EVALUATION OF INSECTICIDES FOR CONTROL OF STORED-PRODUCT PESTS IN TRANSPORT VEHICLES[1]

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ABSTRACT

Thirty-three insecticides were evaluated over a 6 year period for their effectiveness against three species of stored-product insects: the confused flour beetle, *Tribolium confusum* Jacquelin duVal; the black carpet beetle, *Attagenus unicolor* (Brahm); and a warehouse beetle, *Trogoderma glabrum* (Herbst). The tests were conducted in transport trailer vans or sea-going cargo containers. The insecticides were formulated for application as aerosols or dusts or both. Dusts generally caused greater mortality than aerosols. Pyrethroids were more effective than other classes of insecticides tested. Cyfluthrin and *S*-cyano-(3-phenoxyphenyl)-methyl (1 *R*-*cis*-3-(1,2-dibromo-2,2-dichloroethyl)-2,2-dimethylcyclopropanecarboxylate were the most promising pyrethroids. The most effective organophosphate aerosol was *O*-(3-chloro-1-methyl-1*H*-pyrazol-5-yl) *O*-ethyl *O*-methyl phosphorothioate. Generally, carbamates had very limited toxicity, as did other miscellaneous insecticides.

Key Words: Stored products, *Tribolium confusum, Attagenus unicolor, Trogoderma glabrum,* pyrethroids, carbamates, insecticides, organophosphates.

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INTRODUCTION

With the rapid modes of transportation available to modern society, there is the associated risk of inadvertent introduction of insect pests from foreign locales. This has been a matter of concern for the U. S. Department of Agriculture, the U. S. Department of Health, Education and Welfare, and the U. S. Department of Defense which have jointly conducted tests of promising new insecticides for potential as quarantine application. The results of these tests have been reported in a series of papers (Sullivan et al. 1972a; Schechter and Sullivan 1972b; Steiner et al. 1972; Gillenwater et al. 1972; Jakob et al. 1972; Burden 1972; Sullivan et al. 1972b; Smith and Boswell 1972; Schechter et al. 1976) and reports (Morgan et al. In press). Gillenwater et al. (1972) reported the results of tests for control of stored-product insects. Their results indicated that dust formulations of chlorpyrifos alone or a mixture of chlorpyrifos, resmethrin, and propoxur were the most active dust treatments. The most promising aerosol was resmethrin.

The objective of our research was to evaluate new materials and formulations for the control of stored-product insects in transport containers. This paper summarizes the results of tests conducted between 1979 and 1985 in Baltimore, MD, and Miami, FL.

[1] Mention of a proprietary product does not constitute an endorsement or recommendation for its use by the U. S. Dept. of Agriculture nor does it imply registration as amended under FIFRA.

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MATERIALS AND METHODS

Insects

Three species of stored product insects were used in these tests. All insects were laboratory reared at the Stored-Product Insects Research and Development Laboratory, Savannah, GA, in a controlled environment of 27 ± 2°C and 60 ± 3% RH. The following stages and ages of the insects were treated: *Tribolium confusum* duVal adults, one week old, *Attagenus unicolor* (Brahm) (= *A. megatoma* [F.]) larvae, 3 months old, and *Trogoderma glabrum* (Herbst) larvae, 6 weeks old.

Insecticide Application

The tests were conducted in truck vans and sea going containers and were replicated two or three times in Miami, FL (truck vans) or Baltimore, MD (containers). The vans or containers were located and their volume determined. The dusts or aerosols were formulated in the laboratory using standard procedures (Schechter and Sullivan 1972). The dusts were generally formulated with HiSil® 233 except in the one experiment where Diabrite was used as the carrier. Aerosol formulations were also prepared according to the above standard procedures. Freon 11/12 was the aerosol propellant, except for experiments in which the effectiveness of CO_2 as a propellant was evaluated.

Aerosols were applied by an individual walking the length of the closed van or container and releasing the aerosol for a specified amount of time (time release) or until a certain weight had been dispensed (total release). Dust formulations were introduced through a partially open rear door using CO_2 as the propellant. Forty insects of each species, in two petri dishes, 20 insects per dish, were placed ca. 30 cm from one wall at the halfway point of each van or sea going container. After insecticides were introduced, the doors remained closed for 10 minutes. The doors were half opened for the next 20 minutes and the insects were removed 30 minutes after the insecticide application. The insects were transferred to clean petri dishes 4.5 hours after removal from the vans. Knockdown was recorded 24 hours later and was defined as the inability to walk or remain in an upright position. The numbers of dead or moribund insects were recorded after 168 and 336 hours. Moribund insects were those that exhibited only slight movement after light prodding. Mortality was corrected by Abbott's formula (1925) on the basis of the natural mortality among control insects. Control insects were exposed only to the CO_2 propellant. Probit regression could not be estimated because of the limited number of concentrations tested. The compounds and their manufacturers were:

PYRETHROIDS:

Phenothrin: (3-phenoxyphenyl)methyl *cis, trans* -(+)-2,2-dimethyl-3-(2-methyl-1-propenyl)cyclopropanecarboxylate. From MGK.

Permethrin: (3-phenoxyphenyl)methyl 3-(2,2-dichloroethenyl)-2,2-dimethylcyclopropanecarboxylate. From FMC Corp.

Fenvalerate: Cyano (3-phenoxyphenyl)methyl 4-chloro-∝-(1-methylethyl) benzeneacetate. From Sumitomo Chem. Co. Ltd.

Cypermethrin: Cyano (3-phenoxyphenyl) methyl 3-(2,2-dichlorethenyl)-2,2-dimethylcyclopropanecarboxylate. From FMC Corp.

Fluvalinate: *N*-[2-chloro-4-(trifluoromethyl)phenyl]-*DL*-valine cyano (3-phenoxyphenyl)methylester. From Zoecon Corp.

cis-permethrin: (3-phenoxyphenyl)methyl *cis* (±)-3-(2,2-dichloroethenyl)-2,2-dimethylcyclopropanecarboxylate. From FMC Corp.

Cyfluthrin: Cyano(4-fluoro-3-phenoxyphenyl) methyl (3-(2,2-dichloroethenyl)-2,2-dimethylcyclopropanecarboxylate. From Mobay.

HR 475 V: *S*-cyano-(3-phenoxyphenyl)-methyl (1 *R*-*cis*-3-(1,2-dibromo-2,2-dichloroethyl)-2,2-dimethylcyclopropane carboxylate. From Hoechst-Roussel Pharmaceuticals, Inc.

S 2852: (*E*)-1-ethynyl-2-methyl-2-pentenyl *cis,trans*-(+)-2,2-dimethyl-3-(2-methyl-1-propenyl) cyclopropanecarboxylate. From Sumitomo Chem. Co.

Fenopropathrin: Cyano (3-phenoxyphenyl) methyl 2,2,3,3-tetramethylcyclopropanecarboxylate. From Sumitomo Chem. Co.

S 4068: 2-Methyl-3-(prop-2-ynyl)-4-oxocyclopent-2-enyl d-*cis,trans*-chrysanthemate. From Sumitomo Chemical Co.

Cyphenothrin: Cyano(3-phenoxyphenyl)methyl 2,2-dimethyl-3-(2-methyl)1-1-propenylcyclopropanecarboxylate. From Sumitomo Chem. Co.

Bifenthrin: [2-methyl-(1,1'-biphenyl)-3yl] methyl-cis-3-(2-chloro-3,3,3-trifluoropropenyl)-2,2dimethylcyclopropanecarboxlate. From FMC Corp.

Resmethrin: [5-phenylmethyl)-3-furanyl] methyl 2,2-dimethyl-3-(2-methyl 1-propenyl)cyclopropanecarboxylate.

Tetramethrin: (1,3,4,5,6,7-hexahydro-1, 3-dioxo-2*H*-isoindol-2-yl) methyl 2,2-dimethyl-3-(2-methylpropenyl)cyclopropanecarboxylate. From Sumitomo Chem. Co.

ORGANOPHOSPHATES:

M 9270: *O*-[3-chloro-1-(1-methylethyl)-1*H*-pyraxol-5-yl]-*O*-*O*-dimethylphosphorothioate. From Montedison.

M 9526: *O*-(3-chloro-1-methyl-1*H* pyraxol-5-yl) *O,O*-dimethylphosphorothioate. From Montedison.

M 9580: *O*-(3-chloro-1-methyl-1*H*-pyrazol-5-yl) *O*-ethyl *O*-methyl phosphorothioate. From Montedison.

M 9571: *O*-(3-chloro-1-phenyl-1*H*-pyrazol) *O*-ethyl *O*-methylphosphorothioate. From Montedison.

Acephate: *O,S*-dimethyl acetylphosphoramidothioate. From Chevron.

CARBAMATES:

Bendiocarb: 2,2-dimethyl-1,3-benzodioxol-4-yl methylcarbamate. From FBC Limited.

Chloethocarb: 2-(2-chloro-1-methoxyethoxy)phenyl methylcarbamate. From BASF.

Methomyl: Methy *N*-[[(methylamino)carbonyl]oxy]ethanimidothioate. From E. I. duPont de Nemours & Co., Inc.

U 57770: *N*-[[[[[1,3,2-dioxaphosphorinan-2-yl-(1-methylethyl)amino]-thio] methylamino]carbonyl]oxy]-ethanimidothioic acid. From the Upjohn Co.

U 56295: N-[[[[[(5,5-dimethyl-1,3,2-dioxaphosphorinan-2-yl)(1,1-dimethyl) amino]thio]methylamino]carbonyl]oxy]-ethanimidothioic acid. From the Upjohn Co.

U 47319: *N*-[[[[[(diethoxyphosphinothioyl)(1-methylethyl)amino]thio]-methylamino]carbonyl]oxy]ethanimidothioate. From the Upjohn Co.

Carbaryl: 1-naphthyl methylcarbamate. From Union Carbide Corp.
FBC 34570: 2,2-dimethyl-1,3-benzodioxol-4-yl(1-piperdinyl-thio) carbamate. From Nor-Am Chem. Co.

MISCELLANEOUS HETEROCYCLIC COMPOUNDS:
SN 72129: 2-chlorophenyl-3-oxo-β-(4-phenyl-2(3*H*)-thiazolylidene) propionitrile. From Nor-Am. Ag. Prod. Inc.
SLJ 0312: *N*-[3-phenyl-4,5-bis[(trifluoromethyl)imino]-2-thiazolidinylidene]-benzeneamine. From Bayer.

MISCELLANEOUS OTHER INSECTICIDES:
BTS 48011: Ethyl[(4-chlorophenyl)[4-[[trifluoromethyl)sulfonyl]oxy]phenyl] methylene] hydrazinecarboxylate. From FBC Limited.
LAB 96114 I: 6-[(diethoxylphosphinothioyl)oxy]-2,4-dimethyl-3-pyridine-carboxylic acid. From BASF Wyandotte.
DDT: 1,1'-(2,2,2-trichloroethylidene)bis(4-chlorobenzene). From USDA-ARS.

RESULTS AND DISCUSSION

The effectiveness of timed released aerosol formulations or total release formulations of phenothrin and permethrin is presented in Table 1. Timed release of both insecticides consistently produced equal or higher mortality in the two species tested. Differences were greatest for permethrin aerosol applications against *A. unicolor*; the mortality resulting from timed-release applications was more than two-fold that of the total release method (Table 1). Percent knockdown (KD) of *T. confusum* for the timed release applications was higher than that for total release applications at both concentrations, but this did not result in a higher kill (Table 1). These results are readily explainable. The dispersion of the timed release method is due to the applicator walking throughout the trailer. Since the total release aerosol remains stationary, the active ingredient does not have as good a chance to disperse.

The effect of various propellents (CO_2 or Freon) on aerosol treaments of phenothrin was also investigated (Table 1). In the test carried out in Miami in 1981 (1981M) the CO_2 treatment produced slightly higher kill; in the test carried out in Baltimore in 1981 (1981B) the opposite occurred. Since the mortality produced in both tests was low,the only conclusion that can be drawn is that neither carrier is markedly better than the other under these conditions.

The results of a test which compared two different dusts are also tabulated in Table 1. Phenothrin was formulated with either Diabrite or HiSil. For all three species and at both dosages there was clearly higher mortality with the Diabrite formulated material. Diabrite produced 98% mortality of *A. unicolor* whereas the HiSil formulation produced only 6% mortality at 0.021 g/m^3. Against *T. confusum* mortality was ca. 3-fold greater due to the Diabrite dust formulation at the 0.021 g/m^3 rate. Against *T. glabrum* mortality was ca. 7-fold greater for the Diabrite formulation; however, this may be misleading because mortality for the HiSil formulation was very low.

Table 2 presents the knockdown and mortality data of various insecticides formulated for aerosol treatment. The purpose of these experiments was to find

Table 1. Percentage of insects knocked down (KD) or dead plus moribund (D+M) following application of phenothrin or permethrin as total release or timed release formulations and with various carriers in Miami, FL (M) or Baltimore, MD (B).

Insecticide	Formulation	Date and location	Carrier or system	Dose (g[ai]/m^3)	*A. unicolor* KD*	*A. unicolor* D+M†	*T. confusum* KD	*T. confusum* D+M	*T. glabrum* KD	*T. glabrum* D+M
Phenothrin	Aerosol	1979 M&B	Total release	0.0071	100	27	9	4	‡	–
		1980 M	Total release	0.0071	100	5	0	3	–	–
		1979 M&B	Timed release	0.0071	99	34	26	23	–	–
Phenothrin	Aerosol	1981 M	CO_2 propell.	0.00071	66	5	0	8	16	0
		1981 M	Freon	0.00071	54	2	0	2	18	0
		1981 B	CO_2	0.028	91	67	26	8	40	3
		1981 B	Freon	0.028	100	75	63	17	50	5
Permethrin	Aerosol	1979 M&B	Total release	0.0071	99	36	9	9	–	–
		1979 M&B	Timed release	0.0071	99	85	25	9	–	–
		1979 M&B	Total release	0.0088	99	31	5	6	–	–
		1979 M&B	Timed release	0.0088	87	88	52	6	–	–
Phenothrin	Dust	1981 M	Diabrite	0.021	95	98	75	31	44	21
		1981 M	HiSil	0.021	95	6	28	12	46	3
		1981 B	Diabrite	0.064	98	100	100	84	65	26
		1981 B	HiSil	0.064	99	98	100	30	61	17

* KD = Knockdown measured 24 hours after exposure.
† D+M = Dead plus moribund insects 2 weeks after exposure.
‡ Species not tested before 1981.

Table 2. Percentage of insects knocked down (KD) or dead plus moribund (D+M) following aerosol application of insecticides.

Insecticide	Date and location	Dose (g[ai]/m³)	*A. unicolor* KD	*A. unicolor* D+M	*T. confusum* KD	*T. confusum* D+M	*T. glabrum* KD	*T. glabrum* D+M
PYRETHROIDS:								
Phenothrin	1982 M*	0.0071	94	1	0	4	66	0
	1985 M&B	0.0071	100	62	11	16	71	48
	1983 M	0.014	100	98	74	43	70	6
	1984 M	0.014	100	67	17	22	67	16
	1984 B	0.021	99	39	29	16	48	30
	1979 M&B	0.028	93	99	57	10	†	–
	1980 M	0.028	100	97	82	6	–	–
	1982 B	0.028	99	94	52	5	32	13
	1983 B	0.029	100	98	74	43	70	6
	1979	0.035	100	88	91	12	–	–
Fenvalerate	1979 M&B	0.0088	91	24	100	31	–	–
Cypermethrin	1983 M	0.0071	77	53	100	20	70	28
	1979 M&B	0.0088	99	98	100	69	–	–
	1983 B	0.028	99	100	100	100	83	7
	1983 B	0.029	98	100	100	100	76	13
cis-Permethrin	1979	0.0088	95	99	71	13	–	–
Permethrin	1984 M	0.014	100	68	25	27	37	24
	1984 B	0.021	100	85	66	15	47	80
Fluvalinate	1980 M	0.0071	96	1	66	6	–	–
	1981 B	0.028	100	81	100	78	73	11
Cyfluthrin	1981 M	0.0071	96	98	95	64	34	11
	1982 M	0.0071	97	98	100	92	57	16
	1981 B	0.028	96	99	100	100	69	16
	1982 B	0.028	92	100	100	100	26	37
HR 475 V	1981 M	0.0071	93	98	100	88	27	3
	1981 B	0.028	100	98	100	99	61	13
S 2852	1981 M	0.0071	1	0	0	4	0	0
	1982 M	0.0071	0	0	0	4	1	0
	1981 B	0.028	99	99	100	75	58	13
Fenpropathrin	1982 B	0.0071	97	8	32	2	66	3
	1983 M	0.0071	99	36	80	8	72	14
	1982 B	0.028	99	80	100	18	67	18
	1983 B	0.029	99	86	100	50	87	17

Table 2. Continued.

Insecticide	Date and location	Dose (g[ai]/m³)	*A. unicolor* KD	*A. unicolor* D+M	*T. confusum* KD	*T. confusum* D+M	*T. glabrum* KD	*T. glabrum* D+M
S 4068	1983 M	0.0071	8	0	8	5	9	0
	1982 M	0.0071	0	0	0	3	2	0
	1983 B	0.029	89	0	61	50	32	10
	1982 B	0.028	56	4	48	23	18	0
Cyphenothrin	1980 M	0.0071	100	16	100	16	-	-
	1982 M	0.0071	98	63	96	24	36	1
	1985 M&B	0.0071	10	51	100	51	46	0
	1985 M&B	0.014	98	67	100	77	52	3
	1982 B	0.028	99	99	100	75	58	13
ORGANOPHOSPHATES:								
M 9270	1979 B	0.028	91	99	99	100	-	-
M 9526	1979 B	0.028	29	47	28	35	-	-
M 9580	1980 M	0.0044	19	14	36	41	-	-
	1982 M	0.0071	4	3	3	19	32	12
	1980 M	0.0088	16	12	39	55	-	-
	1979 B	0.0177	87	98	100	99	-	-
	1982 B	0.028						
M 9571	1980 B	0.028	91	99	54	55	-	-
MISCELLANEOUS:								
U 43719	1980 M	0.0071	100	97	82	6	-	-
U 57770	1980 M	0.0071	0	0	1	1	-	-
U 56295	1980 M	0.0071	3	38	0	0	-	-
BTS 48011	1983 M	0.0071	0	2	8	56	0	8
	1983 B	0.029	3	0	48	88	15	14
FBC 34570	1984 M	0.014	0	1	0	23	1	1
	1984 B	0.028	0	0	2	25	5	10

* The letter following the date refers to the location at which the test was carried out; M for Miami, FL and B for Baltimore, MD.

† Species not tested before 1981.

insecticides which produce consistently high mortality to all three species at low rates. These insecticides should also have other favorable characteristics such as low mammalian toxicity, some residual activity, stability when formulated as either a dust or aerosol, and low or no odor (Schechter and Sullivan 1972).

Recovery from knockdown occurred consistently in insects exposed to the pyrethroid aerosol formulations. For the organophosphorus materials, mortality was generally higher than initial KD. There was recovery from the carbamate, U 43719, but not from U 56295 or FBC 34570. Mortality of *A. unicolor* due to U56295 was greater than KD, as was BTS 48011 against *T. confusum.*

An examination of the mortality caused by the various aerosol formulations reveals that there was a consistent dose-dependent response for *A. unicolor* and *T. confusum* except for phenothrin. The aerosol formulations were generally more toxic to *A. unicolor* than to *T. confusum. Trogoderma glabrum* was relatively insensitive to all insecticides except for permethrin which caused 80% mortality at 0.021 g/m^3. This same concentration however produced only 15% mortality of *T. confusum.*

Attagenus unicolor was generally the most sensitive of these three species to the pyrethroids. Two exceptions were S 4068 which was more toxic to *T. confusum* than to either *A. unicolor* or *T. glabrum* and HR 475 which was equally toxic to *A. unicolor* and *T. confusum.* Although not all pyrethroids were tested at the same rates, enough were tested at 0.028 g/m^3 to give an indication of the most and least effective materials. Cyfluthrin and HR 475 V were the most active pyrethroid materials. The least active pyrethroids at 0.028 g/m^3, which failed to produce at least 95% mortality in any species, were S 4068, S 3206, fluvalinate and fenpropathrin.

Four organophosphorus materials were formulated as aerosols. These materials showed good activity against *T. confusum* and *A. unicolor.* The best insecticides were M 9270 which produced 99% and 100% mortality to *A. unicolor* and *T. confusum,* respectively, at 0.028 g/m^3, and M 9580 which caused 98% and 99% mortality at the lower rate of 0.018 g/m^3 to *A. unicolor* and *T. confusum,* respectively.

Four of the five remaining aerosol formulated insecticides were carbamates. Only U 43719 at 0.0071 g/m^3 produced substantial mortality — 97% to *A. unicolor.* Although three carbamates, U 43719, U 57770 and U 56295, were tested only at one low concentration (0.0071 g/m^3), U 43719 was clearly the most active carbamate, with activity against *A. unicolor* comparable to some of the most active pyrethroids (HR 475V and cyfluthrin) although there was low activity against *T. confusum.* Compared to M 9580, U 43719 is less toxic than M 9580 against *T. confusum* but more active against *A. unicolor.*

The insecticides when applied as dusts (Table 3) also showed a general dose-dependent response, although it is not as clear as for the aerosol tests because for some insecticides the dosages tested produced only high or low mortality.

Recovery from KD following treatment with phenothrin, fenpropathrin, and cyphenothrin was extensive for all three species. In addition, *A. unicolor* showed high recovery from fluvalinate, fenvalerate, and bifenthrin treatments at lower dosages. *Trogoderma glabrum* exhibited slight to moderate recovery from KD to M 9580 and to all pyrethroids except bifenthrin.

The pattern of relative sensitivity of the three species to dusts differed from that of aerosols. *Tribolium confusum* was generally the most sensitive while *T. glabrum* was the least. The response of *A. unicolor* depended on the class of insecticide. *Attagenus unicolor* and *T. confusum* were about equally sensitive to most of the pyrethroids. *Tribolium confusum* was consistently more sensitive to the non-pyrethroid dust formulations. Most of the insecticides were tested at 0.021 g/m^3, which permits comparison of the activity of the pyrethroids to each other and to the other classes of insecticides. As a class, the pyrethroid dusts were more toxic to all species than either carbamates, organophosphates, or miscellaneous insecticides.

Table 3. Percentage of insects knocked down (KD) or dead plus moribund (D+M) following application of dust formulations.

Insecticide	Date and location	Dose (g[ai]/m^3)	*A. unicolor* KD	*A. unicolor* D+M	*T. confusum* KD	*T. confusum* D+M	*T. glabrum* KD	*T. glabrum* D+M
PYRETHROIDS:								
Phenothrin	1984 M*	0.014	18	0	1	29	9	1
	1982 M	0.021	80	1	3	2	48	2
	1983 M	0.021	78	6	10	0	55	0
	1984 B	0.021	93	0	2	16	41	7
	1985 M&B	0.021	96	27	9	13	54	2
	1983 B	0.029	100	49	86	53	83	5
	1985 M&B	0.042	99	78	62	24	82	30
	1982 B	0.064	98	76	78	5	46	16
Fenvalerate	1980 M	0.021	100	2	100	76	†	–
	1979 M	0.030	100	77	100	100	–	–
	1979 B	0.059	28	39	99	100	–	–
Cypermethrin	1983 M	0.021	96	80	99	98	75	49
	1985 M&B	0.021	98	88	92	100	63	12
	1983 B	0.029	95	96	100	100	90	1
	1985 M&B	0.042	98	99	100	100	75	39
	1982 B	0.064	94	100	100	100	26	42
Permethrin	1984 M	0.014	100	83	96	59	32	18
	1984 B	0.021	100	97	100	88	40	87
	1985 M&B	0.021	100	100	100	83	82	68
	1985 M&B	0.042	100	100	100	100	82	93
Fluvalinate	1981 B	0.032	100	47	100	93	54	10
Cyfluthrin	1981 M	0.021	96	94	100	100	34	22
	1982 M	0.021	99	98	100	100	61	2
	1981 B	0.032	95	98	100	100	61	20
	1982 B	0.064	100	100	100	100	30	19
HR 475 V	1981 M	0.021	88	100	100	100	42	21
S 2852	1982 M	0.021	0	1	2	12	1	1
	1981 B	0.021	0	1	0	7	46	1
	1982 B	0.064	25	17	26	28	22	10
Fenpropathrin	1982 M	0.021	76	3	25	13	50	5
	1983 M	0.021	99	14	92	2	68	3
	1983 B	0.029	98	19	98	59	70	2
	1983 B	0.042	99	51	100	32	76	15
	1985 M&B	0.042	99	48	92	80	63	2
	1982 B	0.064	98	75	100	48	47	9

Table 3. Continued.

Insecticide	Date and location	Dose (g[ai]/m³)	*A. unicolor* KD	*A. unicolor* D+M	*T. confusum* KD	*T. confusum* D+M	*T. glabrum* KD	*T. glabrum* D+M
S 4068	1983 M	0.021	2	0	26	3	2	0
	1982 M	0.021	1	0	0	7	27	0
	1983 B	0.029	16	0	28	38	13	1
Cyphenothrin	1982 M	0.021	99	62	96	83	36	0
	1982 B	0.064	95	96	99	99	39	10
Bifenthrin	1984 M	0.014	100	38	100	95	49	18
	1984 B	0.021	100	79	100	100	58	64
	1985 M&B	0.021	100	99	100	100	87	71
	1985 M&B	0.042	99	99	100	100	77	97
NON-PYRETHROIDS:								
M 9580	1981 M	0.021	86	83	88	100	34	24
	1982 M	0.021	0	1	2	12	1	1
	1981 B	0.042	97	99	100	100	38	9
	1982 B	0.064	25	17	26	28	22	10
Bendiocarb	1984 M	0.014	0	1	12	69	1	1
	1984 B	0.021	0	0	6	55	3	26
Chloethocarb	1984 M	0.014	0	0	1	19	1	7
	1984 B	0.021	1	1	0	15	0	2
	1983 M	0.021	0	1	3	3	0	0
	1983 B	0.029	31	1	25	69	8	3
Acephate	1985 M&B	0.014	0	1	0	12	5	2
	1985 M&B	0.028	11	2	1	14	4	2
SLJ 0312	1985 M&B	0.014	2	0	2	0	5	0
	1985 M&B	0.028	2	1	0	2	3	1
Methomyl	1985 M&B	0.014	3	3	13	78	6	0
	1985 M&B	0.028	4	3	14	89	4	1
LAB 96114	1984 M	0.014	1	0	0	18	0	1
	1984 B	0.021	1	1	0	7	0	0
FBC 34570	1984 M	0.014	0	2	2	20	1	6
	1984 B	0.021	0	0	0	12	0	0
SN 72129	1980 B	0.021	0	4	0	9	–	–
BTS 48011	1983 M	0.021	0	0	17	78	0	9
	1983 B	0.029	3	0	49	90	0	5

* The letter following the date refers to the location at which the test was carried out; M for Miami, FL and B for Baltimore, MD.

† Species not tested before 1981.

The most toxic pyrethroids were cyfluthrin, HR 475 V, bifenthrin, permethrin, and cypermethrin. These materials all produced > 95% mortality to either *A. unicolor* or *T. confusum* at 0.021 g/m^3. The most effective non-pyrethroid was M 9580 which caused substantial mortality to *T. confusum* and *A. unicolor* but not to *T. glabrum* at 0.021 g/m^3. However, it should be noted that mortalities were not as high in 1982 tests as in 1981. This might have been due to decomposition of the material or some other factor.

The results of tests involving combinations of insecticides with synergists or other insecticides are presented in Table 4. The DDT/carbaryl mixture at a 1:1 ratio was the standard for aircraft disinsection until 1984. This mixture was much more toxic to *T. confusum* than to either *A. unicolor* or *T. glabrum*. Mortality of *T. glabrum* and *A. unicolor* was < 10% even at the highest rate for this mixture of 0.18 g/m^3. Resmethrin and a mixture of resmethrin plus piperonyl butoxide (PBO) were tested in 1984. For all three species the mixture was less toxic. For *T. confusum* the difference was slight, but for the other two species it was larger. These data suggest that resmethrin needs to be metabolically activated in order to cause mortality. To the best of our knowledge there are no reports of resmethrin needing metabolic activation in other species. However, the role that possibly toxic metabolites might play in conferring toxicity in this or other species has not been worked out.

Table 4. Percentage of insects knocked down (KD) or dead plus moribund (D+M) following application of insecticide mixtures.

Compound (ratio)	Date	Dose (g[ai]/m^3)	*A. unicolor* KD	*A. unicolor* D+M	*T. confusum* KD	*T. confusum* D+M	*T. glabrum* KD	*T. glabrum* D+M
Carbaryl + DDT	1984 M*	0.015	25	0	35	28	6	0
(1:1)	1984 B	0.023	11	0	13	29	3	0
Dust	1979 B	0.060	39	7	84	86	†	–
	1981 B	0.060	15	8	47	96	17	0
	1982 M	0.060	18	0	18	68	2	2
	1983 M	0.060	15	0	58	63	9	1
	1983 B	0.081	32	0	96	98	14	7
	1981 B	0.180	56	2	100	100	37	9
	1983 B	0.180	52	2	98	100	16	4
Resmethrin	1984 M	0.014	100	27	14	18	36	20
	1984 B	0.021	99	38	96	19	52	42
Resmethrin + PBO	1984 M	0.014	49	3	8	15	15	4
(1:3)	1984 B	0.021	40	1	33	8	54	10
Aerosol								

* The letter following the date refers to the location at which the test was carried out; M for Miami, FL and B for Baltimore, MD.

† Species not tested before 1981.

OVERALL CONCLUSIONS

The pyrethroids, when taken as a class, appear to be effective insecticides for the control of stored-product insects in transport vehicles. Knockdown is poor criterion for evaluating these materials because recovery from knockdown frequently occurs, resulting in an underestimate of the amount of insecticide required and no pattern can be discerned to predict which materials will show significant recovery. Although dust formulations and aerosol applications are both effective, the dust formulations produced higher mortality at the same rates. Organophosphate insecticides were marginally effective as aerosols. The most promising organophosphate, M 9580, was also evaluated as a dust and appeared to have good activity against two of the three species in the 1981 tests. The carbamate and miscellaneous insecticides exhibited poor insecticidal activity as either dusts or aerosols. These trends in activity are not seen when other species are treated. Morgan et al. (1983, 1986) have reported the results of tests with a broad range of insects of inter-continental and international air transportation quarantine importance including *Blattella germanica* (L.), *Dermacentor variabilis* Say), *Glossina morsitans* (Westwood), *Popillia japonica* Newman, *Musca domestica* L., *Spodoptera frugiperda* (J. E. Smith), and *Anopheles quadrimaculatus* Say. They found that the carbamates were sometimes as effective as the pyrethroids but that the activity of the pyrethroids did not seem to differ much depending on which material was tested.

It was not possible to test the major insecticides currently registered for use on stored-products: chlorpyrifos-methyl, malathion, fenitrothion, pirimiphos-methyl and synergized pyrethrins. These insecticides were not included in these experiments since other insects of greater quarantine importance were also tested. It would be of interest to compare the insecticides used in stored product situations with those tested in this experiment in future studies.

The results reported here suggest distinct inter-specific differences existed in the response of the three species to the insecticides. Generally, *T. glabrum* was the least sensitive towards all insecticides. However, bifenthrin and permethrin applied as dusts appear promising for control of *T. glabrum. Attagenus unicolor* and *T. confusum* were about equally sensitive to the pyrethroids, with some exceptions. *Tribolium confusum* was the least sensitive to the non-pyrethroid insecticides.

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