. mercator about 30-32.5°C (Howe, 1956a).

Generally, these two species feed outside the kernels, though individual small larvae do penetrate the germ covering and develop in the embryo and remain as "hidden infestation" during their developmental period. More progeny were developed in rice (Turney, 1957) and other grains (Cotton and Wilbur, 1974) when both the moisture content and the amount of cracked grain kernels were increased. O. surinamensis was reported to be one of the chief insects that cause heating in bulk grain storage in Canada (Sinha, 1971).

The rusty grain beetle

C. ferrugineus does the most damage to farm-stored grain in Western Canada. The adult insect is a flat, reddish-brown beetle, about 2 mm long, which makes it the smallest of the major grain-damaging insects (Fig. 1.e). The females lay eggs under the outer layer of the kernel or in the surface cracks. The larvae tunnel under the germ covering where they feed on the grain until they mature and pupate. Development from egg to adult takes from 24 to 98 days, depending mainly on temperature. The optimum environmental conditions for the development of C. ferrugineus was from 34 to 38°C and 75% R.H. or higher, Populations increased more rapidly in whole rye and wheat grain than in the same materials when they were coarsely ground (Rilett, 1949; Cotton and Wilbur, 1974).

C. ferrugineus is coldhardy and is mainly found in stored grain in Canada; 36 percent of farm granaries were found to be infested in the Prairie Provinces of Canada (Liscombe and Watters, 1962). It was reported to be the chief insect that causes heating in bulk grain storage (Sinha, 1971).

Source and Culturing of Test Insects

Four to five hundred adults of each species used in the tests, were obtained from standard laboratory cultures of the Cereal Crop Protection Section, Research Station, Canada Department of Agriculture, Winnipeg. These insect stocks have been maintained at this laboratory for many years. No strain had any history of exposure to insecticide.

All insect cultures were reared in constant temperature cabinets (Figure 2) which for *T. castaneum* and *C. ferrugineus* were maintained at 30°C and 70% R.H.; *T. confusum*, *O. surinamensis*, and *O. mercator* were maintained at 27.5°C and 70% R.H.

The cultures were kept in 2.6-liter (128 fl oz) jars covered with filter papers. The filter paper was sealed at the top of the jar with wax to prevent the infestation by stored-grain mites. The food media on which the test insects were cultured are illustrated in Table I.

In order to obtain adults of known-age in insect cultures, 400-500 adults of each species were added to fresh culture media in glass jars. After a 3 to 4 day egg-laying period, the adults were removed by means of sifting from the culture media; and a new generation was obtained from the hatched eggs in approximately four weeks for all insect species, except *C. ferrugineus* which required a longer period of development (about six weeks) to complete a generation.

Since the test insects had different periods of development, the experiments were synchronized to coincide with the required age of each test insect.

Figure 2. A constant temperature and humidity cabinet used in laboratory rearing of stored-product insects.

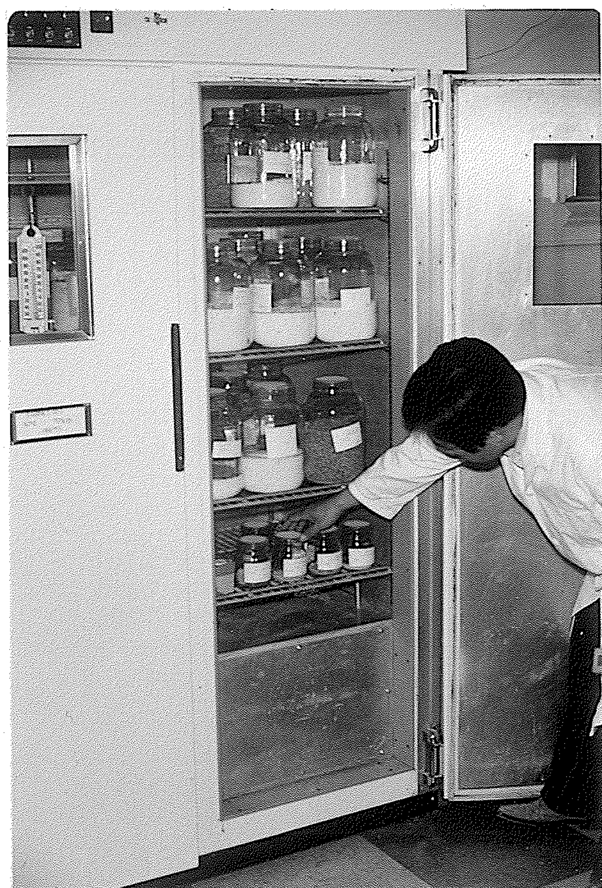


TABLE 1

Culturing data on stock cultures of test insect

Species	Culture medium	Age of test insects (weeks)
T. confusum	Unenriched white flour with 5% Brewer's yeast	2-4
T. castaneum	Unenriched white flour with 5% Brewer's yeast	2-4
O. surinamensis	Rolled oats with 5% Brewer's yeast	2-4
O. mercator	Rolled oats with 5% brewer's yeast	2-4
C. ferrugineus	16% m.c. of whole wheat kernels with 5% wheat germ	2-4

Experimental Insecticides

Names and sources of insecticides

Malathion 83.6% w/v emulsifiable concentrate (Cythion, Grain Protectant Grade), and malathion 25% w/w wettable powder were supplied by Cyanamid of Canada Ltd., Montreal. Bromophos 40% w/v emulsifiable concentrate (Nexion EC 40) was supplied by Green Cross Insecticides, Winnipeg. Iodofenphos 20% w/v emulsifiable concentrate (Nuvanol N 20) was supplied by Ciba-Geigy Canada Ltd., Montreal. Pyrethrins 6% w/v and piperonyl butoxide 60% w/v emulsifiable concentrate (Evercide 66 EC), S-bioallethrin 90% technical grade, and bioethanomethrin 80% technical grade (RU 11 679) were supplied by McLaughlin, Gormley and King, Minneapolis, Minnesota.

The chemical names of the organophosphorus insecticides, malathion, bromophos, iodofenphos; and the pyrethroid insecticides, pyrethrins-piperonyl butoxide (1:10), S-bioallethrin, bioethanomethrin, are as follows:

Malathion	0,0-dimethyl S-1,2-di(ethoxycarbonyl) ethyl phosphorodithioate.
Bromophos	0-(4-bromo-2,5-dichlorophenyl) 0,0-dimethyl phosphorothioate.
Iodofenphos	0-(2,5-dichloro-4-iodophenyl) 0,0-dimethyl phosphorothioate.

Pyrethrins-piperonyl butoxide (1:10)

Pyrethrins	Cinerolene / Pyrethrolene } esters of mono- and di-chrysanthemum carboxylic acid.
Piperonyl Butoxide	Butyl carbitol 6-propylpiperonyl ether; α-2-(2-n-Butoxyethoxy)-ethoxy-4,5-methylene-dioxy-2-propyltoluene.
S-bioallethrin	d-trans chrysanthemum monocarboxylic acid ester of d-2-allyl-4-hydroxy-3-methyl-2-cyclopenten-1-one.

Bioethanomethrin   d-trans ethano chrysanthemate of (5 benzyl-3-furyl) alcohol.

Organophosphorus Insecticide Formulations Used in Wood Surface Experiments

The following formulations were evaluated: malathion emulsifiable concentrate (EC) 83.6%, bromophos emulsifiable concentrate (EC) 40%, and iodofenphos emulsifiable concentrate (EC) 20%. These formulations were diluted with distilled water to provide a deposit of 0.5, 1.0 and 2.5 g active ingredient of each insecticide per square meter when applied to test surfaces at the rate of 0.05 liters per square meter.

Pyrethroid Insecticide Formulations Used in Wood Surface Experiments

The following formulations were evaluated: pyrethrins-piperonyl butoxide emulsifiable concentrate (EC), 6% pyrethrins and 60% piperonyl butoxide; S-bioallethrin 90% oil-emulsion; and bioethanomethrin 80% oil emulsion. These formulations were diluted with Shell-Risella 17 oil, a non-volatile solvent, to provide a deposit of 0.5, 1.0 and 2.5 g active ingredient of each insecticide per square meter when applied to test surfaces at the rate of 0.05 liters per square meter.

Experimental Surfaces

Wood sheets, original 4' x 8' x ½", good one side, fir plywood, were obtained from a local source. The sheets were cut into square panels which measured 30.5 cm x 30.5 cm comprising a total area of 930.25 cm^2 (1 ft^2).

II. METHODS

The amount of insecticide deposited on a target from a sprayer is less than the amount applied because of spray droplet scatter at the boundary of a square area of the target surface. Losses caused by droplet scatter at the periphery of the target during the application of insecticide suspensions, emulsions, and oil emulsions were calculated by Parkin (1966), Lemon (1967), and Watters and Grussendorf (1969). Watters and Grussendorf (1969) found that the amount of Shell Risella 17 oil applied with an air-brush on Whatman no. 1 filter paper targets was about 92 ± 1.1% of the total applied. Thus, it was possible to increase the volume applied to compensate for the known amount that would fail to be deposited on the target.

Schedule for treatments

The various concentrations of each insecticide were applied on the target surfaces with a Pasche air brush (Figure 3), H-5 type nozzle, at a constant pressure of 0.70 kg/cm^2 (10 lb/in^2) for insecticide water-base emulsions, and 1.75 kg/cm^2 (25. lb/in^2) for insecticide oil emulsions. The volume of solutions required to give a uniform distribution of insecticide solutions on wood, after several tests, was found to be 5 ml per total area of 930.25 cm^2.

One test surface of each wood panel was sprayed with 5 ml of each concentration of each insecticide water-base emulsion and oil emulsion to obtain an initial deposit of 0.5, 1.0 and 2.5 g/m^2 (Figure 4).

During application, test surfaces were sprayed under the fume hood. Control surfaces were sprayed prior to the insecticide treatments with distilled water for tests with the insecticide water-base emulsion, and with Shell Risella 17 oil for tests with the insecticide oil emulsion.

Figure 3. Pasche air brush sprayer, H-S type nozzle, for applying insecticide on fir plywood surfaces.

Figure 4. Fir plywood surface was sprayed with Pasche air brush sprayer under air pressure in fume hood.

The sprayer reservoir was washed with acetone after applying each concentration of each insecticide. The spray took 40 seconds to apply the insecticide water-base emulsion to each surface (930.25 cm^2), and 70 seconds to apply the insecticide oil emulsion.

Each experiment surface was replicated 4 times.

The code designations of test surfaces were marked on each surface before application. Storage took place in horizontal shelves (Figure 5) for wood surfaces treated with insecticide water-base emulsion, and in vertical racks (Figure 6) for wood surfaces treated with insecticide oil-emulsion in separate rooms. Both rooms were maintained at 25 ± 2°C and 30 ± 50% R.H. In the storage room with horizontal shelves, one side of the shelves was covered with plastic sheet to act as a barrier to prevent the spread of particles to other parts of the room which might be caused by air turbulence. The appropriate control surfaces were kept apart from the insecticide treated surfaces.

Bioassay of Test Surfaces

According to Iordanou (1968) the difference in mortality of insects either starved or not starved prior to exposure to a chemical, was less than one percent when both insects exposed to the same dosage of the same chemical under the same environmental conditions. Therefore, all the test insects used in these experiments were starved for 4-5 hours prior to exposure. This starvation period appeared to be the most suitable and convenient for the testing schedules.

Exposure of test insects to wood surfaces treated with organophosphorus insecticides

The initial and residual effectiveness of each insecticide was assessed by bioassay with adults of *T. confusum*, *T. castaneum*, *O. surin-*

Figure 5. A horizontal shelf used to store wood surfaces treated with organophosphorus insecticides

Figure 6. Vertical racks used to store wood surfaces treated with pyrethroid insecticides.

amensis, O. mercator and C. ferrugineus at 1, 4, 8, 16, 32, 52 and 80 weeks after treatment. Five groups of 20 adults of each species were confined on each test surface. One group of each species were exposed for 3, 5, 8, 16 and 24 hours.

Exposure of test insects to wood surfaces treated with pyrethroid insecticides

The initial and residual effectiveness of each insecticide was assessed at 1, 4, 8, 16 and 32 weeks after treatment, with adults of the same species and age which came from the same stock culture as those used to test the residual effectiveness of organophosphorus compounds applied on wood surfaces. Five groups of each species were exposed for 5 hours.

Conditions during exposure to test surfaces

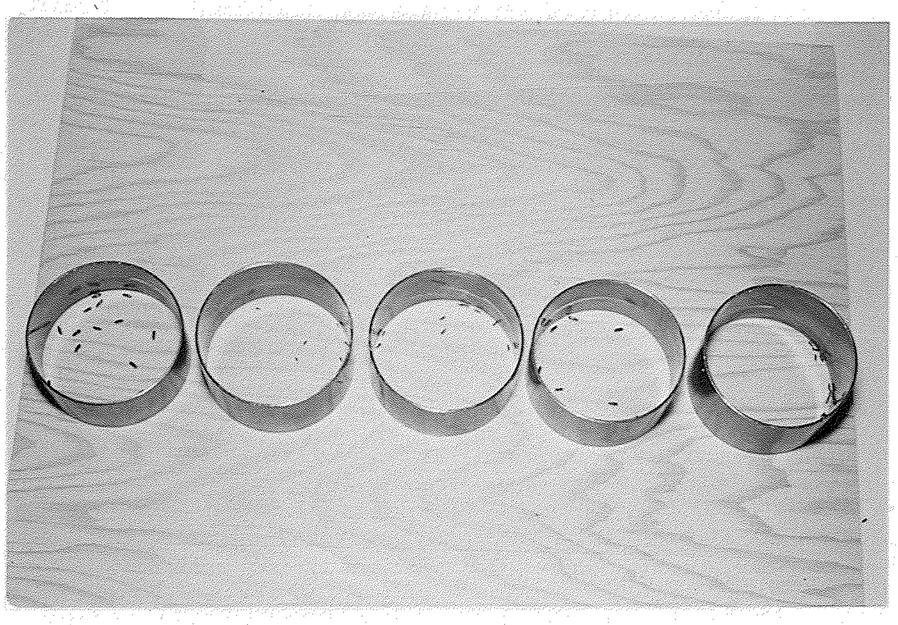
Two-to-four week old adults of all test insects obtained from standard laboratory cultures were counted randomly, without sexing, into batches of twenty. After a starvation period of 5 hours, the insects were confined in copper rings, 5.2 cm in diameter and 3 cm high (Figure 7). The lower part of each ring was coated with fluon, polytetrafluoroethylene dispersion, to prevent the insects from climbing and escaping from the barrier ring. The bioassay of insects was made in the laboratory at 25 ± 2°C and 50 ± 10% R.H., in darkness, to avoid increased activity of the exposed insects which could affect the degree of poisoning.

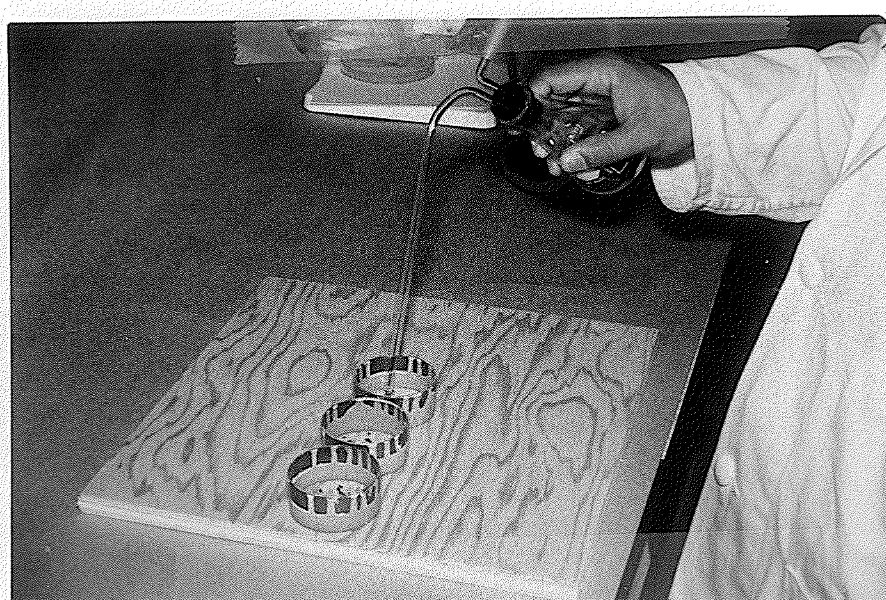
Conditions after exposure to test surfaces

After the required periods of exposure, the treated insects were removed from the test surfaces with an aspirator by means of vacuum (Figure 8). Each lot of treated insects was placed in clean plastic vials, 2.4 cm in diameter and 5 cm high, containing 3 g of crushed wheat.

Figure 7. Test insects were confined on test surface for a required period of exposure.

Figure 8. Test insects were removed from test surface after a required period of exposure by means of vacuum.





The vials were stored at 27.5°C and 70% R.H. for 3 days prior to assessing mortality.

Assessment of Mortality

For assessing the effectiveness of the insecticides against the insect species, examination for mortality were made 3 days after removal from the treated surfaces. Test insects were classified as dead, moribund (knocked down) or alive by the method used by Parkin (1966). They were recorded as moribund (knocked down), or the onset of paralysis, if their locomotory movements clearly lacked coordination or if they layed on their backs and were unable to regain their normal positions. Death was determined by lack of spontaneous movement and by failure to respond to slight pressure from mechanical, heat or light stimulation. The occasional control death was corrected by Abbott's formula.

CHAPTER IV

RESULTS

1. PERSISTENCE ON STRUCTURAL SURFACES OF ORGANOPHOSPHORUS INSECTICIDES IN THE CONTROL OF FIVE SPECIES OF STORED-PRODUCT INSECTS

The persistence of deposits of bromophos, iodofenophos and malathion applied as water-base emulsions on fir plywood surfaces was assessed at 1, 4, 8, 16, 32, 52 and 80 weeks after treatment. The surfaces were bioassayed with adults of *T. confusum*, *T. castaneum*, *O. surinamensis*, *O. mercator* and *C. ferrugineus*. Mortality determinations were made after exposure periods of 3, 5, 8, 16 and 24 hours.

The mortalities of each species at the three dosage deposits, are corrected for control deaths, and shown graphically in Fig. 9-13.

Results of the tests on fir plywood surfaces for the longer exposure period treatments (16 and 24 hours) indicate that very high mortalities of all species were obtained by all of the three insecticides for the full duration of the experiment (Tables 2, 3, 4, 8, 9, 13, 14, 18, 19, 23, 24, 28, 29). Only the results for the exposure period of 5 hours were selected for statistical analysis (Tables 6, 11, 16, 21, 26). The results for the 3, 8, 16 and 24 hour exposure were considered to be sufficiently clear without the need for analysis.

(a) Persistence and Effectiveness of the Three Organophosphorus Insecticides Against Five Species of Stored-Product Insects

Persistence of bromophos on fir plywood surfaces

Table 2, Fig. 9c, Fig. 10c, Fig. 11c, Fig. 12c and Fig. 13c summarize the percent mortality obtained with bromophos against five species of test

TABLE 2

Effect of bromophos[a] applied on fir plywood surfaces at three dosages against five species of stored-product insects

	Percent mortality after exposure periods (hr) of																								
	3					5					8					16					24				
	Age of deposits (weeks)																								
Species	1	4	8	16	52	1	4	8	16	52	1	4	8	16	52	1	4	8	16	52	1	4	8	16	52
Amount of deposit, 0.5 g/m^2																									
T. confusum	36	2	0	0	0	64	27	0	0	0	100	44	19	0	0	100	92	32	0	0	100	97	100	59	6
T. castaneum	65	1	0	0	0	87	16	0	0	0	100	45	0	4	0	100	81	81	44	0	100	100	100	62	32
O. surinamensis	69	15	5	5	0	97	84	49	35	0	100	70	99	74	1	100	100	100	100	5	100	100	100	100	100
O. mercator	60	67	16	27	0	87	100	62	66	0	100	99	97	99	2	100	100	100	99	6	100	100	100	100	100
C. ferrugineus	100	100	100	47	0	100	100	100	89	0	100	100	100	95	0	100	100	100	100	12	100	100	100	100	100
Amount of deposit, 1.0 g/m^2																									
T. confusum	61	41	0	2	0	96	56	54	2	0	100	91	96	24	0	100	99	100	59	0	100	100	100	84	51
T. castaneum	75	10	5	4	0	95	32	59	34	0	100	79	86	57	0	100	99	100	100	0	100	100	100	100	66
O. surinamensis	96	62	86	69	0	100	100	99	99	2	100	100	100	96	30	100	100	100	100	56	100	100	100	100	100
O. mercator	95	96	81	66	0	100	100	99	85	0	100	100	100	100	17	100	100	100	100	39	100	100	100	100	100
C. ferrugineus	100	100	100	100	0	100	100	100	100	17	100	100	100	100	66	100	100	100	100	99	100	100	100	100	100
Amount of deposit, 2.5 g/m^2																									
T. confusum	86	95	80	79	0	97	95	99	95	0	100	100	100	100	0	100	100	100	100	16	100	100	100	100	97
T. castaneum	87	42	90	99	0	100	85	96	100	0	100	100	100	100	9	100	100	100	100	30	100	100	100	100	100
O. surinamensis	100	100	100	100	36	100	100	100	100	41	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
O. mercator	96	100	100	100	26	100	100	100	100	67	100	100	100	100	96	100	100	100	100	100	100	100	100	100	100
C. ferrugineus	100	100	100	100	100	100	100	100	100	95	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

[a]Mortality determinations were made 1, 4, 8, 16 and 52 weeks after treatment. Each value is the average of 4 replicates.

TABLE 3

Effect of iodofenphos[a] applied on fir plywood surfaces at three dosages against five species of stored-product insects

	Percent mortality after exposure periods (hr) of																								
	3					5					8					16					24				
	Age of deposits (weeks)																								
Species	1	4	8	16	52	1	4	8	16	52	1	4	8	16	52	1	4	8	16	52	1	4	8	16	52
Amount of deposit, 0.5 g/m²																									
T. confusum	96	55	47	0	0	100	95	97	0	0	100	100	100	12	0	100	100	100	94	5	100	97	100	100	97
T. castaneum	99	22	69	0	0	100	71	99	2	0	100	100	100	27	0	100	100	100	96	15	100	100	100	100	100
O. surinamensis	95	56	100	0	0	100	99	100	50	1	100	100	100	85	29	100	100	100	100	95	100	100	100	100	100
O. mercator	90	94	100	16	0	99	100	100	75	6	100	100	100	95	31	100	100	100	100	99	100	100	100	100	100
C. ferrugineus	100	100	100	79	1	100	100	100	100	31	100	100	100	100	82	100	100	100	100	96	100	100	100	100	100
Amount of deposit, 1.0 g/m²																									
T. confusum	100	100	100	99	0	100	100	100	100	0	100	100	100	100	40	100	100	100	100	99	100	100	100	100	100
T. castaneum	100	77	99	90	0	100	99	100	100	0	100	100	100	100	46	100	100	100	100	79	100	100	100	100	100
O. surinamensis	100	100	100	100	39	100	100	100	100	66	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
O. mercator	100	100	100	100	41	100	100	100	100	62	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
C. ferrugineus	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Amount of deposit, 2.5 g/m²																									
T. confusum	100	100	100	100	51	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
T. castaneum	100	97	100	100	39	100	95	100	100	84	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
O. surinamensis	100	100	100	100	100	100	100	100	100	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
O. mercator	100	100	100	100	91	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
C. ferrugineus	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

[a]Mortality determinations were made 1, 4, 8, 16 and 52 weeks after treatment. Each value is the average of 4 replicates.

TABLE 4

Effect of malathion[a] applied on fir plywood surfaces at three dosages against five species of stored-product insects

	Percent mortality after exposure periods (hr) of																								
	3					5					8					16					52				
	Age of deposits (weeks)																								
Species	1	4	8	16	52	1	4	8	16	52	1	4	8	16	52	1	4	8	16	52	1	4	8	16	52
Amount of deposit, 0.5 g/m^2																									
T. confusum	96	100	76	61	0	100	97	96	85	0	100	100	100	96	0	100	100	100	100	4	100	100	100	100	97
T. castaneum	96	97	100	20	0	100	100	100	44	0	100	100	100	100	0	100	100	100	100	0	100	100	100	100	100
O. surinamensis	100	100	100	72	0	100	100	100	99	1	100	100	100	100	2	100	100	100	100	54	100	100	100	100	100
O. mercator	100	100	100	95	0	100	100	100	100	0	100	100	100	100	2	100	100	100	100	7	100	100	100	100	100
C. ferrugineus	100	100	94	45	0	100	100	100	76	0	100	100	100	91	0	100	100	100	100	0	100	100	100	100	90
Amount of deposit, 1.0 g/m^2																									
T. confusum	97	100	100	100	1	100	100	99	100	0	100	100	100	96	10	100	100	100	100	47	100	100	100	100	100
T. castaneum	100	100	100	100	0	100	100	100	100	0	100	100	100	100	12	100	100	100	100	26	100	100	100	100	100
O. surinamensis	100	100	100	100	30	100	100	100	100	30	100	100	100	100	79	100	100	100	100	100	100	100	100	100	100
O. mercator	100	100	100	100	22	100	100	100	100	17	100	100	100	100	94	100	100	100	100	100	100	100	100	100	100
C. ferrugineus	100	100	100	100	0	100	100	100	100	0	100	100	100	100	2	100	100	100	100	100	100	100	100	100	90
Amount of deposit, 2.5 g/m^2																									
T. confusum	95	100	100	100	91	100	100	100	100	100	100	100	100	100	99	100	100	100	100	100	100	100	100	100	100
T. castaneum	99	100	100	100	94	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
O. surinamensis	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
O. mercator	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
C. ferrugineus	100	100	100	100	94	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

[a]Mortality determinations were made after 1, 4, 8, 16 and 52 weeks after treatment. Each value is the average of 4 replicates.

insect after exposure periods of 3, 5, 8, 16 and 24 hours. After 16 weeks, bromophos applied at 2.5 g/m^2, provided complete control of all species exposed on surfaces for 3, 5, 8, 16 and 24 hours. After 52 weeks, only at an exposure period of 24 hours, bromophos applied at 2.5 g/m^2, provided complete mortality against all species but it was not adequate to control *T. confusum* and *T. castaneum* at the exposure periods of 5, 8, and 16 hours. At an exposure period of 3 hours, bromophos at this deposit was not effective against any species of test insect except *C. ferrugineus*.

At a deposit of 1.0 g/m^2, bromophos gave high toxicity against all species exposed on surfaces for 24 hours after 52 weeks of treatment. For exposure periods of 8 and 16 hours, this dosage was not adequate to kill any insect species after 52 weeks except *C. ferrugineus*; and for exposure periods of 3 and 5 hours, bromophos provided adequate mortality against all species at 16 weeks except *T. confusum* and *T. castaneum*. Bromophos at this concentration gave only 41 and 10% mortality against *T. confusum* and *T. castaneum*, respectively, after exposure on surfaces for 3 hr at 4 wk after treatment; and provided 54 and 59% mortality against these insects, respectively, after exposure on surfaces for 5 hr at 8 week after treatment.

At a deposit of 0.5 g/m^2, bromophos gave effective control against *O. surinamensis*, *O. mercator* and *C. ferrigineus* exposed on surfaces for 24 hours at 52 weeks after treatment. Bromophos seemed to be more effective against *O. surinamensis*, *O. mercator* and *C. ferrugineus* than *T. confusum* and *T. castaneum*. At a dosage of 0.5 g/m^2, it provided adequate control against *O. surinamensis*, *O. mercator* and *C. ferrugineus* at 16 weeks after treatment when exposed on surfaces for 5, 8, and 16 hours. Although bromophos applied at 0.5 g/m^2 was not fully effective against *T. confusum* *T. castaneum*, *O. surinamensis* and *O. mercator* exposed on surfaces for

3 hours at 1 week after treatment, it gave complete control of *C. ferrugineus* up to 8 weeks after treatment.

Persistence of iodofenphos on fir plywood surfaces

Table 3, Fig. 9b, Fig. 10b, Fig. 11b, Fig. 12b and Fig. 13b summarize the results obtained with iodofenphos for the five species of test insect after exposure periods of 3, 5, 8, 16 and 24 hours. After 52 weeks, iodofenphos applied at 2.5 g/m^2, provided complete control of all species at all exposure periods.

At 1.0 g/m^2, iodofenphos gave adequate control against all species of test insects at all exposure periods for up to 52 weeks after treatment except for *T. confusum* and *T. castaneum*, all of which survived exposure periods of 3 and 5 hours.

The results indicate that iodofenphos required longer exposure periods at 0.5 g/m^2 to kill all species of test insects.

The results also indicate that of the three compounds iodofenphos was the most effective against *Oryzaephilus* spp. and *C. ferrugineus*. At a deposit of 0.5 g/m^2, it persisted against three species for 52 weeks after exposure for 24 hours. Iodofenphos also persisted for 16 weeks against *O. surinamensis*, *O. mercator* and *C. ferrugineus* after exposure for 5 and 8 hours, but was not effective against *T. confusum* and *T. castaneum*. Adequate control of *C. ferrugineus* was obtained at 52 weeks when exposed for 5 and 8 hours. For exposure periods of 3 hours, 0.5 g/m^2, produced high mortalities against *T. confusum*, *T. castaneum*, *O. surinamensis* and *O. mercator* at 8 weeks after treatment, and persisted for at least 16 weeks against *C. ferrugineus* at the same dosage.

Persistence of malathion on fir plywood surfaces

Table 4, Fig. 9a, Fig. 10a, Fig. 11a, Fig. 12a and Fig. 13a summarize the results obtained with malathion for the five species of test insects after exposure periods of 3, 5, 8, 16 and 24 hours. At 52 weeks, malathion applied at 2.5 g/m^2, gave complete mortality of all species at all exposure periods.

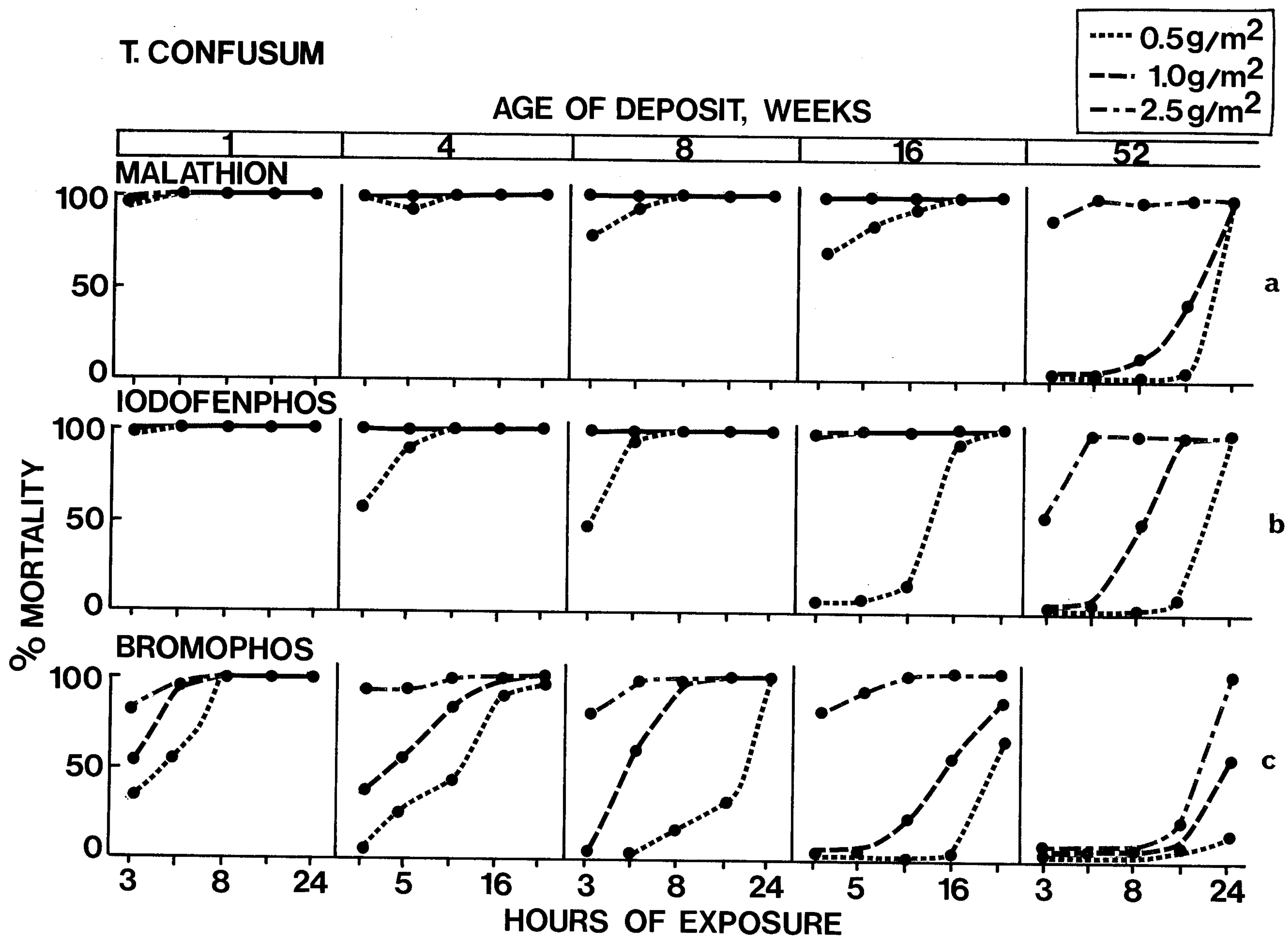
At 1.0 g/m^2, malathion provided complete control against all species at 52 weeks after treatment when exposed on surfaces for 24 hours For an exposure period of 16 hours, its toxicity started to decline against T. confusum and T. castaneum at 52 weeks after treatment but it remained toxic against O. surinamensis, O. mercator and C. ferrugineus at this dosage. At this dosage, malathion also provided complete control of all species exposed on surfaces for 3, 5, and 8 hours for at least 16 weeks after treatment. However, at 52 weeks, malathion at 1.0 g/m^2, was ineffective against O. surinamensis, O. mercator and C. ferrugineus exposed on surfaces for 3, 5 and 8 hours.

At 52 weeks, malathion applied at 0.5 g/m^2, persisted against all species exposed on surfaces for 24 hours. Very few of any species were killed at this concentration at 52 weeks after treatment at exposure periods of 3, 5, 8 and 16 hours except for O. surinamensis at an exposure period of 16 hours.

(b) Susceptibility of Each Insect Species to Each Insecticide

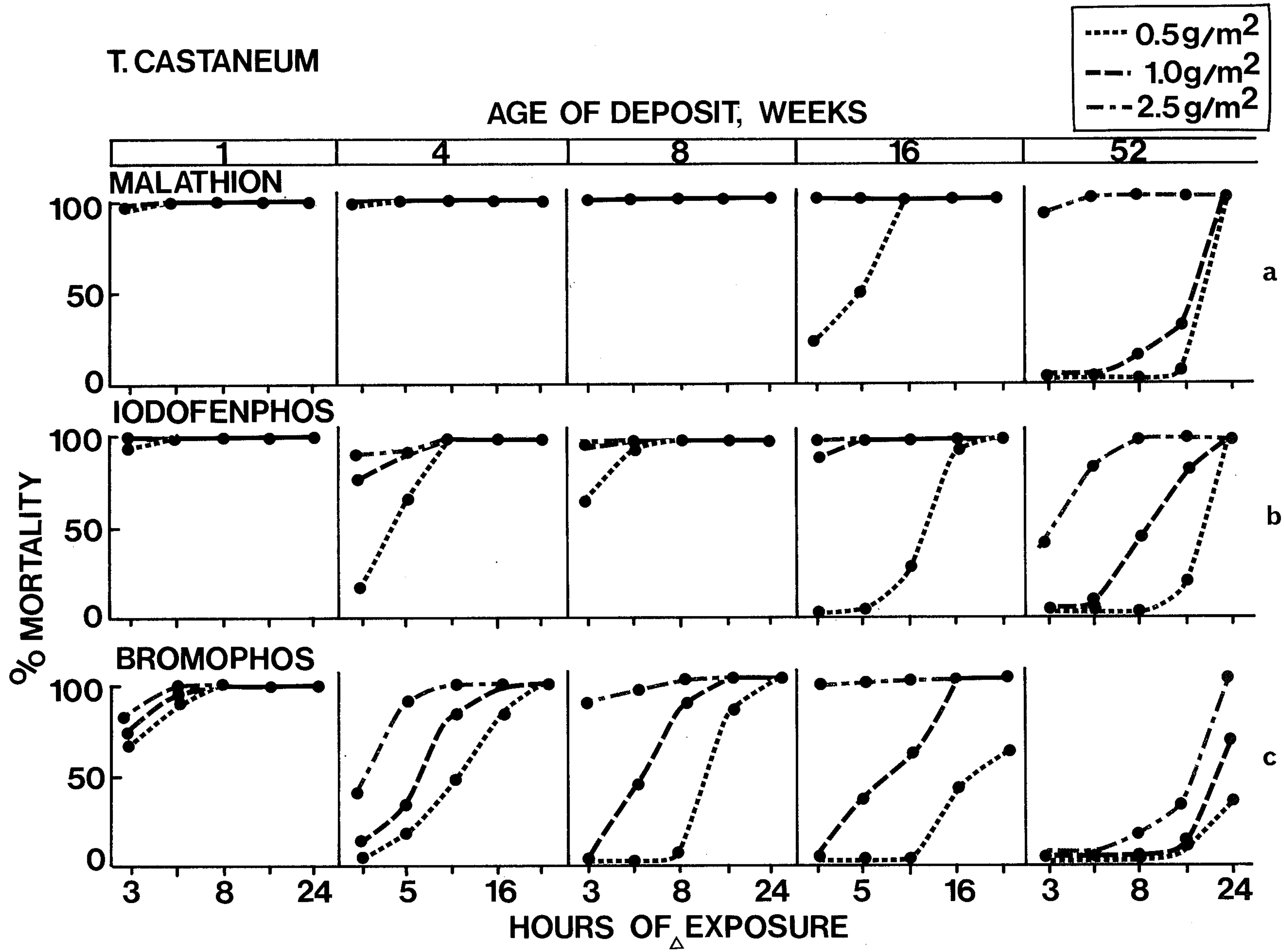
The relative toxicity of bromophos, iodofenphos and malathion to the different species is presented in Figs. 9-13. However, the results of their toxicity to each species and each exposure period have also been illustrated in Tables 5-29 as follows: Tables 5-9 for T. confusum Tables 10-14 for T. castaneum; Tables 15-19 for O. surinamensis; Tables

Figure 9. Percent mortality of adult T. confusum exposed for 3, 5, 8, 16 and 24 hours to deposits of bromophos, iodofenphos and malathion on fir plywood surfaces.



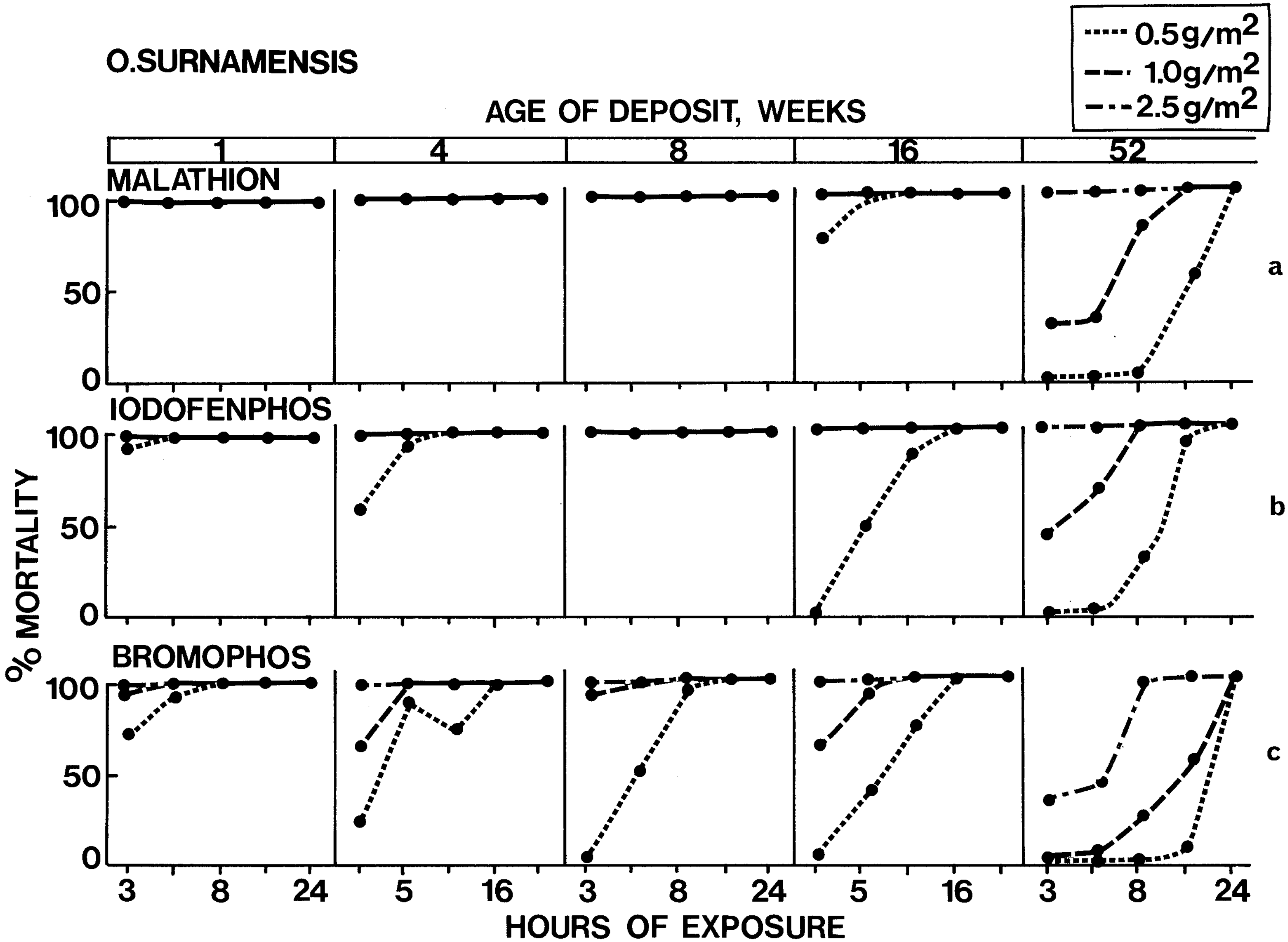
T. CONFUSUM
AGE OF DEPOSIT, WEEKS
0.5g/m2
1.0g/m2
2.5g/m2
1
4
8
16
52
MALATHION
IODOFENPHOS
BROMOPHOS
% MORTALITY
100
50
0
a
b
c
3
8
24
5
16
HOURS OF EXPOSURE

Figure 10. Percent mortality of adult *T. castaneum* exposed for 3, 5, 8, 16 and 24 hours to deposits of bromophos, iodofenphos and malathion on fir plywood surfaces.



T. CASTANEUM
AGE OF DEPOSIT, WEEKS
1
4
8
16
52
0.5g/m2
1.0g/m2
2.5g/m2
MALATHION
IODOFENPHOS
BROMOPHOS
% MORTALITY
100
50
0
a
b
c
3
5
8
16
24
HOURS OF EXPOSURE

Figure 11. Percent mortality of adult _O. surinamensis_ exposed for 3, 5, 8, 16 and 24 hours to deposts of bromophos, iodofenphos and malathion on fir plywood surfaces.



O.SURNAMENSIS
0.5g/m2
1.0g/m2
2.5g/m2
AGE OF DEPOSIT, WEEKS
1
4
8
16
52
MALATHION
IODOFENPHOS
BROMOPHOS
% MORTALITY
100
50
0
a
b
c
3
8
24
5
16
HOURS OF EXPOSURE

Figure 12. Percent mortality of adult O. mercator exposed for 3, 5, 8, 16 and 24 hours to deposits of bromophos iodofenphos and malathion on fir plywood surfaces.

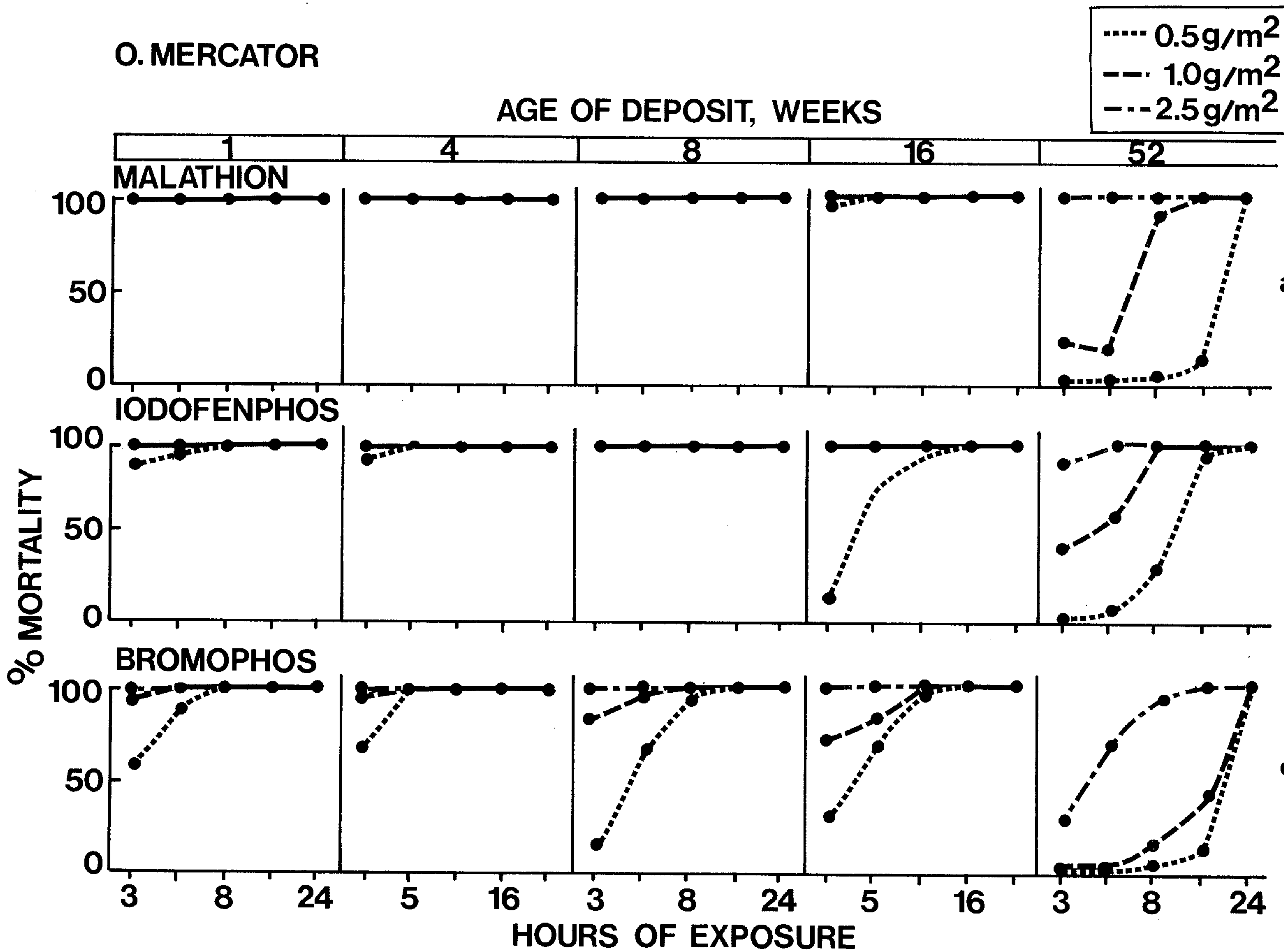
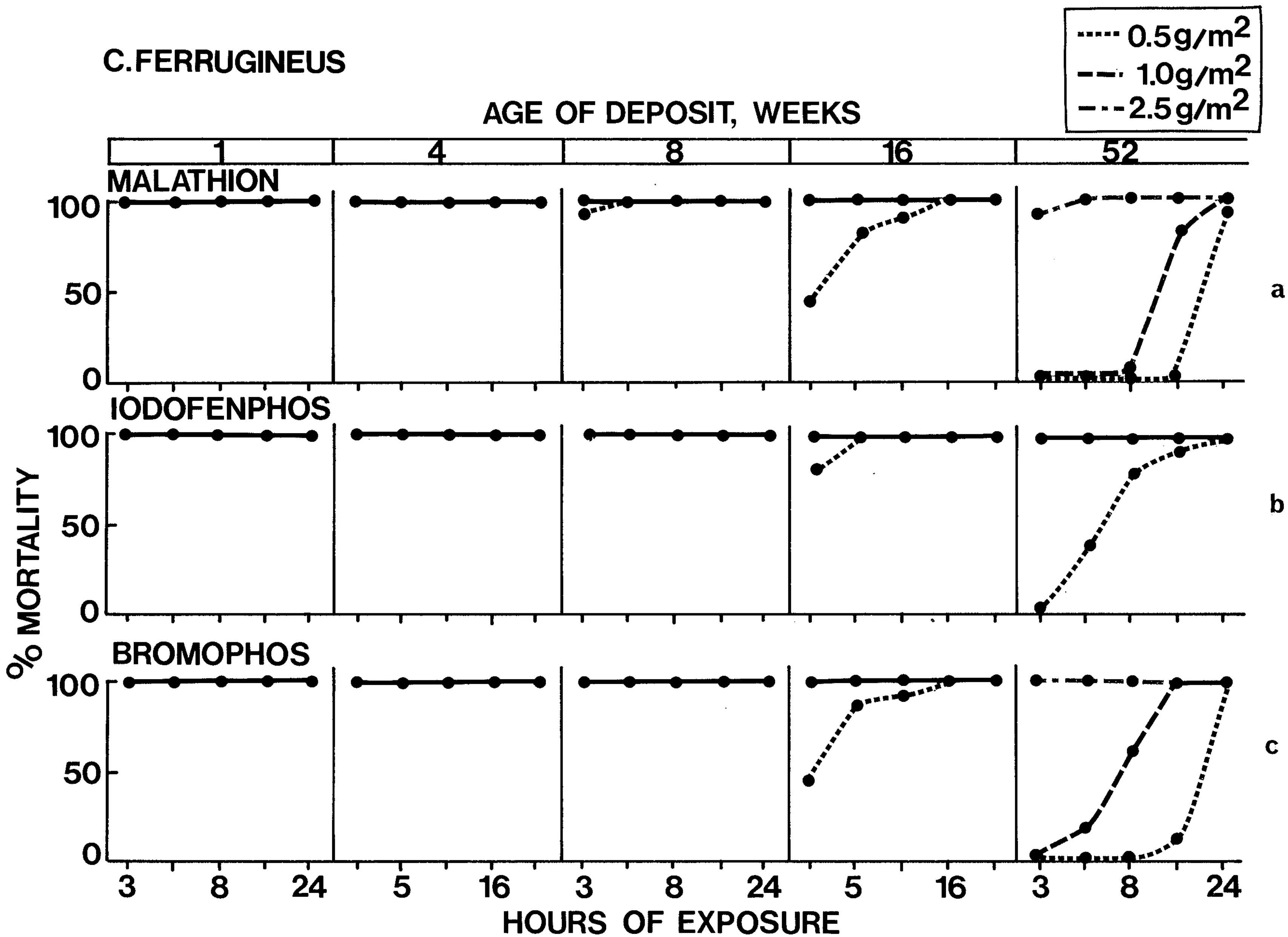

O. MERCATOR
AGE OF DEPOSIT, WEEKS
0.5g/m2
1.0g/m2
2.5g/m2
1
4
8
16
52
MALATHION
IODOFENPHOS
BROMOPHOS
% MORTALITY
100
50
0
a
b
c
3
8
24
5
16
HOURS OF EXPOSURE

Figure 13. Percent mortality of adult *C. ferrugineus* exposed for 3, 5, 8, 16 and 24 hours to deposits of bromophos, iodofenphos and malathion on fir plywood surfaces.


C.FERRUGINEUS
AGE OF DEPOSIT, WEEKS
1
4
8
16
52
0.5g/m2
1.0g/m2
2.5g/m2
MALATHION
IODOFENPHOS
BROMOPHOS
% MORTALITY
100
50
0
3
8
24
5
16
HOURS OF EXPOSURE
a
b
c

20-24 for *O. mercator*; and Tables 25-29 for *C. ferrugineus*.

Relative susceptibility of *T. confusum* to bromophos, iodofenphos and malathion

Tables 5-9 and Fig. 9 show the relative susceptibility of *T. confusum* to each insecticide at exposure periods of 3, 5, 8, 16 and 24 hours.

Table 6 shows the percent mortality of the different insecticides against *T. confusum* exposed on surfaces for 5 hours. There were sufficient differences in response to different insecticides of this species. The relative toxicity of bromophos, iodofenphos and malathion at different dosages and different ages of deposit to *T. confusum* is presented in this table.

The orders of toxicity of the different amounts of deposit and different ages of deposit of insecticides to *T. confusum* exposed on surfaces for 5 hours were as follows. At a deposit of 0.5 g/m^2, malathion > iodofenphos > bromophos; at 1.0 g/m^2, iodofenphos = malathion > bromophos; at 2.5 g/m^2, iodofenphos = malathion > bromophos; and at 1 week after treatment, malathion = iodofenphos > bromophos; at 4 weeks, malathion = iodofenphos > bromophos; at 8 weeks, malathion = iodofenphos > bromophos; at 16 weeks, malathion > iodofenphos > bromophos; at 52 weeks, malathion = iodofenphos > bromophos.

Malathion was decidedly the most toxic insecticide against *T. confusum* followed by iodofenphos while bromophos was the least toxic among the three insecticides tested.

TABLE 5

The percent mortality of T. <u>confusum</u> beetle after exposure for 3 hours to three organophosphorus insecticides deposits on fir plywood surfaces.

Insecticide	Percent mortality after age of deposit (weeks)				
	1	4	8	16	52
<u>Amount of deposits, 0.5 g/m^2</u>					
Bromophos	36	2	0	0	0
Iodofenphos	96	55	47	0	0
Malathion	96	100	76	61	0
<u>Amount of deposit, 1.0 g/m^2</u>					
Bromophos	61	41	0	2	0
Iodofenphos	100	100	100	99	0
Malathion	97	100	100	100	1
<u>Amount of deposit, 2.5 g/m^2</u>					
Bromophos	86	95	80	79	0
Iodofenphos	100	100	100	100	51
Malathion	95	100	100	100	91

TABLE 6

The percent morality of *T. confusum* beetle after exposure for 5 hours to three organophosphorus insecticide deposits on fir plywood surfaces.

Insecticide	Percent mortality after age of deposit (weeks)[1] ± S.E.: 1	4	8	16	52
Amount of deposit, 0.5 g/m²					
Bromophos	64 ± 14.77a[2]	27 ± 13.62a	0 a	0 a	0
Iodofenphos	100 ± 0 b	95 ± 3.53b	97 ± 2.39b	0 a	0
Malathion	100 ± 0 b	97 ± 2.50b	96 ± 3.75b	85 ± 7.36b	0
Amount of deposit, 1.0 g/m²					
Bromophos	96 ± 2.39a	56 ± 17.0a	54 ± 14.05a	2 ± 2.50a	0
Iodofenphos	100 ± 0 a	100 ± 0 b	100 ± 0 b	100 ± 0 b	0
Malathion	100 ± 0 a	100 ± 0 b	99 ± 1.25b	100 ± 0 b	0
Amount of deposit, 2.5 g/m²					
Bromophos	97 ± 1.44a	95 ± 2.04b	99 ± 1.25a	95 ± 2.04a	0 a
Iodofenphos	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 b
Malathion	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 b

[1] Mean of 4 replicates.

[2] Common letter following column indicates no significant difference at 5% level between insecticides at the same amount of deposit.

S.E.-standard error of replicate mean.

TABLE 7

The percent mortality of *T. confusum* beetle after exposure for 8 hours to three organophosphorus insecticide deposits on fir plywood surfaces.

Insecticide	Percent mortality after age of deposit (weeks)				
	1	4	8	16	52
Amount of deposits, 0.5 g/m^2					
Bromophos	100	44	19	0	0
Iodofenphos	100	100	100	12	0
Malathion	100	100	100	96	0
Amount of deposit, 1.0 g/m^2					
Bromophos	100	91	96	24	0
Iodofenphos	100	100	100	100	40
Malathion	100	100	100	100	10
Amount of deposit, 2.5 g/m^2					
Bromophos	100	100	100	100	0
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	99

TABLE 8

The percent mortality of *T. confusum* beetle after exposure for 16 hours to three organophosphorus insecticide deposits on fir plywood surfaces.

Insecticide	Percent mortality after age of deposit (weeks) 1	4	8	16	52
Amount of deposits, 0.5 g/m^2					
Bromophos	100	92	32	0	0
Iodofenphos	100	100	100	94	5
Malathion	100	100	100	100	4
Amount of deposit, 1.0 g/m^2					
Bromophos	100	99	100	59	0
Iodofenphos	100	100	100	100	99
Malathion	100	100	100	100	47
Amount of deposit, 2.5 g/m^2					
Bromophos	100	100	100	100	16
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	100

TABLE 9

The percent mortality of *T. confusum* beetle after exposure for 24 hours to three organophosphorus insecticide deposits on fir plywood surfaces.

Insecticide	Percent mortality after age of deposit (weeks) 1	4	8	16	52
Amount of deposits, 0.5 g/m^2					
Bromophos	100	97	100	59	6
Iodofenphos	100	97	100	100	97
Malathion	100	100	100	100	97
Amount of deposit, 1.0 g/m^2					
Bromophos	100	100	100	84	51
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	100
Amount of deposit, 2.5 g/m^2					
Bromophos	100	100	100	100	97
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	100

Table 6 shows significant differences in toxicity among the three amounts of deposit of each compound.

Bromophos : $2.5\ g/m^2 > 1.0\ g/m^2 > 0.5\ g/m^2$

Iodofenphos : $2.5\ g/m^2 > 1.0\ g/m^2 > 0.5\ g/m^2$

Malathion : $2.5\ g/m^2 > 1.0\ g/m^2 = 0.5\ g/m^2$

Relative susceptibility of *T. castaneum* to bromophos, iodofenphos and malathion

Tables 10-14 and Fig. 10 show the relative susceptibility of *T. castaneum* to insecticides at the exposure periods of 3, 5, 8, 16 and 24 hours.

Table 11 shows the percent mortality of the different insecticides against *T. castaneum* exposed on surfaces for 5 hours. There were significant differences in response to different insecticides of this species. The relative toxicity of bromophos, iodofenphos and malathion at the different amounts of deposit and different ages of deposit to *T. castaneum* is presented in this table.

The orders of toxicity of the different amounts of deposit and different ages of deposit of insecticides to *T. castaneum* exposed on surfaces for 5 hours were as follows: at a deposit of $0.5\ g/m^2$, malathion > iodofenphos > bromophos; at $1.0\ g/m^2$, malathion = iodofenphos > bromophos; at $2.5\ g/m^2$, malathion = iodofenphos > bromophos; and at 1 week after treatment, malathion = iodofenphos = bromophos; at 4 weeks, malathion > iodofenphos > bromophos; at 8 weeks, malathion = iodofenphos > bromophos; at 16 weeks, malathion > iodofenphos > bromophos; at 52 weeks, malathion = iodofenphos > bromophos.

In general, similar patterns of insecticide effectiveness were obtained at the three dosages for this species as for *T. confusum*. Thus

TABLE 10

The percent mortality of *T. castaneum* beetle after exposure for 3 hours to three organophosphorus insecticide deposits on fir plywood surfaces.

	Percent mortality after age of deposit (weeks)				
Insecticide	1	4	8	16	52
Amount of deposits, 0.5 g/m^2					
Bromophos	65	1	0	0	0
Iodofenphos	99	22	69	0	0
Malathion	96	97	100	20	0
Amount of deposit, 1.0 g/m^2					
Bromophos	75	10	5	4	0
Iodofenphos	100	77	99	90	0
Malathion	100	100	100	100	0
Amount of deposit, 2.5 g/m^2					
Bromophos	87	42	90	99	0
Iodofenphos	100	97	100	100	39
Malathion	99	100	100	100	94

TABLE 11

The percent mortality of *T. castaneum* beetle after exposure for 5 hours to three organophosphorus insecticide deposits on fir plywood surfaces.

Insecticide	Percent mortality after age of deposit (weeks)[1] ± S.E.				
	1	4	8	16	52
Amount of deposit, 0.5 g/m^2					
Bromophos	87 ± 3.23a[2]	16 ± 6.88a	0 a	0 a	0 a
Iodofenphos	100 ± 0 a	71 ± 12.81a	99 ± 4.33b	2 ± 1.44a	0 a
Malathion	100 ± 0 a	100 ± 0 b	100 ± 0 b	44 ± 19.72b	0 a
Amount of deposit, 1.0 g/m^2					
Bromophos	95 ± 3.75a	32 ± 19.20a	46 ± 4.27a	34 ± 16.88a	0 a
Iodofenphos	100 ± 0 a	99 ± 4.33b	100 ± 0 b	100 ± 0 b	0 a
Malathion	100 ± 0 a	100 ± 0 b	100 ± 0 b	100 ± 0 b	0 a
Amount of deposit, 2.5 g/m^2					
Bromophos	100 ± 0 a	85 ± 4.56a	96 ± 2.39a	100 ± 0 a	0 a
Iodofenphos	100 ± 0 a	95 ± 0 a	100 ± 0 a	100 ± 0 a	84 ± 16.25b
Malathion	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 b

[1]Mean of 4 replicates.
[2]Common letter following column indicates no significant difference at 5% level between insecticides at the same amount of deposit.
S.E.-standard error of replicate mean.

TABLE 12

The percent mortality of *T. castaneum* beetle after exposure for 8 hours to three organophosphorus insecticide deposits on fir plywood surfaces.

	Percent mortality after age of deposit (weeks)				
Insecticide	1	4	8	16	52
Amount of deposits, 0.5 g/m^2					
Bromophos	100	45	0	4	0
Iodofenphos	100	100	100	27	0
Malathion	100	100	100	44	0
Amount of deposit, 1.0 g/m^2					
Bromophos	100	79	86	57	0
Iodofenphos	100	100	100	100	46
Malathion	100	100	100	100	0
Amount of deposit, 2.5 g/m^2					
Bromophos	100	100	100	100	9
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	100

TABLE 13

The percent mortality of *T. castaneum* beetle after exposure for 16 hours to three organophosphorus insecticide deposits on fir plywood surfaces.

	Percent mortality after age of deposit (weeks)				
Insecticide	1	4	8	16	52
Amount of deposits, 0.5 g/m^2					
Bromophos	100	81	81	44	0
Iodofenphos	100	100	100	96	15
Malathion	100	100	100	100	0
Amount of deposit, 1.0 g/m^2					
Bromophos	100	99	100	100	0
Iodofenphos	100	100	100	100	79
Malathion	100	100	100	100	26
Amount of deposit, 2.5 g/m^2					
Bromophos	100	100	100	100	30
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	100

TABLE 14

The percent mortality of _T. castaneum_ beetle after exposure for 24 hours to three organophosphorus insecticide deposits on fir plywood surfaces.

	Percent mortality after age of deposit (weeks)				
Insecticide	1	4	8	16	52
Amount of deposits, 0.5 g/m^2					
Bromophos	100	100	100	62	32
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	100
Amount of deposit, 1.0 g/m^2					
Bromophos	100	100	100	100	66
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	100
Amount of deposit, 2.5 g/m^2					
Bromophos	100	100	100	100	100
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	100

malathion was the most effective against *T. castaneum* followed by iodofenphos and bromophos was the least effective compound.

Table 11 also shows significant differences in toxicity among the three amounts of deposit of each compound.

Bromophos	:	2.5 g/m^2 > 1.0 g/m^2 > 0.5 g/m^2
Iodofenphos	:	2.5 g/m^2 > 1.0 g/m^2 > 0.5 g/m^2
Malathion	:	2.5 g/m^2 > 1.0 g/m^2 > 0.5 g/m^2

Relative susceptibility of *O. surinamensis* to bromophos, iodofenphos and malathion

Tables 15-19 and Fig. 11 show the relative susceptibility of *O. surinamensis* to insecticides at exposure periods of 3, 5, 8, 16 and 24 hours.

Table 16 shows the percent mortality of the different insecticides against *O. surinamensis* exposed on surfaces for 5 hours. There were significant differences in response to different insecticides of this species. The relative toxicity of bromophos, iodofenphos and malathion at the different amounts of deposit and different ages of deposit to *O. surinamensis* is presented in this table.

The orders of toxicity of the different amounts of deposit and different ages of deposit of insecticides to *O. surinamensis* exposed on surfaces for 5 hours were as follows: at a deposit of 0.5 g/m^2, malathion > iodofenphos > bromophos; at 1.0 g/m^2, iodofenphos > malathion > bromophos; at 2.5 g/m^2, malathion = iodofenphos > bromophos; and at 1 week after treatment, malathion = iodofenphos = bromophos; at 4 weeks, malathion = iodofenphos = bromophos; at 8 weeks, malathion = iodofenphos > bromophos; at 16 weeks, malathion > iodofenphos = bromophos; at 52 weeks, iodofenphos > malathion > bromophos.

TABLE 15

The percent mortality of *O. surinamensis* beetle after exposure for 3 hours to three organophosphorus insecticide deposits on fir plywood surfaces.

Insecticide	Percent mortality after age of deposit (weeks)				
	1	4	8	16	52
Amount of deposits, 0.5 g/m^2					
Bromophos	69	15	5	5	0
Iodofenphos	95	56	100	0	0
Malathion	100	100	100	72	0
Amount of deposit, 1.0 g/m^2					
Bromophos	96	62	86	69	0
Iodofenphos	100	100	100	100	39
Malathion	100	100	100	100	30
Amount of deposit, 2.5 g/m^2					
Bromophos	100	100	100	100	36
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	100

TABLE 16

The percent mortality of *O. surinamensis* beetle after exposure for 5 hours to three organophosphorus insecticide deposits on fir plywood surfaces.

Insecticide	Percent mortality after age of deposit (weeks)[1] ± S.E. 1	4	8	16	52
Amount of deposit, 0.5 g/m²					
Bromophos	97 ± 2.5a[2]	84 ± 11.43a	49 ± 1.25a	35 ± 13.38a	0 a
Iodofenphos	100 ± 0 a	99 ± 1.25b	100 ± 0 b	50 ± 7.07b	1 ± 1.25a
Malathion	100 ± 0 a	100 ± 0 b	100 ± 0 b	99 ± 1.25c	1 ± 1.25a
Amount of deposit, 1.0 g/m²					
Bromophos	100 ± 0 a	100 ± 0 a	99 ± 1.25a	99 ± 1.25a	2 ± 1.44a
Iodofenphos	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	66 ± 23.04b
Malathion	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	30 ± 14.72c
Amount of deposit, 2.5 g/m²					
Bromophos	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	41 ± 10.68a
Iodofenphos	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	99 ± 1.25b
Malathion	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 b

[1] Mean of 4 replicates.
[2] Common letter following column indicates no significant difference at 5% level between insecticides at the same amount of deposit.
S.E.-standard error of replicate mean.

TABLE 17

The percent mortality of O. surinamensis beetle after exposure for 8 hours to three organophosphorus insecticide deposits on fir plywood surfaces.

	Percent mortality after age of deposit (weeks)				
Insecticide	1	4	8	16	52
Amount of deposits, 0.5 g/m^2					
Bromophos	100	70	99	74	1
Iodofenphos	100	100	100	85	29
Malathion	100	100	100	100	2
Amount of deposit, 1.0 g/m^2					
Bromophos	100	100	100	96	30
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	79
Amount of deposit, 2.5 g/m^2					
Bromophos	100	100	100	100	100
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	100

TABLE 18

The percent mortality of O. surinamensis beetle after exposure for 16 hours to three organophosphorus insecticide deposits on fir plywood surfaces.

Insecticide	Percent mortality after age of deposit (weeks)				
	1	4	8	16	52
Amount of deposits, 0.5 g/m^2					
Bromophos	100	100	100	100	5
Iodofenphos	100	100	100	100	95
Malathion	100	100	100	100	54
Amount of deposit, 1.0 g/m^2					
Bromophos	100	100	100	100	56
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	100
Amount of deposit, 2.5 g/m^2					
Bromophos	100	100	100	100	100
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	100

TABLE 19

The percent mortality of *O. surinamensis* beetle after exposure for 24 hours to three organophosphorus insecticide deposits on fir plywood surfaces.

Insecticide	Percent mortality after age of deposit (weeks)				
	1	4	8	16	52
Amount of deposits, 0.5 g/m^2					
Bromophos	100	100	100	100	100
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	100
Amount of deposit, 1.0 g/m^2					
Bromophos	100	100	100	100	100
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	100
Amount of deposit, 2.5 g/m^2					
Bromophos	100	100	100	100	100
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	100

There was no significant difference in persistence and toxicity between iodofenphos and malathion. The results indicate that iodofenphos and malathion were equally effective against O. surinamensis while bromophos was the least toxic among the three insecticides tested.

Table 16 also shows significant differences in toxicity among the three amounts of deposit of each compound.

Bromophos : 2.5 g/m^2 > 1.0 g/m^2 > 0.5 g/m^2

Iodofenphos: 2.5 g/m^2 > 1.0 g/m^2 > 0.5 g/m^2

Malathion : 2.5 g/m^2 > 1.0 g/m^2 > 0.5 g/m^2

Relative susceptibility of O. mercator to bromophos, iodofenphos and malathion

Tables 20-24 and Fig. 12 show the relative susceptibility of O. mercator to insecticides at the exposure periods of 3, 5, 8, 16 and 24 hours.

Table 21 shows the percent mortality of the different insecticides against O. mercator exposed on surfaces for 5 hours. There were significant differences in response to different insecticides of this species. The relative toxicity of bromophos, iodofenphos and malathion at the different amounts of deposit and different ages of deposit to O. mercator is presented in this table.

The orders of toxicity of different amounts of deposit and different ages of deposit of insecticides to O. mercator exposed on surfaces for 5 hours were as follows: at a deposit of 0.5 g/m^2, malathion = iodofenphos > bromophos; at 1.0 g/m^2, iodofenphos > malathion bromophos; at 2.5 g/m^2, malathion = iodofenphos > bromophos; and at 1 week after treatment, malathion = iodofenphos > bromophos; at 4 weeks,

TABLE 20

The percent mortality of O. mercator beetle after exposure for 3 hours to three organophosphorus insecticide deposits on fir plywood surfaces.

Insecticide	Percent mortality after age of deposit (weeks)				
	1	4	8	16	52
Amount of deposits, 0.5 g/m^2					
Bromophos	60	67	16	27	0
Iodofenphos	90	94	100	16	0
Malathion	100	100	100	95	0
Amount of deposit, 1.0 g/m^2					
Bromophos	95	96	81	66	0
Iodofenphos	100	100	100	100	44
Malathion	100	100	100	100	22
Amount of deposit, 2.5 g/m^2					
Bromophos	96	100	100	100	26
Iodofenphos	100	100	100	100	91
Malathion	100	100	100	100	100

TABLE 21

The percent mortality of *O. mercator* beetle after exposure for 5 hours to three organophosphorus insecticide deposits on fir plywood surfaces.

Insecticide	Percent mortality after age of deposit (weeks)[1] ± S.E.				
	1	4	8	16	52
Amount of deposit, 0.5 g/m^2					
Bromophos	87 ± 4.79a[2]	100 ± 0 a	62 ± 4.33a	66 ± 6.25a	0 a
Iodofenphos	99 ± 1.25a	100 ± 0 a	100 ± 0 b	75 ± 4.08a	6 ± 3.14a
Malathion	100 ± 0 a	100 ± 0 a	100 ± 0 b	100 ± 0 b	0 a
Amount of deposit, 1.0 g/m^2					
Bromophos	100 ± 0 a	100 ± 0 a	99 ± 1.25a	85 ± 11.73a	0 a
Iodofenphos	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 b	62 ± 21.65b
Malathion	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 b	17 ± 14.21c
Amount of deposit, 2.5 g/m^2					
Bromophos	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	67 ± 21.36a
Iodofenphos	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 b
Malathion	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 b

[1] Mean of 4 replicates.
[2] Common letter following column indicates no significant difference at 5% level between insecticides at the same amount of deposit.
S.E.-standard error of replicate mean.

TABLE 22

The percent mortality of *O. mercator* beetle after exposure for 8 hours to three organophosphorus insecticide deposits on fir plywood surfaces.

Insecticide	Percent mortality after age of deposit (weeks): 1	4	8	16	52
Amount of deposits, 0.5 g/m^2					
Bromophos	100	99	97	99	2
Iodofenphos	100	100	100	95	31
Malathion	100	100	100	100	2
Amount of deposit, 1.0 g/m^2					
Bromophos	100	100	100	100	17
Iodofenphos	100	100	100	100	100
Malathion	100	99	100	100	94
Amount of deposit, 2.5 g/m^2					
Bromophos	100	100	100	100	96
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	100

TABLE 23

The percent mortality of O. mercator beetle after exposure for 16 hours to three organophosphorus insecticide deposits on fir plywood surfaces.

Insecticide	Percent mortality after age of deposit (weeks)				
	1	4	8	16	52
Amount of deposits, 0.5 g/m^2					
Bromophos	100	100	100	99	6
Iodofenphos	100	100	100	100	99
Malathion	100	100	100	100	7
Amount of deposit, 1.0 g/m^2					
Bromophos	100	100	100	100	39
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	100
Amount of deposit, 2.5 g/m^2					
Bromophos	100	100	100	100	100
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	100

TABLE 24

The percent mortality of O. mercator beetle after exposure for 24 hours to three organophosphorus insecticide deposits on fir plywood surfaces.

	Percent mortality after age of deposit (weeks)				
Insecticide	1	4	8	16	52
Amount of deposits, 0.5 g/m^2					
Bromophos	100	100	100	100	100
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	100
Amount of deposit, 1.0 g/m^2					
Bromophos	100	100	100	100	100
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	100
Amount of deposit, 2.5 g/m^2					
Bromophos	100	100	100	100	100
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	100

malathion = iodofenphos = bromophos; at 8 weeks, malathion = iodofenphos > bromophos, at 16 weeks, malathion > iodofenphos> bromophos; at 52 weeks, iodofenphos > malathion > bromophos.

There was no significant difference in persistence and toxicity between iodofenphos and malathion. Iodofenphos was equally effective as that of malathion against O. mercator while bromophos was the least toxic among the three insecticides tested.

Table 21 also shows significant differences in toxicity among the three amounts of deposit of each compound.

Bromophos	:	2.5 g/m^2 > 1.0 g/m^2 > 0.5 g/m^2
Iodofenphos	:	2.5 g/m^2 > 1.0 g/m^2 > 0.5 g/m^2
Malathion	:	2.5 g/m^2 > 1.0 g/m^2 = 0.5 g/m^2

Relative susceptibility of C. ferrugineus to bromophos, iodofenphos and malathion

Tables 25-29 and Fig. 13 show the relative susceptibility of C. ferrugineus to insecticides at exposure periods of 3, 5, 8, 16 and 24 hours.

Table 26 shows the percent mortality of the different insecticides against C. ferrugineus exposed on surfaces for 5 hours. There were significant differences in response to different insecticides of this species. The relative toxicity of bromophos, iodofenphos and malathion at the different amounts of deposit and different ages of deposit to C. ferrugineus is presented in this table.

The orders of toxicity of the different amounts of deposit and different ages of deposit of insecticides to C. ferrugineus exposed on surfaces for 5 hours were as follows: at a deposit of 0.5 g/m^2,

TABLE 25

The percent mortality of *C. ferrugineus* beetle after exposure for 3 hours to three organophosphorus insecticide deposts on fir plywood surfaces.

Insecticide	Percent mortality after age of deposit (weeks) 1	4	8	16	52
Amount of deposits, 0.5 g/m^2					
Bromophos	100	100	100	47	0
Iodofenphos	100	100	100	79	1
Malathion	100	100	94	45	0
Amount of deposit, 1.0 g/m^2					
Bromophos	100	100	100	100	0
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	0
Amount of deposit, 2.5 g/m^2					
Bromophos	100	100	100	100	100
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	94

TABLE 26

The percent mortality of _C. ferrugineus_ beetle after exposure for 5 hours to three organophosphorus insecticide deposits on fir plywood surfaces.

Insecticide	Percent mortality after age of deposits (weeks)[1] ± S.E. 1	4	8	16	52
Amount of deposit, 0.5 g/m²					
Bromophos	100 ± 0 a[2]	100 ± 0 a	100 ± 0 a	89 ± 6.57a	0 a
Iodofénphos	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 b	31 ± 20.24b
Malathion	100 ± 0 a	100 ± 0 a	100 ± 0 a	76 ± 9.87c	0 a
Amount of deposit, 1.0 g/m²					
Bromophos	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	17 ± 14.36a
Iodofenphos	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 b
Malathion	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	0 c
Amount of deposit, 2.5 g/m²					
Bromophos	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	95 ± 3.53a
Iodofenphos	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a
Malathion	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a

[1] Mean of 4 replicates.

[2] Common letter following column indicates no significant difference at 5% level between insecticides at the same amount of deposit.

S.E.-standard error of replicate mean.

TABLE 27

The percent mortality of C. ferrugineus beetle after exposure for 8 hours to three organophosphorus insecticide deposits on fir plywood surfaces.

	Percent mortality after age of deposit (weeks)				
Insecticide	1	4	8	16	52
Amount of deposits, 0.5 g/m^2					
Bromophos	100	100	100	95	0
Iodofenphos	100	100	100	100	82
Malathion	100	100	100	91	0
Amount of deposit, 1.0 g/m^2					
Bromophos	100	100	100	100	66
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	2
Amount of deposit, 2.5 g/m^2					
Bromophos	100	100	100	100	100
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	100

TABLE 28

The percent mortality of *C. ferrugineus* beetle after exposure for 16 hours to three organophosphorus insecticide deposits on fir plywood surfaces.

Insecticide	Percent mortality after age of deposits (weeks)				
	1	4	8	16	52
Amount of deposits, 0.5 g/m^2					
Bromophos	100	100	100	100	12
Iodofenphos	100	100	100	100	96
Malathion	100	100	100	100	0
Amount of deposit, 1.0 g/m^2					
Bromophos	100	100	100	100	99
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	85
Amount of deposit, 2.5 g/m^2					
Bromophos	100	100	100	100	100
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	100

TABLE 29

The percent mortality of *C. ferrugineus* beetle after exposure for 24 hours to three organophosphorus insecticide deposits on fir plywood surfaces.

	Percent mortality after age of deposit (weeks)				
Insecticide	1	4	8	16	52
Amount of deposits, 0.5 g/m^2					
Bromophos	100	100	100	100	97
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	90
Amount of deposit, 1.0 g/m^2					
Bromophos	100	100	100	100	100
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	100
Amount of deposit, 2.5 g/m^2					
Bromophos	100	100	100	100	100
Iodofenphos	100	100	100	100	100
Malathion	100	100	100	100	100

iodofenphos > bromophos = malathion; at 1.0 g/m^2, iodofenphos > bromophos = malathion; at 1.0 g/m^2, iodofenphos > bromophos = malathion; at 2.5 g/m^2, iodofenphos = bromophos = malathion. At 1, 4, and 8 weeks after treatment, at all deposits, iodofenphos = bromophos = malathion; at 16 weeks, at 1.0 and 2.5 g/m^2, iodofenphos = bromophos = malathion but at 0.5 g/m^2, iodofenphos > bromophos > malathion; and at 52 weeks, iodofenphos produced 31% mortality but malathion and bromophos were completely ineffective.

Although iodofenphos seems to be the most effective against C. ferrugineus at all dosages, there were no significant differences among these three insecticides.

Table 26 also shows significant differences in toxicity among the three amounts of deposit of each compound.

Bromophos	:	2.5 g/m^2 > 1.0 g/m^2 > 0.5 g/m^2
Iodofenphos	:	2.5 g/m^2 > 1.0 g/m^2 > 0.5 g/m^2
Malathion	:	2.5 g/m^2 > 1.0 g/m^2 > 0.5 g/m^2

(c) Evaluation of Extended Age of Deposit of Organophosphorus Insecticides on Wood Surfaces Against Five Species of Stored-Product Insects.

In spite of the high mortalities still being affected by all insecticides at 52 weeks when test species were exposed for 24 hours (Table 9, 14, 19, 24, 29), the surfaces were used for additional exposures of further batches of insects after 80 weeks. The resulting percentage mortalities are summarized in Table 30.

TABLE 30

The percent mortality of five species of stored-product insects after exposure for 24 hours to bromophos, iodofenphos and malathion[a] deposits on fir plywood surfaces which were used once previously at 52 weeks.

	Percent mortality at age of deposit of 80 weeks		
Species	bromophos	iodofenphos	malathion
Amount of deposit, 0.5 g/m^2			
T. confusum	0	1	10
T. castaneum	0	4	83
O. surinamensis	29	70	95
O. mercator	49	47	51
C. ferrugineus	29	70	19
Amount of deposit, 1.0 g/m^2			
T. confusum	0	100	27
T. castaneum	7	97	87
O. surinamensis	76	100	100
O. mercator	100	100	95
C. ferrugineus	100	100	55
Amount of deposit, 2.5 g/m^2			
T. confusum	4	100	100
T. castaneum	27	100	100
O. surinamensis	100	100	100
O. mercator	100	100	100
C. ferrugineus	100	100	100

[a]Mortality determinations were made at 80 weeks after treatment. Each value is the average of 4 replicates.

2. PERSISTENCE ON STRUCTURAL SURFACES OF PYRETHROID INSECTICIDES IN THE CONTROL OF FIVE SPECIES OF STORED-PRODUCT INSECTS

The relative toxicities of the three pyrethroid insecticides to five stored-product insects are shown in histograms (Figs. 14-16). The mortalities were determined at 1, 4, 8, 16 and 32 weeks after treatment; in most compounds tested very little mortality occurred after 16 weeks.

Tables 31-33 give the percent mortality after each species was exposed for 5 hours on surfaces treated with pyrethroids.

(a) Persistence and Effectiveness of the Three Pyrethroid Insecticides Against Five Species of Stored-Product Insects

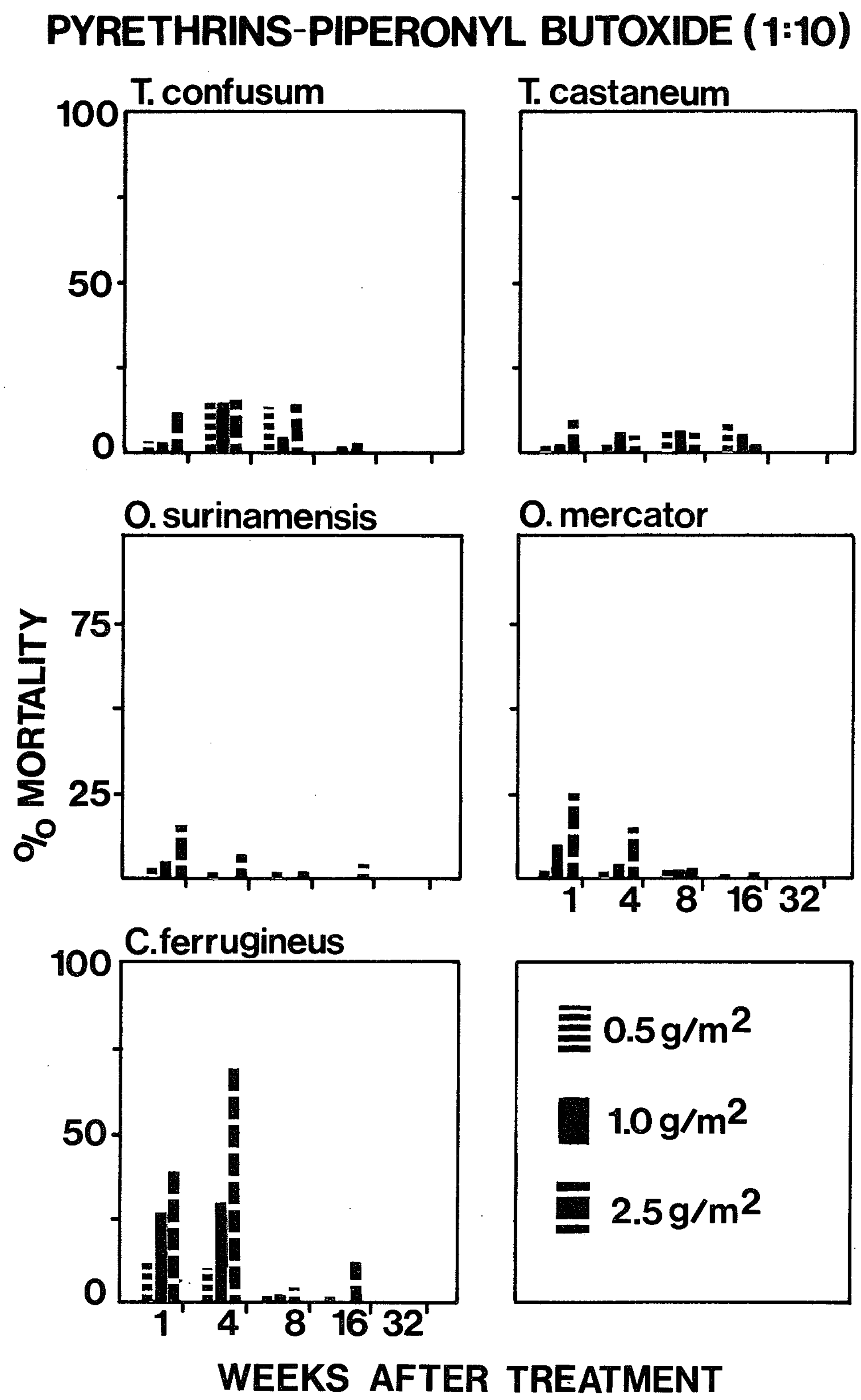
Persistence of pyrethrins-piperonyl butoxide (1:10) on fir plywood surfaces

The results indicated that the residual effectiveness of this treatment against all species on fir plywood surfaces did not last longer than 8 weeks (Fig. 14, Table 31). A very low mortality was obtained with all species at all dosages applied. *C. ferrugineus* was the only species susceptible to this synergized pyrethrins. At a concentration as high as 2.5 g/m^2, only 69 percent mortality was obtained against this insect at 4 weeks. However, pyrethrins-piperonyl butoxide (1:10) was proved to be more effective than S-bioallethrin against *C. ferrugineus* but less effective than bioethanomethrin ($P < 0.05$).

Persistence of S-bioallethrin on fir plywood surfaces

Fig. 15 and Table 32 show that S-bioallethrin was the most effective compound tested against *Tribolium* spp. At 2.5 g/m^2, it provided effective control of *T. castaneum* up to 16 weeks. However, deposits of 0.5 and 1.0 g/m^2 were ineffective against *O. surinamensis*, *O. mercator* and *C. ferrugineus*, exposed on surfaces for 5 hours.

Figure 14. Relative susceptibility of five stored-produce species exposed for 5 hours to oil emulsion deposits of pyrethrins-piperonyl butoxide (1:10) on fir plywood surfaces at different times after treatment.



PYRETHRINS-PIPERONYL BUTOXIDE (1:10)
T. confusum
T. castaneum
O. surinamensis
O. mercator
C.ferrugineus
% MORTALITY
100
50
0
75
25
1
4
8
16
32
0.5 g/m2
1.0 g/m2
2.5 g/m2
WEEKS AFTER TREATMENT

TABLE 31

The percent mortality of five species of stored-product insects after exposure for 5 hours on pyrethrins-piperonyl butoxide[a] (1:10) deposits on fir plywood surfaces.

Species	Percent mortality after age of deposit (weeks)				
	1	4	8	16	32
Amount of deposit, 0.5 g/m^2					
T. confusum	4	14	9	0	0
T. castaneum	1	2	0	0	0
O. surinamensis	2	1	0	0	0
O. mercator	2	1	2	1	0
C. ferrugineus	11	10	2	1	0
Amount of deposit, 1.0 g/m^2					
T. confusum	4	15	5	1	0
T. castaneum	2	5	0	0	0
O. surinamensis	4	0	1	0	0
O. mercator	9	4	2	0	0
C. ferrugineus	26	29	2	0	0
Amount of deposit, 2.5 g/m^2					
T. confusum	12	16	14	2	0
T. castaneum	10	5	0	0	0
O. surinamensis	15	7	0	4	0
O. mercator	24	14	2	1	0
C. ferrugineus	39	69	4	12	0

[a]Mortality determinations were made 1, 4, 8, 16 and 32 weeks after treatment. Each value is the average of 4 replicates.

Figure 15. Relative susceptibility of five stored-product species exposed for 5 hours to oil emulsion deposits of S-bioallethrin on fir plywood surfaces at different times after treatment.

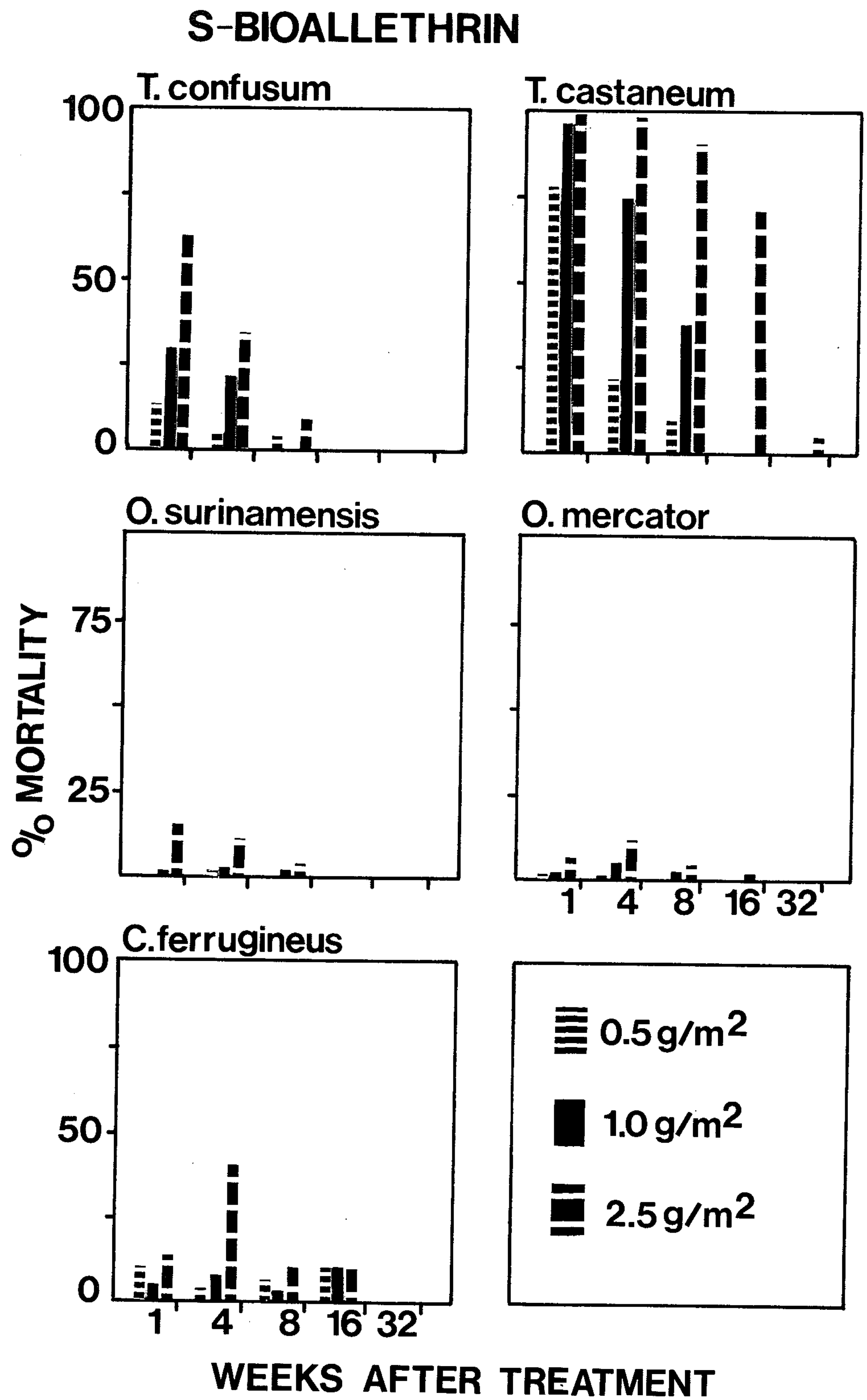

S-BIOALLETHRIN
T. confusum
T. castaneum
O. surinamensis
O. mercator
C.ferrugineus
% MORTALITY
100
50
0
75
25
1
4
8
16
32
0.5 g/m2
1.0 g/m2
2.5 g/m2
WEEKS AFTER TREATMENT

TABLE 32

The percent mortality of five species of stored-product insects after exposure for 5 hours on S-bioallethrin[a] deposits on fir plywood surfaces.

	Percent mortality after age of deposit (weeks)				
Species	1	4	8	16	32
Amount of deposit, 0.5 g/m^2					
T. confusum	14	5	4	0	0
T. castaneum	79	22	9	0	0
O. surinamensis	0	1	0	0	0
O. mercator	1	1	0	0	0
C. ferrugineus	9	2	5	9	0
Amount of deposit, 1.0 g/m^2					
T. confusum	30	21	0	0	0
T. castaneum	97	75	32	0	0
O. surinamensis	1	2	2	0	0
O. mercator	2	4	2	0	0
C. ferrugineus	4	7	2	9	0
Amount of deposit, 2.5 g/m^2					
T. confusum	64	32	9	0	0
O. castaneum	99	99	90	71	5
O. surinamensis	15	12	4	0	0
O. mercator	7	11	4	2	0
C. ferrugineus	22	39	9	9	0

[a]Mortality determinations were made 1, 4, 8, 16 and 32 weeks after treatment. Each value is the average of 4 replicates.

Figure 16. Relative susceptibility of five stored-product species exposed for 5 hours to oil emulsion deposits of bioethanomethrin on fir plywood surfaces at different times after treatment.

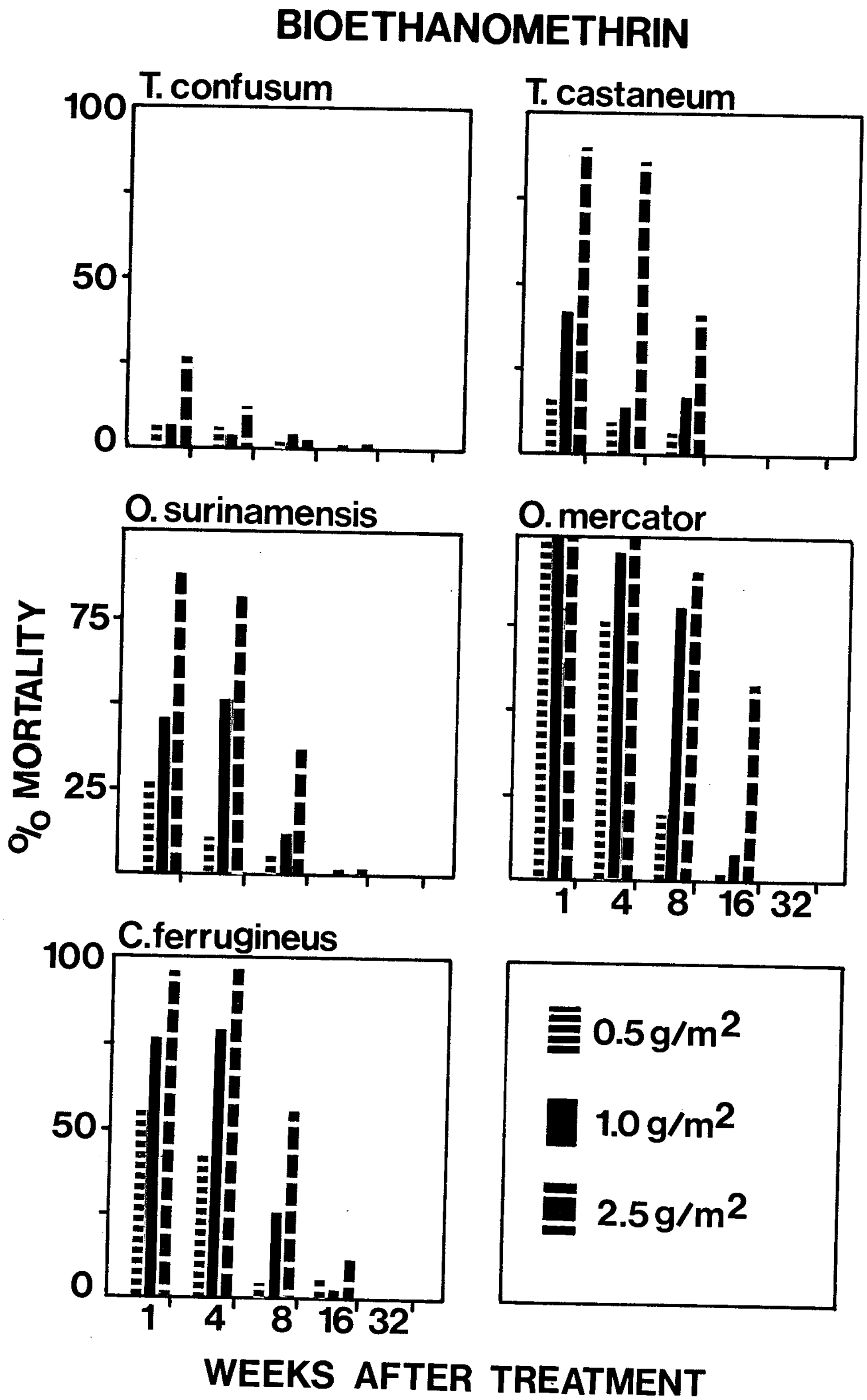

BIOETHANOMETHRIN
T. confusum
T. castaneum
O. surinamensis
O. mercator
C.ferrugineus
100
50
0
75
25
% MORTALITY
1
4
8
16
32
0.5 g/m2
1.0 g/m2
2.5 g/m2
WEEKS AFTER TREATMENT

TABLE 33

The percent mortality of five species of stored-product insects after exposure for 5 hours on bioethanomethrin[a] deposits on fir plywood surfaces.

Species	Percent mortality after age of deposit (weeks)				
	1	4	8	16	32
Amount of deposit, 0.5 g/m^2					
T. confusum	7	7	2	1	0
T. castaneum	15	9	7	0	0
O. surinamensis	27	10	7	1	0
O. mercator	100	76	22	2	0
C. ferrugineus	54	41	4	5	0
Amount of deposit, 1.0 g/m^2					
T. confusum	7	4	4	0	0
T. castaneum	41	14	17	0	0
O. surinamensis	45	50	11	0	0
O. mercator	100	96	80	10	0
C. ferrugineus	76	77	25	2	0
Amount of deposit, 2.5 g/m^2					
T. confusum	26	12	2	1	0
T. castaneum	90	86	41	0	0
O. surinamensis	89	82	37	2	0
O. mercator	100	100	99	57	0
C. ferrugineus	95	97	54	12	0

[a]Mortality determinations were made 1, 4, 8, 16 and 32 weeks after treatment. Each value is the average of 4 replicates.

Persistence of bioethanomethrin on fir plywood surfaces

T. confusum is the only species resistant to bioethanomethrin (Fig. 16,Table 33). It had low toxicity against this species 1 week after treatment. However, at 2.5 g/m^2, it persisted for 8 weeks against T. castaneum, O. surinamensis, O. mercator and C. ferrugineus, after an exposure period of 5 hours.

(b) Susceptibility of Each Insect Species to Each Insecticide

The relative toxicity of pyrethrins-piperonyl butoxide, S-bioallethrin and bioethanomethrin to the different species is summarized in Figs. 14-15. However, the results of their toxicity to each species at the same exposure period (5 hours) have also been illustrated in Tables 34-38.

Relative susceptibility of T. confusum to pyrethrins-piperonyl butoxide, S-bioallethrin and bioethanomethrin

Table 34 shows the relative susceptibility of T. confusum to each insecticide at exposure period of 5 hours. The results indicate that there were some significant differences in response of this species to different insecticides. The relative toxicity of pyrethrins-piperonyl butoxide, S-bioallethrin and bioethanomethrin at different amounts of deposit and different ages of deposit to T. confusum is shown in this table.

The orders of toxicity of the different amounts of deposit and different ages of deposit of insecticides to T. confusum exposed on surfaces for 5 hours were as follows. At a deposit of 0.5 g/m^2, pyrethrins-piperonyl butoxide = S-bioallethrin = bioethanomethrin; at 1.0 g/m^2, S-bioallethrin > pyrethrins-piperonyl butoxide = bioethanomethrin; at

TABLE 34

The percent mortality of T. confusum beetle after exposure for 5 hours to three pyrethroid insecticide deposits on fir plywood surfaces.

Insecticide	Percent mortality after age of deposit (weeks)[1] ± S.E. 1	4	8	16	32
Amount of deposit, 0.5 g/m^2					
Pyrethrins-P.B.	4 ± 2.39a[2]	14 ± 2.39a	9 ± 4.27a	0 a	0
S-bioallethrin	14 ± 5.91a	5 ± 2.04a	4 ± 1.25a	0 a	0
Bioethanomethrin	7 ± 2.50a	7 ± 1.44a	2 ± 1.44a	1 ± 1.25a	0
Amount of deposit, 1.0 g/m^2					
Pyrethrins-P.B.	4 ± 1.25a	15 ± 2.89a,b	5 ± 3.54a	1 ± 2.89a	0
S-bioallethrin	30 ± 12.42b	21 ± 5.15a	0 a	0 a	0
Bioethanomethrin	7 ± 1.44a	4 ± 2.39b	4 ± 2.39a	0 a	0
Amount of deposit, 2.5 g/m^2					
Pyrethrins-P.B.	12 ± 2.50a	16 ± 5.15a	14 ± 2.39a	2 ± 3.23a	0
S-bioallethrin	64 ± 12.81b	32 ± 4.33b	9 ± 4.27a,b	0 a	0
Bioethanomethrin	26 ± 5.54c	12 ± 5.20a	2 ± 2.50b	1 ± 1.25a	0

[1]Mean of 4 replicates.
[2]Common letter following column indicates no significant difference at 5% level between insecticides at the same amount of deposit.
S.E.-standard error of replicate mean.

2.5 g/m^2, S-bioallethrin > pyrethrins-piperonyl butoxide = bioethanomethrin; and at 1 week after treatment, S-bioallethrin > bioethanomethrin > pyrethrins-piperonyl butoxide; at 4 weeks, S-bioallethrin = pyrethrins-piperonyl butoxide > bioethanomethrin; at 8 weeks, pyrethrins-piperonyl butoxide = S-bioethanomethrin, pyrethrins-piperonyl butoxide > bioethanomethrin, S-bioallethrin = bioethanomethrin; at 16 and 32 weeks, all compounds were completely ineffective.

S-bioallethrin was the most effective insecticide against *T. confusum* while pyrethrins-piperonyl butoxide and bioethanomethrin were ineffective.

Table 34 also shows significant differences in toxicity among the three amounts of deposit of each compound.

Pyrethrins-piperonyl butoxide	:	2.5 g/m^2 > 1.0 g/m^2 = 0.5 g/m^2
S-bioallethrin	:	2.5 g/m^2 > 1.0 g/m^2 > 0.5 g/m^2
Bioethanomethrin	:	2.5 g/m^2 > 1.0 g/m^2 = 0.5 g/m^2

Relative susceptibility of *T. castaneum* to pyrethrins-piperonyl butoxide, S-bioallethrin and bioethanomethrin

Table 35 shows the relative susceptibility of *T. castaneum* to each insecticide at an exposure period of 5 hours. The results indicate that there were significant differences in response of different insecticides to this species. The relative toxicity of pyrethrins-piperonyl butoxide, S-bioallethrin and bioethanomethrin at different amounts of deposit and different ages of deposit to *T. castaneum* is shown in this table.

The orders of toxicity of the different amounts of deposit and different ages of deposit to *T. castaneum* exposed on surfaces for 5 hours

TABLE 35

The percent mortality of _T. castaneum_ beetle after exposure for 5 hours to three pyrethroid deposits on fir plywood surfaces.

Insecticide	Percent morality after age of deposit (weeks)[1] ± S.E. 1	4	8	16	32
Amount of deposits, 0.5 g/m^2					
Pyrethrins-P.B.	1 ± 1.25a[2]	2 ± 1.44a	0 a	0	0
S-bioallethrin	79 ± 11.43b	22 ± 5.20b	9 ± 2.39a	0	0
Bioethanomethrin	15 ± 2.04a	9 ± 2.39b	7 ± 2.50a	0	0
Amount of deposit, 1.0 g/m^2					
Pyrethrins-P.B.	2 ± 1.44a	5 ± 2.04a	0 a	0	0
S-bioallethrin	97 ± 2.50b	75 ± 2.89b	32 ± 9.35b	0	0
Bioethanomethrin	41 ± 9.44c	14 ± 6.25a	17 ± 6.29b	0	0
Amount of deposit, 2.5 g/m^2					
Pyrethrins-P.B.	10 ± 7.07a	5 ± 2.04a	0 a	0 a	0 a
S-bioallethrin	99 ± 1.25b	99 ± 1.25b	90 ± 3.54b	71 ± 7.74b	5 ± 2.04a
Bioethanomethrin	90 ± 4.56b	86 ± 6.25c	41 ± 12.81c	0 a	0 a

[1]Mean of 4 replicates.
[2]Common letter following column indicates no significant difference at 5% level between insecticides at the same amount of deposit.
S.E.-standard error of replicate mean.

were as follows: at a deposit of 0.5 g/m^2, S-bioallethrin > bioethanomethrin = pyrethrins-piperonyl butoxide; at 1.0 and 2.5 g/m^2, S-bioallethrin > bioethanomethrin > pyrethrins-piperonyl butoxide ; and at 1, 4, and 8 weeks after treatment, at all deposits, S-bioallethrin > bioethanomethrin but pyrethrins-piperonyl butoxide was not effective at all; at 16 weeks, only S-bioallethrin provided 71% mortality but its effectiveness declined at 32 weeks, and bioethanomethrin and pyrethrins-piperonyl butoxide were completely ineffective.

S-bioallethrin was the most effective compound against T. castaneum followed by bioethanomethrin while pyrethrins-piperonyl butoxide was ineffective.

Table 35 also shows significant differences in toxicity among the three amounts of deposit of each compound.

Pyrethrins-piperonyl butoxide	: 2.5 g/m^2 = 1.0 g/m^2 = 0.5 g/m^2
S-bioallethrin	: 2.5 g/m^2 > 1.0 g/m^2 > 0.5 g/m^2
Bioethanomethrin	: 2.5 g/m^2 > 1.0 g/m^2 > 0.5 g/m^2

Relative susceptibility of O. surinamensis to pyrethrins-piperonyl butoxide, S-bioallethrin and bioethanomethrin

Table 36 shows the relative susceptibility of O. surinamensis to each insecticide at exposure period of 5 hours. The results indicate that there were significant differences in response of this species to different insecticides. The relative toxicity of pyrethrins-piperonyl butoxide, S-bioallethrin and bioethanomethrin at different amounts of deposit and different ages of deposit to O. surinamensis is presented in this table.

TABLE 36

The percent mortality of O. surinamensis beetle after exposure for 5 hours to three pyrethroid insecticide deposits on fir plywood surfaces.

Insecticide	Percent mortality after age of deposit (weeks)[1] ± S.E. 1	4	8	16	32
Amount of deposit, 0.5 g/m²					
Pyrethrins-P.B.	2 ± 1.44a[2]	1 ± 1.25a	0 a	0	0
S-bioallethrin	0 a	1 ± 1.25a	0 a	0	0
Bioethanomethrin	27 ± 5.95b	10 ± 3.54a	7 ± 3.15a	1 ± 1.25a	0
Amount of deposit, 1.0 g/m²					
Pyrethrins-P.B.	4 ± 2.39a	0 a	1 ± 1.25a	0	0
S-bioallethrin	1 ± 1.25a	2 ± 1.44a	2 ± 1.44a	0	0
Bioethanomethrin	45 ± 9.79b	50 ± 9.79b	11 ± 7.18a	0	0
Amount of deposit, 2.5 g/m²					
Pyrethrins-P.B.	15 ± 2.04a	7 ± 3.23a	0 a	4 ± 2.39a	0
S-bioallethrin	15 ± 3.54a	12 ± 3.23a	4 ± 2.39a	0 a	0
Bioethanomethrin	89 ± 6.57b	82 ± 6.61b	37 ± 12.50b	2 ± 1.44a	0

[1]Mean of 4 replicates.
[2]Common letter following column indicates no significant difference at 5% level between insecticides at the same amount of deposit.
S.E.- standard error of replicate mean.

The orders of toxicity of the different amounts of deposit and different ages of deposit to _O. surinamensis_ exposed on surfaces for 5 hours were as follows: at deposits of 0.5, 1.0 and 2.5 g/m^2, bioethanomethrin produced 27% mortality at 1 week, 50% mortality at 4 weeks, and 37% mortality at 8 weeks, respectively, but its toxicity declined at 4 weeks, 8 weeks and 16 weeks after treatment, respectively; pyrethrins-piperonyl butoxide and S-bioallethrin were ineffective at these dosages against this insect.

Bioethanomethrin was shown to be the only effective compound against _O. surinamensis_ among the insecticides tested.

Table 36 also shows significant differences in toxicity among the three amounts of deposit of each compound.

Pyrethrins-piperonyl butoxide	: $2.5\ g/m^2 = 1.0\ g/m^2 = 0.5\ g/m^2$
S-bioallethrin	: $2.5\ g/m^2 > 1.0\ g/m^2 = 0.5\ g/m^2$
Bioethanomethrin	: $2.5\ g/m^2 > 1.0\ g/m^2 > 0.5\ g/m^2$

Relative susceptibility of _O. mercator_ to pyrethrins-piperonyl butoxide, S-bioallethrin and bioethanomethrin

Table 37 shows the relative susceptibility of _O. mercator_ to each insecticide at an exposure period of 5 hours. The results indicate that there were significant differences in response to different insecticides of this species. The relative toxicity of pyrethrins-piperonyl butoxide, S-bioallethrin and bioethanomethrin at different deposits and different ages of deposit to _O. mercator_ is presented in this table.

The orders of toxicity of the different amounts of deposit and different ages of deposit to _O. mercator_ exposed on surfaces for 5 hours

Table 37

The percent mortality of _O. mercator_ beetle after exposure for 5 hours to three pyrethroid insecticide deposits on fir plywood surfaces.

Insecticide	Percent mortality after age of deposit (weeks)[1] ± S.E. 1	4	8	16	32
Amount of deposit, 0.5 g/m^2					
Pyrethrins-P.B.	2 ± 1.44a[2]	1 ± 1.25a	2 ± 1.44a	1 ± 1.25a	0
S-bioallethrin	1 ± 1.25a	1 ± 1.25a	0 a	0 a	0
Bioethanomethrin	100 ± 0 b	76 ± 6.25b	22 ± 3.23b	2 ± 1.44a	0
Amount of deposit, 1.0 g/m^2					
Pyrethrins-P.B.	9 ± 2.39a	4 ± 3.75a	2 ± 1.44a	0 a	0
S-bioallethrin	2 ± 1.44a	4 ± 2.39a	2 ± 1.44a	0 a	0
Bioethanomethrin	100 ± 0 b	96 ± 3.75b	80 ± 10.80b	10 ± 7.07b	0
Amount of deposit, 2.5 g/m^2					
Pyrethrins-P.B.	24 ± 7.18a	14 ± 4.27a	2 ± 2.39a	1 ± 1.25a	0
S-bioallethrin	7 ± 1.44b	11 ± 5.15a	4 ± 1.25a	2 ± 1.44a	0
Bioethanomethrin	100 ± 0 c	100 ± 0 b	99 ± 1.25b	57 ± 11.99b	0

[1]Mean of 4 replicates.
[2]Common letter following column indicates no significant difference at 5% level between insecticides at the same amount of deposit.
S.E.-standard error of replicate mean.

were as follows: at deposits of 0.5, 1.0 and 2.5 g/m^2, there were significant differences between bioethanomethrin and S-bioallethrin and pyrethrins-piperonyl butoxide at ages of deposit up to 8, 16 and 24 weeks, respectively after treatment. However, at 2.5 g/m^2, pyrethrins-piperonyl butoxide produced 24% mortality 1 week after treatment, while S-bioallethrin was ineffective.

Bioethanomethrin was shown to be the only effective compound against O. mercator among insecticides tested.

Table 37 also shows significant differences in toxicity among the three amounts of deposit of each compound.

Pyrethrins-piperonyl butoxide	: 2.5 g/m^2 > 1.0 g/m^2 = 0.5 g/m^2
S-bioallethrin	: 2.5 g/m^2 > 1.0 g/m^2 = 0.5 g/m^2
Bioethanomethrin	: 2.5 g/m^2 > 1.0 g/m^2 = 0.5 g/m^2

Relative susceptibility of C. ferrugineus to pyrethrins-piperonly butoxide, S-bioallethrin and bioethanomethrin.

Table 38 shows the relative susceptibility of C. ferrugineus to each insecticide at exposure period of 5 hours. The results indicate that there were significant differences in response to different insecticides of this species. The relative toxicity of pyrethrins-piperonyl butoxide, S-bioallethrin, and bioethanomethrin at different amounts of deposit and different ages of deposit to C. ferrugineus is presented in this table.

The orders of toxicity of the different amounts of deposit and different ages of deposit to C. ferrugineus exposed on surfaces for 5 hours were as follows: at a deposit of 0.5 g/m^2, bioethanomethrin > S-bioallethrin = pyrethrins-piperonyl butoxide; at 1.0 and 2.5 g/m^2 bioethanomethrin > pyrethrins-piperonyl butoxide > S-bioallethrin; and at

TABLE 38

The percent mortality of *C. ferrigineus* beetle after exposure for 5 hours to three pyrethroid insecticide deposits on fir plywood surfaces.

Insecticide	Percent mortality after age of deposit (weeks)[1] ± S.E. 1	4	8	16	32
Amount of deposit, 0.5 g/m²					
Pyrethrins-P.B.	11 ± 3.75a[2]	10 ± 5.40a	2 ± 1.44a	1 ± 1.25a	0
S-bioallethrin	9 ± 3.75a	2 ± 1.44a	5 ± 2.00a	9 ± 3.15a	0
Bioethanomethrin	54 ± 2.39b	41 ± 5.54b	4 ± 2.39a	5 ± 3.54a	0
Amount of deposit, 1.0 g/m²					
Pyrethrins-P.B.	26 ± 8.26a	29 ± 4.27a	2 ± 1.44a	0 a	0
S-bioallethrin	4 ± 2.39b	7 ± 3.23b	2 ± 2.50a	9 ± 3.16a	0
Bioethanomethrin	76 ± 6.57c	77 ± 8.54c	12 ± 11.37b	2 ± 2.50a	0
Amount of deposit, 2.5 g/m²					
Pyrethrins-P.B.	39 ± 7.74a	69 ± 12.48a	4 ± 2.04a	12 ± 3.23a	0
S-bioallethrin	22 ± 6.61b	39 ± 4.27b	9 ± 3.75a	9 ± 3.75a	0
Bioethanomethrin	95 ± 2.04c	97 ± 2.50c	54 ± 10.08b	12 ± 3.23a	0

[1]Mean of 4 replicates.
[2]Common letter following column indicates no significant difference at 5% level between insecticides at the same amount of deposit.
S.E.-standard error of replicate mean.

1 and 4 weeks after treatment, bioethanomethrin > pyrethrins-piperonyl butoxide > S-bioallethrin; at 8 weeks, bioethanomethrin > S-bioallethrin > pyrethrins-piperonyl butoxide.

Bioethanomethrin was the most effective insecticide against *C. ferrugineus* followed by pyrethrins-piperonyl butoxide while S-bioallethrin was the least effective.

Table 38 also shows significant differences in toxicity among the three amounts of deposit of each compound.

Pyrethrins-piperonyl butoxide	: $2.5\ g/m^2 > 1.0\ g/m^2 > 0.5\ g/m^2$
S-bioallethrin	: $2.5\ g/m^2 > 1.0\ g/m^2 = 0.5\ g/m^2$
Bioethanomethrin	: $2.5\ g/m^2 > 1.0\ g/m^2 > 0.5\ g/m^2$

CHAPTER V

DISCUSSION

1. PERSISTENCE ON STRUCTURAL SURFACES OF ORGANOPHOSPHORUS INSECTICIDES IN THE CONTROL OF FIVE SPECIES OF STORED-PRODUCT INSECTS

(a) Persistence and Effectiveness of Bromophos, Iodofenphos, and Malathion Against Five Species of Stored-Product Insects

Persistence of bromophos on fir plywood surfaces

The results, as summarized in Table 2, show the initial loss of effectiveness of bromophos on surfaces to be more rapid than those of malathion and iodofenphos against all species except *C. ferrugineus*. At a shorter exposure period (3 hours), the toxicity of bromophos completely declined against most of the species tested at 4 weeks after treatment. Similar results were obtained by the persistence test on filter papers by Parkin and Forster (1967). They found that bromophos showed a definite loss in efficacy against *S. granarius*, *T. castaneum* and *O. surinamensis* after a 1-week storage test, whereas fenitrothion showed a similar fall at the 4-week test.

There were significant differences in effectiveness at all dosages applied, between bromophos and other insecticides tested against all species at an exposure period of 5 hours ($P < 0.05$) but there was no significant difference between bromophos and malathion against *C. ferrugineus*. However, at a longer exposure period (24 hours), bromophos provided complete control against all species for at least 52 weeks after treatment, and against both species of *Oryzaephilus*, and *C. ferrugineus* for at least 80 weeks after treatment (Table 30). These results are in agreement with those of Green et al. (1970) who found that bromophos kills slowly so that treated insects may disperse and oviposit before they die. The reason for this slow action may be due to a slow translocation of the toxicant in vivo or because an interval for more extensive metabolism is required. Using topical application methods on T. castaneum beetles, Dyte and Rowlands (1970) found that bromoxon was no more toxic than bromophos, whereas malaoxon was more than three times more toxic than malathion and fenitroxon was about 1.5 times more toxic than fenitrothion. Adult T. castaneum produced considerably more internal oxons from malathion, than from bromophos. It is also possible that one or more metabolites beside the oxon contribute to the insecticidal effect of bromophos (Rowlands 1966, Dyte and Rolands 1968, 1970). This phenomenon may also occur in T. confusum. Lemon (1966, 1967) reported that T. confusum was more resistant than T. castaneum to bromophos. However, it may not occur in O. surinamensis, O. mercator, and C. ferrugineus since the results obtained from this study show that T. confusum and T. castaneum were more resistant to bromophos than these species. At 0.5 g/m^2, bromophos sprayed on bags or on hessian sheets, which covered stacks of bagged maize, gave less effective protection than that obtained with lindane and malathion applied routinely against the tropical warehouse moth, Ephestia cautella Walker, in Malawi (Schulten, 1973).

Tyler et al. (1969) and Hope et al. (1970) reported that good control was obtained with bromophos, water-dispersible powder, applied at 0.54 g/m^2 to an infested wooden-floor in a farm building against S. granarius; O. surinamensis; the waste grain beetle, Alphitophagus bifasciatus (Say); and Cryptolestes spp. Protection lasted at least 46 weeks after exposure period of 3 hours except against T. castaneum which resulted in only 54% kill at 10 weeks after treatment. These results are not in agreement with the results obtained in this study possibly because of the different formulation that was used. Also, in the test by Tyler et al. (1969) and Hope et al. (1970) the insecticide was applied by motorized knapsack sprayer to the internal surfaces of the farm building. It is likely that this type of sprayer might produce uneven distribution of insecticide deposits on the surfaces.

The results obtained from this study are in agreement with Lemon (1967) who emphasized that bromophos would be less important than malathion as a grain protectant as it is likely to be more expensive; and Green et al. (1970) who concluded that bromophos may be considered to be a possible alternative to malathion as a grain protectant only if insect resistance to malathion becomes a problem and there is no better alternative.

Persistence of iodofenphos on fir plywood surfaces

The results, as summarized in Table 3, and the observations made during the experiments indicate that similar patterns to those of bromophos were obtained with iodofenphos. Although, at 0.5 g/m^2, iodofenphos was more effective than bromophos against all species at the exposure periods of 3 and 5 hours, it was less effective than malathion against most of the species tested except C. ferrugineus. At the lowest dosage and at shorter exposure periods, iodofenphos was found to be less effective than malathion; this may be due to its slow action which Rowlands (1967, 1971) also found. He also reported that ronnel, iodofenphos and fenitrothion followed similar metabolic pathways of bromophos while malathion did not undergo this phenomenon.

Iodofenphos treatments exhibited a greater residual toxicity. At 1.0 g/m^2, iodofenphos was more effective against all species than malathion at any exposure periods up to 52 weeks after treatment. This may be due to the fact that the slower breakdown of iodofenphos compared with either ronnel or bromophos is possibly due to the more electro-positive nature of the I-substituent in the benzene ring structure compared with Cl^- or Br^- (Rowlands, 1973). Blackman (1969) reported that iodofenphos was more toxic to T. castaneum adults than malathion, and McDonald and Speirs (1971) reported that it was more effective against P. interpunctella larvae than malathion and Gardona when applied topically. It was also reported to be more toxic to the black carpet beetle, Attagenus megatoma (F.), but less toxic to T. confusum than malathion. Although Gradidge (1970) showed that iodofenphos was less toxic than malathion against O. surinamensis in a preliminary assessment on filter papers, it was generally more effective than malathion when applied as an emulsion at 0.8 g/m^2 to various surfaces against this insect (Gradridge et al.,1970).Green (1973) reported that iodofenphos gave as good control as malathion both in laboratory and field trials when applied as either an admixture or a surface treatment to unshelled groundnuts against a lindane-resistant Gambian strain, Caryedon serratus Oliv. Both compounds appear to be satisfactory replacements for lindane.

Iodofenphos was also proved to have a long residual life on surfaces. The results, as shown in Table 30, shows that iodofenphos applied at 1.0 and 2.5 g/m^2 on fir plywood surfaces lasted for at least 80 weeks against all species tested after an exposure period of 24 hours. At 1.0 g/m^2, it was more toxic than malathion against all species.

Wilkin *et al*. (1973a,b) demonstrated that the effectiveness of iodofenphos was longer than that of malathion when applied to warm and moist wheat against *O. surinamensis*, which is the species most susceptible to malathion.

Persistence of malathion on fir plywood surfaces

Malathion remained effective longer than was expected from this study at storage and experimental temperatures of about 25±2°C. These temperatures may prolong the persistence and effectiveness of malathion on fir plywood surfaces. These results are in agreement with those obtained in the study made by Iordanou and Watters (1969). They reported that malathion showed positive temperature coefficients against five stored-product insects. It was highly effective against all test species at 26.7°C and effectiveness was reduced at 15.5°C and 10°C. Parkin (1966) found that malathion applied on wood and sacking at 0.43 g/m^2, persisted only for 2 to 4 months against *T. castaneum* after exposure for 3 and 6 days. Lemon (1967) reported that high mortalities of *T. confusum* were obtained for 16 weeks after exposure for 6 days on filter papers treated at 0.75 g/m^2. At a rate of 0.86 g/m^2, Parkin and Scott (1960) found that malathion persisted on filter paper for 16 months against *S. granarius*, *T. castaneum* and *O. surinamensis* after exposure for 6 days. Slominski and Gojmerac (1972) also reported that malathion applied at 1.0 g/m^2 on plywood, persisted for 28 weeks against black carpet beetle larvae, *Attagenus megatoma* (F.), at an initial exposure period of 4 days, with subsequent exposure of 7 days, whereas bomophos applied at the same rate persisted for only 6 weeks.

The results, as summarized in Table 4, indicate that malathion was highly persistent and toxic to all test species at all dosages used.

There was only a slight breakdown at 80 weeks for exposure period of 24 hours. These results agree well with the findings of Parkin (1966), Okwelogu (1968), and Watters (1970) who reported that malathion was stable on surfaces that are near neutral in pH. Watters (1974) reported that at 1.5 g/m^2, malathion applied on concrete floor of a bin containing stored oats, showed complete mortality against O. surinamensis exposed on surfaces for 24 hours at 11 months after treatment. Similar results were obtained with T. confusum, exposed on surfaces for 48 hours at 7½ months after treatment (Watters, 1970). The results indicate that residual effectivenss of malathion applied to the surfaces several months previosuly is due to the neutral pH of the concrete floors impregnated with grain dust (Watters, 1970, 1974). However, Cogburn (1972) reported that at 1.26 g/m^2, malation was over 90% effective for 2 weeks and at 2.5 g/m^2, it was over 95% effective for 5 weeks against T. confusum on concrete floors in a Gulf of Mexico port warehouse. The difference in results may be attributed to the fact that the treated floor may not have been fully impregnated with dust, and therefore would probably have a high pH.

According to results obtained in this study, T. confusum was more resistant to malathion than T. castaneum, O. surinamensis and O. mercator. Similarresults were obtained from both field trials by Watters (1970, 1974). Parkin (1966) reported that O. surinamensis was more susceptible than T. castaneum to residues of malathion. Lemon (1966) obtained higher mortalities with T. castaneum than with T. confusum in tests with malation applied topically. The difference in susceptibility of these two species was explained by the fact that the insects differ in size, T. confusum being 26 percent heavier than T. castaneum. Similar results were obtained in the present study.

Iordanou and Watters (1969) also reported that T. confusum was the most resistant species and C. ferrugineus was the most susceptible to malathion.

(b) Species Susceptibility to Organophosphorus Insecticides

In general, T. confusum and T. castaneum were more susceptible to malathion than iodofenphos and bromophos (Fig. 10), especially at 0.5 g/m^2 but there was no significant difference ($P < 0.05$) between the two species when exposed to iodofenphos at 1.0 and 2.5 g/m^2 for 5 hours. At 1.0 and 2.5 g/m^2, iodofenphos provided more residual protection than malathion and bromophos against these species. It produced 100 and 97% mortality to T. confusum and T. castaneum, respectively after exposure for 24 hours, whereas malathion was only 27 and 87% effective against these species, respectively. These results agree with the results of Lemon (1966) who reported that T. confusum was more susceptible to malathion than to bromophos,when the insecticides were applied topically. Iordanou and Watters (1969) found that malathion was more effective against T. confusum and T. castaneum than bromophos at all temperatures. However, in field experiments, Watters (1970) found that both compounds were equally effective against T. confusum exposed for 2 days on a concrete floor impregnated with grain dust in a terminal elevator.

Iodofenphos was reported to be less toxic to T. confusum than malathion when applied topically (McDonald and Speirs, 1971) but was proved to be more toxic to T. castaneum than malathion (Blackman, 1969).

O. surinamensis was highly susceptible to malathion (Parkin, 1960; Green, 1969) and bromophos (Iordanou and Watters, 1969). Although iodofenphos was less toxic than malation against O. surinamensis in a preliminary assessment on filter papers, at 0.8 g/m^2, it was generally more toxic than malathion on brick, concrete, asbestos and galvanized metal (Gradidge, 1970; Gradidge et al., 1970). The results obtained from this study indicate that at the three dosages tested, there was no significant difference in toxicity between malathion and iodofenphos to O. surinamensis exposed on surfaces for 5 hours. However, at 0.5 g/m^2, malathion was more effective than iodofenphos against O. surinamensis and at 1.0 g/m^2, it was less effective than iodofenphos against this species, whereas at 2.5 g/m^2, both compounds were equally effective. Wilkin et al. (1973a,b) demonstrated that iodofenphos lasted longer than malathion when applied to warm and moist wheat against O. surinamensis which is the species most susceptible to malathion.

Green et al. (1970) indicated that application of 9.3 ppm of bromophos will likely provide adequate control of O. surinamensis for up to 12 months. However, Iordanou and Watters (1969) reported that bromophos was less effective than malathion at temperatures of 10 to 26.5°C. These results are in agreement with the results obtained in this study.

The relative susceptibility of O. mercator to the insecticides tested was similar to that obtained with O. surimanensis. Since O. mercator is not an economically important pest in storages only a few studies have been reported. O. surinamensis was found to be more susceptible to malathion and bromophos. The results obtained by Iordanou and Watters (1969) showed that this species was more susceptible to malathion than bromophos at all temperatures tested. These results are in agreement with the results obtained in this study. The results, as shown in Table 21, indicate that, in general, iodofenphos was equally as effective as malathion and was more toxic than bromophos against *O. mercator* exposed on surfaces for 5 hours ($P < 0.05$). At all dosages, these three insecticides were equally effective against this species after exposure for 24 hours at 80 weeks after treatment.

This study showed that malathion, bromophos and iodofenphos, in general, were highly persistent against. *O. mercator*. Although there were no significant differences in the toxicity of these compounds against *C. ferrugineus*, the results, as shown in Table 26, indicate that bromophos and malathion were slightly less effective than iodofenphos against this insect exposed on surfaces for 5 hours ($P < 0.05$). Similar results were obtained from Tyler *et al.* (1969) and Hope *et al.* (1970) who reported results with bromophos water-dispersible powder, applied at 0.54 g/m^2 to an infested wooden-floor in a farm building against *Cryptolestes* spp. Protection lasted at least 46 weeks after the insects were exposed for 3 hours. Iordanou and Watters (1969) also found that *C. ferrugineus* was the most susceptible species to malathion and bromophos; bromophos was more toxic than malathion at high temperatures, whereas malathion was more toxic than bromophos at low temperatures.

The orders of effectivenss of the three organophosphorus insecticides against the following species ($P < 0.05$) after exposure for 5 hours at each amount of deposit are summarized as follows:

Species	Amount of Deposit (g/m^2)	Order of Effectiveness
T. confusum / T. castaneum	0.5	malathion > iodofenphos > bromophos
	1.0	malathion = iodofenphos > bromophos
	2.5	malathion = iodofenphos > bromophos
O. surinamensis	0.5	malathion > iodofenphos > bromophos
	1.0	iodofenphos > malathion > bromophos
	2.5	iodofenphos = malathion > bromophos
O. mercator	0.5	iodofenphos = malathion > bromophos
	1.0	iodofenphos > malathion > bromophos
	2.5	iodofenphos = malathion > bromophos
C. ferrugineus	0.5	iodofenphos > bromophos = malathion
	1.0	iodofenphos > bromophos = malathion
	2.5	iodofenphos > bromophos = malathion

2. PERSISTENCE ON STRUCTURAL SURFACES OF THREE PYRETHROID INSECTICIDES IN THE CONTROL OF FIVE SPECIES OF STORED-PRODUCT INSECTS

(a) Persistence and Effectiveness of Pyrethrins-Piperonyl Butoxide (1:10), S-bioallethrin, and Bioethanomethrin Against Five Species of Stored-Product Insects

The results, as shown in Tables 31, 32 and 33, indicate that in general, pyrethrins-piperonyl butoxide (1:10) was found to be the least effective compound among 3 pyrethroids against most of the species tested. S-bioallethrin was the most effective insecticide against *T. confusum* and *T. castaneum*, whereas bioethanomethrin was the most effective compound against *O. surinamensis*, *O. mercator* and *C. ferrugineus* ($P < 0.05$).

The ineffectiveness of pyrethrins-piperonyl butoxide (1:10), applied as an oil spray to fir plywood surfaces, contrasts with the results of Watters and Smallman (1953) who showed that at a deposit of 1.18 g/m^2, pyrethrins-piperonyl butoxide (1:10) applied as a spray gave good control of the hairy spider beetle, *Ptinus villiger* (Reitter), for about 6 weeks. Subsequently, Watters (1961) found that at 0.54 g/m^2, pyrethrins-piperonyl butoxide (1:10) controlled this insect for between 4 and 6 weeks. Parkin (1966) showed that filter papers treated with 2.37 g/m^2 pyrethrins-piperonyl butoxide (1:10) were toxic to *O. surinamensis* for 16 months. This disagreement may be explained partly by the fact that the test by Watters and Smallman (1953) and Watters (1961) used a longer exposure time than that reported in the test by Parkin (1966) where the insects were continuously exposed for 4 days.

The results, as shown in Fig. 15, correspond with the results of Parkin (1966) who reported that at 2.37 g/m^2, pyrethrins-piperonyl butoxide

(1:10) applied on filter papers were much less toxic to S. granarius and T. castaneum than C. ferrugineus exposed on surfaces for 4 days.

According to the results also obtained by this study, pyrethrins-piperonyl butoxide (1:10) applied as an oil spray at 2.5 g/m^2, produced 69% mortality against C. ferrugineus exposed on surfaces for 5 hours at 4 weeks after treatment. Similar results were obtained by Watters (1968) who reported that fir plywood panels treated with a pyrethrins-piperonyl butoxide (1:10) oil spray at a rate of 1.3 g/m^2, and stored for 2 months in contact with grain were still toxic to C. ferrugineus. He also reported that 0.13% pyrethrins - 1.27% piperonyl butoxide mixture applied at 17.3 liters per 1000 m^3 as a fog in empty granary bin, remained effective against C. ferrugineus exposed on treated plywood and grooved plywood surfaces for 24 hours at 11 months after treatment.

The results obtained from this study (Fig. 16) indicate that the effectiveness of S-bioallethrin against Tribolium spp., corresponds to the results of Lloyd (1973b) who reported that bioallethrin and allethrin, the related compounds of S-bioallethrin, were slightly superior to pyrethrins and were of similar toxicity to resmethrin where used against T. castaneum without synergist but were much inferior to pyrethrins against S. granarius. The greater toxicity of the improved biological activity, (+)-trans isomers compared to the other constituents of allethrin and resmethrin has been shown for several insect species (Elliott, 1971; Elliott et al. 1969). Nishizawa (1971), and Rauch and Lhoste (1974) reported that allethrin, bioallethrin and S-bioallethrin are particularly suitable for mosquito coils used in Japan and Southeast Asia. Because of their heat stability they are well dispersed in the smoke during the burning of the coils. S-bioallethrin was the most effective (Rauch and Lhoste, 1974).

The ineffectiveness of S-bioallethrin against *O. surinamensis*, *O. mercator* and *C. ferrugineus*, obtained from this study, may improve if synergized with piperonyl butoxide. Lloyd *et al.* (1970), Lloyd (1973a,b) and Davies (1974) reported that S-bioallethrin was found to be more effective when synergized by piperonyl butoxide.

Briggs *et al.* (1974) reported that bioethanomethrin, the ethanochrysanthemate RU 11 679, is more lethal than bioresmethrin and is less polar than most of the other highly lethal pyrethroids, the epoxidation product still produces a good knockdown agent, which also retains some killing action. These reasons are in agreement with the results, as shown in Table 17, obtained from this study. Bioresmethrin appears to be effective against a wide range of stored grain insects (Lloyd 1973a,b; Ardley 1974). Ardley (1974) found that bioresmethrin-piperonyl butoxide gave more effective protection than pyrethrins-piperonyl butoxide, resmethrin-piperonyl butoxide, bioresmethrin-antioxidant and malathion, against most of the resistant and susceptible species of stored grain insects except *Tribolium* spp. Lloyd (1973b) reported that the greater toxicity of bioresmethrin over resmethrin against *T. castaneum*, and susceptible and pyrethrin-resistant *S. granarius*, was much reduced when these compounds were synergized with piperonyl butoxide. The persistence of resmethrin has been shown to be superior to pyrethrins as a surface treatment (Hadaway *et al.*, 1970). The results obtained from this study, indicate that bioethanomethrin seems to follow similar patterns of synergized bioresmethrin. According to the results obtained from this study, bioethanomethrin showed, in general, the most promising compound among insecticides tested against all species except *Tribolium* spp. These results are in agreement with the results obtained with bioresmethrin by Ardley (1974). However, there is no adequate information on bioethanomethrin and S-bioallethrin whether synergized or not, to support the results from the present study, since these two insecticides are relatively new.

(b) Species Susceptibility to Pyrethroid Insecticides

The orders of effectiveness of the three pyrethroids against the following species, at the 5% level of significance, after exposure for 5 hours at each amount of deposit are summarized as follows:

Species	Amount of Deposit (g/m^2)	Order of Effectiveness
T. confusum	0.5	Pyrethrins-P.B. = S-bioallethrin = Bioethanomethrin
	1.0	S-bioallethrin > Pyrethrins-P.B. = Bioethanomethrin
	2.5	S-bioallethrin > Pyrethrins-P.B. = Bioethanomethrin
T. castaneum	0.5	S-bioallethrin > Bioethanomethrin = Pyrethrins-P.B.
	1.0	S-bioallethrin > Bioethanomethrin > Pyrethrins-P.B.
	2.5	S-bioallethrin > Bioethanomethrin > Pyrethrins-P.B.
O. surinamensis	0.5	Bioethanomethrin > Pyrethrins-P.B. = S-bioallethrin
	1.0	Bioethanomethrin > Pyrethrins-P.B. = S-bioallethrin
O. mercator	2.5	Bioethanomethrin > Pyrethrins-P.B. = S-bioallethrin
C. ferrugineus	0.5	Bioethanomethrin > S-bioallethrin = Pyrethrins-P.B.
	1.0	Bioethanomethrin > Pyrethrins-P.B. > S-bioallethrin
	2.5	Bioethanomethrin > Pyrethrins-P.B. > S-bioallethrin

CHAPTER VI

SUMMARY

The relative persistence and effectiveness of several pyrethroid and organophosphorus insecticides applied at various dosages on fir plywood surfaces were evaluated against five stored-product species exposed for various periods. Surface treatment is commonly employed in the prevention and protection of stored grain and foodstuffs. Besides temperature and relative humidity, the nature of substrate and formulation applied, the method of application, and type and pH of structural surface proved to be important factors influencing the persistence and effectiveness of insecticides.

Under the conditions of these investigations the following results were obtained:

1. Bromophos was the least effective insecticide among the compounds tested. At all dosages, bromophos was less effective than iodofenphos and malathion against all species except *C. ferrugineus* exposed on surfaces for 5 hours ($P < 0.05$). There was no significant difference in toxicity between malathion and bromophos against *C. ferrugineus* at all dosages after exposure for 5 hours but at 0.5 and 1.0 g/m^2, bromophos was less effective than iodofenphos ($P < 0.05$).

   At an exposure period of 24 hours, bromophos provided complete control against *O. surinamensis*, *O. mercator* and *C. ferrugineus* at 80 weeks but was not toxic against *Tribolium* spp.

2. Iodofenphos, in general, was the most effective against *O. surinamensis*, *O. mercator* and *C. ferrugineus* but was less toxic than malathion against *T. confusum* and *T. castaneum* after exposure for 5 hours

($P < 0.05$). At a deposit of 1.0 g/m^2, iodofenphos was the most effective against all species tested but at 0.5 g/m^2, it was less toxic than malation against all species except C. ferrugineus after exposure for 5 hours; at 2.5 g/m^2, iodofenphos was equally effective as malathion against all species ($P < 0.05$).

Iodofenphos was the most persistent insecticide. At 1.0 g/m^2, it provided complete mortality against all species tested after exposure for 24 hours at 80 weeks, whereas malathion produced 27 and 83% mortality against T. confusum and T. castaneum, respectively and at 0.5 g/m^2, it was completely ineffective against Tribolium spp.

3. In general, malathion was the most effective insecticide against most of the species except C. ferrugineus exposed on surfaces for 5 hours. At a deposit of 0.5 g/m^2, malathion was the most effective compound among insecticides tested; at 1.0 g/m^2, malathion was less toxic than iodofenphos against all species but was equally effective as iodofenphos against Tribolium spp.; at 2.5 g/m^2, malathion and iodofenphos were not significantly different against all species ($P < 0.05$).

At an exposure period of 24 hours, malathion persisted for at least 80 weeks at all dosages against all species, except T. confusum and C. ferrugineus at 0.5 g/m^2.

4. T. confusum and T. castaneum were the most susceptible species to malathion followed by iodofenphos whereas they were the least susceptible species to bromophos. O. surinamensis and O. mercator were the most susceptible species to malathion and iodofenphos but they were the least susceptible insects to bromophos. There was no significant difference between the three compounds against C. ferrigineus.

5. Pyrethrins-piperonyl butoxide (1:10) was the least effective compound among the pyrethroids tested ($P < 0.05$). It was ineffective

against all species exposed on surfaces for 5 hours, except C. ferrigineus which at 2.5 g/m^2, produced 69% mortality at 4 weeks after treatment.

6. S-bioallethrin was the most toxic compound against Tribolium spp. ($P < 0.05$). At 2.5 g/m^2, S-bioallethrin provided 71% mortality against T. castaneum exposed on surfaces for 5 hours at 16 weeks after treatment, but produced only 64% mortality against T. confusum at 1 week. S-bioallethrin was ineffective against O. surinamensis, O. mercator and C. ferrugineus.

7. Bioethanomethrin was the most effective pyrethroid against all species, except T. confusum which was highly resistant to this insecticide. At 2.5 g/m^2, bioethanomethrin was 41% effective against T. castaneum, 57% against O. surinamensis, 37% against O. mercator, and 54% against C. ferrugineus after exposure for 5 hours at 8, 16, 8, and 8 weeks after treatment, respectively.

8. T. confusum was the most resistant species to pyrethroids tested. T. castaneum was highly resistant to pyrethrins-piperonyl butoxide (1:10) but was highly susceptible to S-bioallethrin and bioethanomethrin. Both Oryzaephilus spp. were highly susceptible to bioethanomethrin, especially O. surinamensis, but they were highly resistant to other pyrethroids tested. C. ferrugineus was the least susceptible to all compounds, especially bioethanomethrin followed by pyrethrins-piperonyl butoxide while S-bioallethrin was the least effective.

Some practical conclusions from the results of these experiments show that malathion, which is an insecticide of low mammalion toxicity, may be recommended when the treated surfaces are near neutral pH, when long residual effectiveness is not required, and when several species of stored-product insect are present. When a longer residual life is required, iodofenphos which is of lower mammalian toxicity than malathion, may be considered. When malathion-resistant species such as *T. castaneum* occur or when *C. ferrugineus* alone is present, iodofenphos may be more appropriate than malathion.

While both initial and residual toxicities of iodofenphos against various species are readily apparent, further work is needed to clarify the residual toxicity of this insecticide on various structural surfaces, particularly highly alkaline surfaces. More work is also required for the comparative residual toxicity of iodofenphos at various temperatures.

It is of interest that bioethanomethrin has been proved to be a very promising compound against stored-product insects. Although more work needs to be done on the surface treatment as well as on the direct treatment of this pyrethroid to stored grain and foodstuffs, there may be a future role for this highly effective compound as a grain protectant.

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