Pyrethroid Resistance and Synergism in a Field Strain of the German Cockroach (Dictyoptera: Blattellidae)

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ABSTRACT A field-collected strain of the German cockroach, *Blattella germanica* (L.), was highly resistant to 10 pyrethroid insecticides (cyfluthrin, cyhalothrin, cypermethrin, fenvalerate, esfenvalerate, fluvalinate, permethrin, resmethrin, sumithrin, tralomethrin) based on topical applications and comparison with a known susceptible strain. Resistance ratios ranged from 29 to 337. In general, pyrethroid compounds with an alpha-cyano functional group were more toxic than those lacking this moiety, but resistance ratios were similar for both classes of compound. The metabolic inhibitors DEF and PBO were tested for synergism in conjunction with cypermethrin (alpha-cyano) and permethrin (non alpha-cyano). Application of synergists resulted in partial elimination of resistance, suggesting that the basis of resistance involves enhanced metabolism as well as target site insensitivity. These results suggest that pyrethroid insecticides may have a very short functional life in German cockroach control unless they are used judiciously.

KEY WORDS Insecta, *Blattella germanica*, pyrethroids, resistance

DEVELOPMENT OF RESISTANCE to pesticides is one of biggest concerns in household and structural pest control. The German cockroach, *Blattella germanica* (L.), is the species with greatest resistance problems in this area (Cochran 1987, 1989; Scott et al. 1990; Rust & Reierson 1990). Because of its preeminence as a household pest, tremendous amounts of pesticides are applied for its control across the country, both by homeowners and professional pest control companies. Most populations of German cockroaches are isolated within buildings, although there is probably constant passive dispersal at low levels between structures. The combination of insecticide pressure and isolated populations can result in rapid development of resistance. The ability of German cockroaches to disperse by "hitchhiking" with movement of persons, goods, and vehicles ensures that once resistance develops, it can spread rapidly.

Pyrethroids are one of the latest groups of insecticidal compounds registered for residential and commercial use against the German cockroach (Koehler & Patterson 1988); chemicals in this class are gaining increasing acceptance among professional pest control operators (Fisher 1990, Robinson & Zhai 1990). Scattered incidences of pyrethrins and pyrethroid resistance in field populations have been observed at relatively low levels, but this is much less common than resistance to organophosphate and carbamate insecticides (Cochran 1987, 1989, Scott et al. 1990, Rust & Reierson 1991). Robinson & Zhai (1990) recently described a case history in which control failure with cypermethrin was observed within a few years after initially good results. Published studies on physiology of pyrethrins and pyrethroid resistance in German cockroaches were based on strains with low levels of resistance (Scott & Matsumura 1981, 1983).

In late 1987, a local pest control operator found that cypermethrin no longer gave adequate control in an apartment in a complex that he serviced regularly. The operator had been using this pesticide regularly for several years before the control failure. Increased doses failed to affect the population. Our objectives in this study were to characterize the resistance profile of this field-collected strain to cypermethrin and other pyrethroids and to examine the effects of possible synergists on this resistance.

Materials and Methods

The resistant field strain (Village Green) of German cockroaches was colonized from an infested apartment in Gainesville, Fla. in 1988. Susceptible cockroaches were from the Orlando Normal strain, which has been in continuous culture in the USDA–ARS Laboratory in Gainesville since 1947. The Orlando Normal strain is susceptible to a wide variety of pesticides (Milio et al. 1987, Wadleigh et al. 1989). Colonies were reared at 25°C at 50% RH with a 12:12 (L:D) photoperiod. The colony diet

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Table 1. Toxicity of pyrethroid insecticides to two strains of German cockroaches at 26°C

Toxicant	Strain	No. insects	No. doses	Slope	±SE	Doses[a]					Resistance ratios[b]
						Min	Max	LD_{50}	95% CL		
Cyfluthrin	Orlando	110	4	9.43	4.86	0.12	0.18	0.16	0.15	0.18	—
	Field	120	4	8.77	8.76	12.43	15.99	14.21	13.15	15.63	87.5
Cyhalothrin	Orlando	150	5	6.10	1.10	0.08	0.16	0.09	0.08	0.10	—
	Field	120	4	5.29	1.48	3.55	5.33	3.85	2.72	4.28	40.6
Cypermethrin	Orlando	110	4	10.11	1.29	0.41	0.61	0.39	0.30	0.43	—
	Field	150	5	3.99	0.47	21.32	44.41	40.68	35.53	55.42	103.6
Fenvalerate	Orlando	120	4	11.34	1.65	1.23	2.05	1.13	0.87	1.23	—
	Field	150	5	6.63	0.68	106.58	177.64	110.31	91.13	120.97	97.7
Esfenvalerate	Orlando	150	5	9.84	0.71	0.25	0.51	0.28	0.25	0.30	—
	Field	120	5	5.07	0.61	7.11	14.21	8.17	6.75	9.06	29.4
Fluvalinate	Orlando	120	4	8.12	0.62	1.64	8.18	2.65	2.38	3.01	—
	Field	120	4	4.59	0.81	888.18	1,421.09	893.15	523.31	1,021.23	337.2
Permethrin	Orlando	120	4	21.89	2.64	3.07	3.58	3.06	2.82	3.17	—
	Field	120	4	15.31	1.31	124.34	177.64	137.85	130.92	143.53	45.1
Resmethrin	Orlando	150	5	7.59	0.54	4.09	8.18	5.07	4.62	5.45	—
	Field	120	4	3.45	0.42	355.27	888.18	520.47	416.56	610.53	102.6
Sumithrin	Orlando	140	5	14.40	1.00	5.62	8.18	6.66	6.36	6.91	—
	Field	120	4	6.02	0.96	710.54	1,065.81	757.44	603.25	828.85	113.8
Tralomethrin	Orlando	150	5	4.69	0.09	0.16	0.41	0.17	0.14	0.19	—
	Field	150	5	7.63	0.98	12.43	35.53	12.26	9.59	13.50	72.2

[a] Doses in ng/mg body weight.
[b] LD_{50} resistant strain/LD_{50} susceptible strain.

was Purina rodent chow. Live weights of male cockroaches from the Village Green and Orlando strains were 53.1 mg ± 0.6 mg ($\bar{x}$ ± SD), (n = 44) and 48.8 mg ± 0.3 mg, (n = 40), respectively.

Topical applications of insecticides were made to the first abdominal sternite of male cockroaches that had been anesthetized with CO_2. Toxicants were dissolved in acetone and applied in 1-μl droplets. Cockroaches were subsequently held in plastic Petri dishes for 24 h at 26°C in a water-jacketed environmental chamber at ≈50% RH before evaluating mortality. Groups of 10 males were treated with each concentration on a given date for each toxicant. Experiments were repeated at least three times. Topical applications were made on the Orlando strain from December 1988 to March 1989 and on the Village Green strain from July 1989 until December 1989. Toxicity of cypermethrin to the field strain, initially tested in July 1989, was retested in March 1990 to check for modification of resistance after colonization in the laboratory.

The following technical grade insecticides were tested: cyfluthrin (94%, Mobay, Kansas City, Mo.), cyhalothrin (95%, ICI Americas, Goldsboro, N.C.), cypermethrin (92.81%, ICI Americas), fenvalerate (96%, Fermenta Corp., Kansas City, Mo.), esfenvalerate (82.5%, MGK Co., Minneapolis, Minn.), fluvalinate (90%, Zoecon Corp., Dallas, Tex.), permethrin (94.33%, Fairfield American Corp., Medina, N.Y.), resmethrin (23.8/76.2% *cis/trans* isomers, Roussell-Bio, Lincoln Park, N.J.), sumithrin (90% MGK Co.), and tralomethrin (96%, Roussell-Bio).

Piperonyl butoxide (PBO, 100%, MGK), a microsomal monooxygenase inhibitor, and *s,s,s*-tributyl phosphorothioate (DEF, 99%, Mobay), an esterase inhibitor, were applied in combination with cypermethrin and permethrin to both strains to test for synergism in April 1990. Synergists were applied in 1-μl drops to the venter of the first abdominal segment 2 h before topical application of the toxicants. PBO and DEF were applied at concentrations of 100 and 30 μg per insect, respectively.

Data were analyzed using probit analysis following the method of Finney (1971). All regressions were estimated from the responses of at least 110 cockroaches and four doses giving >0 and <100% mortality.

Results

High levels of resistance were observed in the Village Green strain to all pyrethroids tested, with resistance ratios ranging from 29.4 for esfenvalerate to 337.2 for fluvalinate (Table 1). In general, compounds with an alpha-cyano moiety (cyfluthrin, cyhalothrin, cypermethrin, fenvalerate, esfenvalerate, fluvalinate, tralomethrin) were more toxic to both strains than those lacking it (permethrin, resmethrin, sumithrin) by almost an order of magnitude. Toxicity of fluvalinate, an alpha-cyano compound, was the exception, its toxicity was much lower than for other similar insecticides. Resistance ratios for compounds with the alpha-cyano group were within the same range as for those lacking the moiety. The Village Green strain had higher resistance ratios to all pyrethroids tested than have been reported previously from any field-collected strain by topical application (Scott & Matsumura 1983, Scott et al. 1986, Scott et al. 1990). High resistance ratios have been reported on the basis of timed exposure to pesticidal residues (e.g., Cochran

Table 2. Effects of two metabolic synergists on toxicity of cypermethrin and permethrin to two strains of German cockroaches

Toxicant	Strain	No. insects	No. doses	Slope	±SE	Doses[a]					Synergist ratio[b]	Synergized resistance ratio[c]
						Min	Max	LD_{50}	95% CL			
Cypermethrin + pbo	Orlando	120	4	7.09	0.62	0.31	0.61	0.43	0.41	0.47	0.91	—
Cypermethrin + def	Orlando	120	4	4.71	0.58	0.31	0.61	0.33	0.27	0.39	1.19	—
Permethrin + pbo	Orlando	120	4	3.71	0.48	2.05	5.11	4.91	4.09	7.16	0.62	—
Permethrin + def	Orlando	120	4	6.35	0.50	2.05	5.11	3.07	2.66	3.27	1.00	—
Cypermethrin + pbo	Field	120	4	2.35	0.40	14.21	35.53	16.17	8.35	20.61	2.52	4.14
Cypermethrin + def	Field	120	4	2.63	0.41	14.21	35.53	15.28	8.53	18.83	2.66	39.2
Permethrin + pbo	Field	120	4	4.46	0.57	53.29	106.58	89.88	79.58	109.78	1.53	29.4
Permethrin + def	Field	150	5	3.80	0.34	35.53	106.58	84.20	73.72	101.61	1.64	27.5

[a] Doses in ng/mg body weight.
[b] LD_{50} toxicant/LD_{50} toxicant + synergist.
[c] LD_{50} toxicant + synergist, resistant strain/LD_{50} susceptible strain.

1989), but his results are not directly comparable with ours because of the different methods of pesticide exposure. Studies on resistance of German cockroaches to pyrethroid (Scott et al. 1986) and organophoshate insecticides (Milio et al. 1987) have shown large discrepancies between resistance ratios determined by topical applications and timed exposures to treated surfaces.

Slopes of the regression lines for Village Green strains were significantly lower than those of the Orlando strain for a given toxicant (based on failure of 95% CI to overlap), indicating greater heterogeneity in the field strain. The relative homogeneity of the Orlando strain may be attributable to >40 yr of laboratory culture. The Village Green strain has not been exposed to pyrethroid insecticides for almost 2 yr that it has been in laboratory culture. Nonetheless, based on periodic tests with cypermethrin, resistance has not noticeably diminished. This suggests that the genetic basis for pyrethroid resistance is fixed in the population or that resistant genes do not have deleterious effects under laboratory conditions.

Synergists did not significantly modify susceptibility of Orlando strain, suggesting low levels of activity by the detoxification systems inhibited by these compounds (Table 2). In all cases in their susceptible strain, Scott et al. (1990) found that PBO and DEF did not synergize pyrethroid toxicity. In the Village Green strain, addition of synergists increased susceptibility but did not eliminate resistance entirely. Treatment with PBO and DEF decreased resistance to cypermethrin from 104-fold to 41- and 39-fold with respect to the susceptible strain (Table 2, synergized resistance ratio), respectively. PBO and DEF decreased resistance to permethrin from 45-fold to 29- and 28-fold, respectively.

Discussion

Cypermethrin is the first widely used pyrethroid pesticide for German cockroach control by professional pest control operators and has been available for <5 yr. Other pyrethroid compounds are now available both for professional use and as consumer products for household use. Because of resistance problems with other classes of pesticides, high expectations have been generated for this class of compounds. Pyrethroids are also considered attractive because of rapid activity and low odor.

The Village Green strain shows high resistance to all pyrethroid pesticides tested, including older compounds such as resmethrin and newer compounds with the alpha-cyano functional group. Resistance ratios observed in this strain are higher than any that have previously been reported based on topical applications (Scott & Matsumura 1983, Scott et al. 1986, Scott et al. 1990). The Village Green strain was also more resistant in absolute terms than strains studied by these authors for specific pesticides (permethrin, cypermethrin, cyfluthrin). Not only are resistance ratios high with respect to other cases of pyrethroid resistance, they are higher than resistance ratios for most other classes of compounds used against German cockroaches (Milio et al. 1987, Wadleigh et al. 1989, Scott et al. 1990, Rust & Reierson 1991). Natural pyrethrins have been used against German cockroaches for control and as flushing agents for decades, but their use has been limited by comparison with chlorinated hydrocarbon, organo-phosphate, and carbamate pesticides during the same period. Scott & Matsumura (1981, 1983) showed that there was some cross-resistance between DDT resistance and pyrethroid resistance in German cockroaches. Previous exposure to pyrethrins or DDT may have been the basis for the rapid development of pyrethroid resistance in this strain.

The high levels of resistance, combined with the partial suppression of resistance by application of PBO and DEF, suggests two resistance mechanisms: target site insensitivity and increased metabolism. Previous work by Scott & Matsumura (1981, 1983) on pyrethroid resistance indicated that the physiological basis of resistance in their Ger-

man cockroach strain was probably a *kdr*-like mechanism. Enhanced metabolism is also a pyrethroid resistance mechanism in German cockroaches. Resistance in some strains is suppressed by metabolic inhibitors (Salleh 1980, Scott et al. 1990), and increased pyrethroid metabolism has been demonstrated in others (Salleh 1980).

In previous cases of resistance to organophosphates or carbamates, continued control is still feasible by increasing rates or by the addition of synergists. High levels of resistance to all pyrethroids tested here combined with the lack of synergism indicates that the whole class of compounds is ineffective against this strain. If this type of resistance becomes widespread, an entire class of compounds may be rendered useless in a short time if resistance management is not practiced.

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