AEROSOL EVALUATION OF SELECTED ADULTICIDES AGAINST COLONIZED AND FIELD STRAINS OF MOSQUITOES[1, 2]

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ABSTRACT. Eight experimental pyrethroids, DDT, lindane and malathion were compared for effectiveness against laboratory colonies of insecticide-susceptible and DDT-insecticide-resistant strains and a field-collected strain of *Anopheles quadrimaculatus,* a laboratory colony of *Aedes taeniorhynchus,* and a field-collected strain of *Psorophora columbiae.*

In the initial laboratory evaluation against *Ae. taeniorhynchus* the pyrethroids were from 5X to 29X more effective than malathion. The pyrethroids were less effective against the DDT-resistant strain of *An. quadrimaculatus* than against the insecticide-susceptible strain. Against the field strain, they were intermediate in effectiveness. The pyrethroids were from 7 to 139X more effective than malathion against *Ps. columbiae.* The LC_{50} value of malathion against the field strain of *An. quadrimaculatus* was 26X greater than the value found in 1980 and 50X greater than the value found in 1978.

INTRODUCTION

In our evaluation program for potential mosquito adulticides we seek compounds that are equivalent to or are more effective than the malathion standard in wind tunnel aerosol evaluation against a laboratory strain of *Aedes taeniorhynchus* (Wiedemann). Those meeting these performance characteristics are selected for further evaluation against natural mosquito populations or field-collected specimens. In the present studies, eight pyrethroids were evaluated against rice field mosquitoes at the Arkansas Rice Branch and Extension Center in Stuttgart, Arkansas.

In recent years, several authors have reported on the presence of cross-resistance to pyrethroids present in DDT-resistant mosquito strains (Chadwick et al. 1977, Prasittisuk and Busvine 1977, and Rongsriyam and Busvine 1975). These studies with various species resistant to DDT showed lower sensitivity to allethrin, bioresmethrin, and permethrin than in strains of similar species susceptible to DDT. This correlation indicated that in the early stages of evaluation, studies should be included to determine the effect insecticide resistance has on the efficacy of pyrethroids. Therefore, in the present study, in addition to the malathion standard, comparative studies were also conducted with DDT and lindane.

MATERIALS AND METHODS

The adulticides evaluated were Sumitomo S-3206 [cyano (3-phenoxyphenyl) methyl 2,2,3,3,tetramethylcyclopropanecarboxylate], Sumitomo S-2703 [(+)−cyano (3-phenoxyphenyl) methyl 2,2-dimethyl-3-(2-methyl-1-propenyl) cyclopropanecarboxylate], ICI PP-563 [cyano (3-phenoxyphenyl) methyl cis-(Z)-3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethylcyclopropanecarboxylate], FCR 1272 [cyano (4-fluoro-3-phenoxyphenyl) methyl 3-(2,2-dichlorethenyl)-2,2-dimethyl cyclopropanecarboxylate], FMC 54617 [2,3-dihydro-4-phenyl-1*H*-inden-2-yl *cis*-(±)-3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethylcyclopropanecarboxylate], FMC 54800 [(2-methyl[1,1′-biphenyl]-3-yl)methyl *cis*-3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2 dimethylcyclopropanecarboxylate], Zoecon ZR-3210 [(±)-α-cyano(3-phenoxyphenyl)methyl *N*-[2-chloro-4-(trifluoromethyl)phenyl]-*D*-valine], Bayer NAK-1654 [([pentafluorophenyl]-methyl)- 1R, 3R-3-(2,2-dichlorethenyl)-2,2 dimethylcyclopropanecarboxylate], DDT, lindane, and malathion. Each adulticide was tested using the technical compound in an acetone solution across a range of 4 to 6 discriminating concentrations with 6 replicates of 25 female mosquitoes each per concentration. The mosquitoes used from the colonies

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were 4–6 days old. The wind tunnel and testing procedures used were described by Mount et al. (1976) except that the custom-fabricated atomizing nozzle was replaced with a 2050–70 commercial nozzle (Spray Systems® J2A assembly). The same portable wind tunnel was used for evaluation in the two locations.

The mosquito colony species used in these tests were *Anopheles quadrimaculatus* Say, an insecticide-susceptible strain established in 1942 and an insecticide-resistant strain maintained under constant exposure to DDT since 1965 (Wilson et al. 1972), and *Ae. taeniorhynchus*, established in 1957 and maintained free of insecticide exposure.

The field-collected species tested were *An. quadrimaculatus* and *Psorophora columbiae* (Dyar and Knab) from Stuttgart, AR. Battery powered aspirators with plastic holding tubes were used to collect specimens of *An. quadrimaculatus* from resting areas in a cattle barn in Stuttgart, AR. These collections were made in the early afternoon, returned to the laboratory in cooled insulated chests, and treated that afternoon. CDC traps baited with CO_2 were used to collect specimens of *Ps. columbiae* in the vicinity of rice fields adjacent to the experiment station. These traps were modified by the method described by Sandoski et al. (1983) to collect mosquitoes through openings below the fan. Collections were made between 1800 and 2200 hr. Specimens were stored in cooled insulated chests and the mosquitoes were supplied with sugar water in cotton pads placed on top of the collection cage. Tests were conducted the morning following collection.

Concentration-mortality data obtained in these tests were analyzed on a Hewlett-Packard Model 9810-A calculator with a probit analysis program written according to the procedures given by Finney (1971) to determine the LC_{50}, LC_{90} and 95% confidence limits.

RESULTS AND DISCUSSION

After the initial screening studies against *Ae. taeniorhynchus* indicated the potential of the pyrethroids as adulticides, additional laboratory studies were conducted to further define their effectiveness compared to the malathion standard. Toxicity data were also obtained for DDT and lindane. These data are presented in Table 1. Compared to the standard, the effectiveness of the pyrethroids ranged from ca. 5-29X at the LC_{50} level. However, at the LC_{90} level, the pyrethroids were less effective, ranging from ca. 2-14X compared to the standard.

These materials were also tested against laboratory-reared insecticide-susceptible and DDT-resistant strains of *An. quadrimaculatus*. These data are presented in Tables 2 and 3.

In the evaluations against the susceptible strain, the pyrethroids ranged from 14-118X more effective than malathion at the LC_{50} level.

Table 1. Toxicity of wind tunnel generated aerosols to laboratory insecticide-susceptible *Aedes taeniorhynchus* (95% confidence limits in parentheses).

Adulticide	LC-50 (μg/ml)	Reciprocal LC-50 ratio to malathion	LC-90 (μg/ml)	Reciprocal LC-90 ratio to malathion	Slope
DDT	1200 (1078–1378)	0.06	9000 (6942–12466)	0.02	0.6417
Lindane	175 (160–190)	0.4	660 (574–804)	0.3	0.9585
Malathion	72 (67–75)	—	200 (196–245)	—	1.2608
Sumitomo S-3206	15.0 (13.4–16.2)	5	74 (51–86)	3	0.8708
ICI PP 563	2.5 (2.3–2.8)	29	17.0 (15.1–19.9)	12	0.6719
Sumitomo S-2703	10.0 (9.1–11.5)	7	120 (85–182)	2	0.5228
FCR 1272	4.7 (4.3–5.1)	15	26.7 (22.8–31.9)	7	0.7384
FMC 54800	15.0 (13.5–16.0)	5	86 (74–104)	2	0.7248
FMC 54617	3.3 (3.0–3.7)	22	23 (20–28)	9	0.6618
ZR 3210	11.0 (9.9–11.5)	6	48 (42–56)	4	0.8510
Bayer NAK-1654	5.6 (5.3–6.0)	13	14.0 (12.8–16.5)	14	1.3657

Table 2. Toxicity of wind tunnel generated aerosols to laboratory insecticide-susceptible *Anopheles quadrimaculatus* (95% confidence limits in parentheses).

Adulticide	LC-50 (μg/ml)	Reciprocal LC-50 ratio to malathion	LC-90 (μg/ml)	Reciprocal LC-90 ratio to malathion	Slope
DDT	115 (108–122)	0.4	296 (263–343)	0.3	1.3506
Lindane	155 (148–165)	0.3	390 (342–462)	0.2	1.4045
Malathion	47 (45–50)	—	97 (89–107)	—	1.7895
Sumitomo S-3206	1.0 (0.9–1.1)	47	5.2 (4.1–7.1)	19	0.7760
ICI PP 563	0.5 (0.5–0.5)	95	1.6 (1.3–1.9)	60	1.1287
Sumitomo S-2703	0.9 (0.9–1.1)	53	5.0 (4.0–6.8)	19	0.7713
FCR 1272	0.4 (0.4–0.5)	118	1.4 (1.2–1.7)	69	1.0943
FMC 54800	0.4 (0.4–0.4)	118	0.7 (0.6–0.7)	138	2.3276
FMC 54617	1.1 (1.0–1.2)	43	3.1 (2.8–3.6)	31	1.2157
ZR 3210	2.1 (1.9–2.2)	22	6.3 (5.6–7.3)	15	1.1525
Bayer NAK-1654	3.3 (3.2–3.5)	14	5.9 (5.5–6.5)	16	2.2166

Table 3. Toxicity of wind tunnel generated aerosols to laboratory DDT insecticide-resistant *Anopheles quadrimaculatus* (95% confidence limits in parentheses).

Adulticide	LC-50 (μg/ml)	Reciprocal LC-50 ratio to malathion	LC-90 (μg/ml)	Reciprocal LC-90 ratio to malathion	Slope
DDT	43×10^4 (23×10^4–18×10^5)	8×10^{-5}	15.5×10^6 (3×10^6–78×10^6)	6.6×10^{-6}	0.3567
Lindane	165 (151–179)	0.2	555 (484–648)	0.2	1.0577
Malathion	36 (33–38)	—	103 (92–116)	—	1.2133
Sumitomo S-3206	5.3 (4.5–6.1)	7	31.5 (24.1–45.5)	3	0.2655
ICI PP 563	0.7 (0.6–0.8)	51	4.3 (3.4–5.9)	24	0.7229
Sumitomo S-2703	8.0 (7.3–8.8)	4	31.5 (26.9–38.5)	3	0.9388
FCR 1272	2.0 (1.8–2.2)	18	8.8 (7.3–11.1)	12	0.8757
FMC 54800	8.0 (7.4–8.7)	4	28.2 (24.5–33.7)	4	1.0192
FMC 54617	10.0 (9.3–10.9)	4	36.7 (31.2–44.8)	3	0.9895
ZR 3210	10.2 (9.4–11.0)	4	35.3 (30.3–42.7)	3	1.0285
Bayer NAK-1654	43.0 (40.2–45.9)	0.8	122.0 (108.3–141.1)	0.8	1.2302

Against the susceptible strain, malathion was ca. 2X and 3X more effective at the LC_{50} level than DDT and lindane, respectively.

When evaluated against the resistant strain, the effectiveness of the pyrethroids was lower, ranging from 1–51X more effective than malathion. Interestingly, malathion had a significantly lower LD_{50} level against the resistant strain than against the susceptible strain. Lindane, especially at the LC_{90} level, was not as effective against the resistant strain as malathion, since at this level malathion was about 5X more effective.

The resistance level of the resistant strain to DDT is at a point where DDT has become an inefficient insecticide. The LC_{50} and the LC_{90} values should be considered as estimates because they are based on low mortality levels. The highest concentration used in the discriminating dosage range was 10% (100 mg/ml). At higher levels (15–20%), incomplete solubility occurs. In addition, at these levels, the solvent evaporates when sprayed in the wind tunnel to the point that the target insects are exposed to solid particles rather than a solution and the tip of the spray nozzle becomes coated with the insecticide interfering with formation of the aerosol. At the concentrations of DDT that were tested, 100, 50 and 25 mg/ml, the respective percent mortalities were 30.7±3.0%, 21.3±2.3%, and 16±2.0%. Thus, extrapolation from these mortality levels by log-probit analysis indicates LC_{50} and LC_{90} concentrations that can be used for comparative purposes but cannot be accurately tested.

In tests against the field strain of *An. quadrimaculatus* (Table 4), the LC_{50} of malathion was 3.3×10^3 μg/ml and the LC_{90} was 52×10^3 μg/ml. These values represent increases of 26X and 5X, respectively, of the levels determined in 1980, and 50X and 24X increases, respectively, of the levels determined in 1978 (Roberts et al. 1980, 1982) for species collected from the same location.

The LC_{50} values of the pyrethroids were higher against the field strain than the laboratory susceptible strain, but six of these were lower than those for the laboratory resistant strain. When compared to the malathion LC_{50} in the field strain, the pyrethroids ranged from 184–1737X more effective. At the LC_{90} level, effectiveness of these pyrethroids compared to malathion ranged from 782–9557X.

Against the field strain, lindane was equivalent to malathion at the LC_{50} level, but was about 3X more effective at the LC_{90} level. The log probit values for DDT show a high degree of resistance to this insecticide in the field strain, but not to the degree shown by the laboratory resistant strain. However, the log probit values were more reliable for the field strain. At dosages of 100, 50, 25 and 10 mg/ml, the re-

Table 4. Toxicity of wind tunnel generated aerosols to field-collected females of *Anopheles quadrimaculatus* at Stuttgart, AR, 1982 (95% confidence limits in parentheses).

Adulticide	LC-50 (μg/ml)	Reciprocal LC-50 ratio to malathion	LC-90 (μg/ml)	Reciprocal LC-90 ratio to malathion	Slope
DDT	95×10^3 (79×10^3–121×10^3)	0.03	12×10^5 (7×10^5–24×10^5)	0.4	0.5024
Lindane	3.8×10^3 (3.5×10^3–4.2×10^3)	0.9	15×10^3 (13×10^3–18×10^3)	3.4	0.9497
Malathion	3.3×10^3 (2.9×10^3–3.9×10^3	—	52×10^3 (36×10^3–81×10^3)	—	0.4671
Sumitomo S-3206	8.2 (7.3–9.0)	402	42.3 (36.5–50.6)	1220	0.7788
ICI PP 563	1.9 (1.8–2.1)	1736	7.9 (6.7–9.6)	6533	0.9003
Sumitomo S-2703	3.8 (3.6–4.2)	868	18.1 (15.2–22.3)	2851	0.8290
FCR 1272	1.9 (1.7–2.0)	1737	5.4 (4.8–6.2)	9557	1.2063
FMC 54800	1.9 (1.6–2.1)	1737	13.4 (10.0–20.2)	3851	0.6455
FMC 54617	5.6 (5.1–6.0)	589	21.3 (17.5–27.7)	2423	0.9519
ZR 3210	7.6 (6.8–8.5)	434	66.0 (51.6–88.8)	782	0.5914
Bayer NAK-1654	17.9 (16.9–18.8)	184	43.5 (40.0–47.9)	1186	1.4414

spective mortalities were 48.2±2.4%, 39.1±10.1%, 28.0±4.0% and 10.7±2.3%.

The data for the evaluation of the adulticides against the field strain of *Ps. columbiae* are presented in Table 5. Malathion was more effective against this species than against the field strain of *An. quadrimaculatus*. Compared to previous tests with *Ps. columbiae*, the malathion LC_{50} level is 4X that found in 1980 and equivalent to that found in 1978, while the LC_{90} level was about 2X and 1X, respectively, for these years (Roberts et al. 1980, 1982). This indicated that little resistance to malathion has developed in the population. Additional testing over several additional years will be needed to determine if resistance is developing in the population. The pyrethroids were highly effective against this species, ranging from 7-139X at the LC_{50} level and 5-162X at the LC_{90} level, compared to malathion.

Malathion was about 5X more effective against *Ps. columbiae* than lindane and about 11X more effective than DDT. While the LC_{50} levels are not of the same magnitude as found for *An. quadrimaculatus*, it appears that there is resistance to these two adulticides, but lack of comparative data from previous years prevents any estimate of the development of resistance.

In comparing the LC_{50} levels of the pyrethroids, there appears to be some correlation to these levels and those of DDT. In the three strains of *An. quadrimaculatus* studied, there is a wide range in response to DDT. The laboratory susceptible strain is the least, the laboratory resistant strain is the greatest, while the field strain is intermediate in response to DDT. Also, while the field strain shows resistance to lindane and malathion, the laboratory resistant strain is of the same magnitude of response as the laboratory susceptible strain.

The LC_{50} values of 7 of the 8 pyrethroids were increased by factors of 5-20X when tested against the laboratory resistant strain as compared to the laboratory susceptible strain of *An. quadrimaculatus*. When tested against the field strain of *An. quadrimaculatus*, the LC_{50} values of S-2703, FMC 54800, FMC 54617 and NAK-1654 were intermediate to those for the laboratory strains. FCR 1272 and ZR 3210 were not significantly different, and S-3206 was significantly larger than the LC_{50} values of the laboratory resistant strains. One compound, PP 563, had a significantly greater LC_{50} value against the field strain than those values for both the laboratory strains. Thus, there appears to be an effect of resistance to DDT and possibly to lindane and malathion on the efficacy of the pyrethroids tested in this study.

References Cited

Chadwick, P. R., J. F. Invest and M. J. Bowron. 1977. An example of cross-resistance to pyrethroids in DDT-resistant *Aedes aegypti*. Pestic. Sci. 8:618–624.

Table 5. Toxicity of wind tunnel generated aerosols to field-collected females *Psorophora columbiae* at Stuttgart, AR, 1982 (95% confidence limits in parentheses).

Adulticide	LC-50 (μg/ml)	Reciprocal LC-50 ratio to malathion	LC-90 (μg/ml)	Reciprocal LC-90 ratio to malathion	Slope
DDT	1380 (1240–1508)	0.09	5080 (4447–5982)	0.09	0.9818
Lindane	597 (556–642)	0.2	1820 (1563–2217)	0.2	1.1471
Malathion	125 (116–134)	—	439 (389–506)	—	1.0186
Sumitomo S-3206	9.3 (8.5–10.1)	13	36.5 (30.8–45.3)	12	0.9336
ICI PP 563	1.3 (1.2–1.3)	96	2.8 (2.6–3.1)	157	1.6012
Sumitomo S-2703	6.5 (6.0–7.1)	19	26.6 (22.8–32.4)	16	0.9138
FCR 1272	3.4 (3.1–3.7)	37	11.0 (9.7–12.9)	40	1.0925
FMC 54800	0.9 (0.8–1.0)	139	2.7 (2.4–3.1)	163	1.1707
FMC 54617	5.7 (5.4–6.1)	22	16.9 (14.6–20.1)	26	1.1895
ZR 3210	17.3 (15.9–18.8)	7	88.5 (77.1–103.8)	5	0.7859
Bayer NAK-1654	13.4 (13.0–13.8)	9	21.1 (20.1–22.4)	21	2.8023

Finney, D. J. 1971. Probit analysis. 3rd edition, Cambridge University Press. 333 pp.

Mount, G. A., N. W. Pierce and K. F. Baldwin. 1976. A new wind-tunnel system for testing insecticidal aerosols against mosquitoes and flies. Mosq. News 36:127–131.

Prasittisuk, C. and J. R. Busvine. 1977. DDT-resistant mosquito strains with cross-resistance to pyrethroids. Pestic. Sci. 8:527–533.

Roberts, R. H., K. F. Baldwin, J. L. Pinson, T. W. Walker and M. V. Meisch. 1980. Effectiveness of nine pyrethroids against *Anopheles quadrimaculatus* Say and *Psorophora columbiae* (Dyar and Knab) in Arkansas. Mosq. News 40:43–46.

Roberts, R. H., M. V. Meisch and C. Sandoski. 1982. Wind tunnel evaluation of new compounds as adulticides against two species of mosquitoes found in rice fields. Mosq. News 42:217–219.

Rongisriyam, Y. and J. R. Busvine. 1975. Cross-resistance in DDT-resistant strains of various mosquitoes (Diptera, Culicidae). Bull. Entomol. Res. 65:459–471.

Sandoski, C. A., M. V. Meisch, D. A. Case and J. K. Olson. 1983. Effects of collection and handling techniques on riceland mosquitoes used in laboratory and field insecticide susceptibility tests. Mosq. News 43:445–448.

Wilson, H. G., G. C. LaBrecque, D. E. Weidhaas and J. B. Gahan. 1972. Comparison of susceptible and DDT-resistant mosquito colonies to insecticides. Mosq. News 32:215–218.