Residual Effectiveness of Insect Growth Regulators Applied to Carpet for Control of Cat Flea (Siphonaptera: Pulicidae) Larvae

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ABSTRACT Three insect growth regulators, fenoxycarb, methoprene, and pyriproxyfen, formulated as total release aerosols, were tested for their residual effectiveness on carpet in bioassays with cat flea, *Ctenocephalides felis* (Bouché),,larvae. All treatments except methoprene produced significant mortality for the 7-mo duration of the test. In general, fenoxycarb and the higher rates of pyriproxyfen reduced adult flea emergence by >80%.

KEY WORDS *Ctenocephalides felis*, cat flea, insect growth regulator

INSECTICIDES THAT ARE currently used as household or outdoor treatments for cat fleas, *Ctenocephalides felis* (Bouché), are usually applied for residual control. Burden and Smittle (1968) developed laboratory bioassays to evaluate residual efficacy of chlorinated hydrocarbon, organophosphate, and carbamate insecticides on filter paper. Those bioassays indicated that chlorpyrifos, diazinon, and malathion could provide >90% mortality of adult oriental rat flea, *Xenopsylla cheopis* (Rothschild), for >24 wk. Silverman et al. (1980) demonstrated >87% mortality of cat flea larvae exposed on filter paper with 3-wk-old deposits of several organophosphate and carbamate insecticides. Goose (1980) showed that filter paper residues of bendiocarb gave 16 wk of 100% mortality of exposed oriental rat fleas. These laboratory assays predicted that the traditional pulicides could provide weeks to months of effective control of fleas.

However, tests of insecticides applied to surfaces such as carpet or soil have provided more variable results. Rust and Reierson (1988) reported that residues of chlorpyrifos, propetamphos, permethrin, diazinon, malathion, and carbaryl applied to nylon carpet provided >90% kill of adult cat fleas for >21 d. Vacuuming and simulated wear did not significantly affect residual activity. Microencapsulated pyrethrins applied to carpeting, or to wood or tile flooring, provided an average of 95% control at 30 d (Bennett and Lund 1977). However, Koehler et al. (1986), working with a known insecticide-resistant strain of the cat flea, found that seven insecticides registered for cat flea control on carpet provided significant mortality for only 1–7 d. Osbrink et al. (1986) similarly found that carpet treated with insecticides, then aged for 24 h, failed to provide adult mortality when fleas were confined on the treatments for 24 h, and lost all activity when tested at day 7. These tests indicated that it is more difficult to control fleas on carpet than on filter paper.

Although insect growth regulators are active in laboratory assays, their performance in field situations is likely dependent on both the surfaces to which they are applied and environmental conditions (Henderson and Foil 1993). The objective of our study was to determine the residual activity of three insect growth regulators, fenoxycarb, methoprene, and pyriproxyfen, applied to carpet.

Materials and Methods

Insecticides. Five rates of pyriproxyfen (MGK, Minneapolis, MN) (0.15, 0.075, 0.05, 0.025, and 0.01% [AI]) were used as 0.18-liter total release aerosols. These were compared with two standard total release aerosol formulations containing fenoxycarb (Raid Max Fogger, 0.18 liter; S.C. Johnson & Son, Racine, WI; 0.60% fenoxycarb, 0.50% pyrethrins, 1.00% piperonyl butoxide, 1.67% N-octyl bicycloheptene dicarboximide) and methoprene (Black Flag Flea Ender, 0.15 liter; Boyle-Midway Household Products, New York; 0.075% [S]-methoprene, 1.0% propoxur, 0.47% DDVP, 0.03% related compounds).

Fleas. Larvae (48 h old) were obtained from a laboratory colony of cat fleas. Eggs were collected from trays beneath caged cats, which had been infested with adult fleas, and held in a rearing room

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(27°C, 80% RH) until eclosion. Larvae were maintained on powdered bovine blood until 2 d after hatching and then sieved (Tyler equivalent 16 mesh) and separated for testing. Under these conditions, the majority of larvae were in the second instar 48 h after eclosion (see Moser 1989).

Treatment Procedure. Medium-weight, light-colored nylon jute-backed carpet (1.6-cm-long strands, 36 multifiber strands per square centimeter) (Master's Touch, Shaw, Dalton, GA) was cut into 6.45-cm^2 squares. Groups of 35 squares (225.75 cm^2) were affixed to paper, closely appressed to simulate a solid piece of carpet.

Each group of carpet samples was exposed to a different total release aerosol containing one of the insect growth regulators to be tested. Applications were made in empty apartments (≈104 m^3). The carpet was placed 1 m from the aerosol can, and the aerosol was released as per the label by depressing the sprayer tab. All personnel vacated the room, which was left closed for 2 h, then aired for 1 h. The groups of carpet samples were retrieved, brought to the laboratory, and stored in three separate rooms (based on insect growth regulator treatment). In addition to these seven treatments, a subsample of carpet was left untreated and served as the control. Assuming complete and uniform dispersal of the aerosols, the amounts of active ingredient per carpet sample were as follows: pyriproxyfen: 0.01%, 0.39 mg/m^2; 0.025%, 0.96 mg/m^2; 0.05%, 1.92 mg/m^2; 0.075%, 2.89 mg/m^2; 0.15%, 5.78 mg/m^2; fenoxycarb: 0.60%, 23.09 mg/m^2; and methoprene: 0.075%, 2.41 mg/m^2.

Bioassays. The bioassay was conducted by infesting the squares (6.45 cm^2) of treated carpet with cat flea larvae. Carpet squares were placed on sand (1.5-cm depth) in waxed paper cups (7.3-cm diameter, 4.5-cm height). Each square was embedded in sand up to the base of the carpet fibers. Powdered bovine blood (0.02 g) was placed in the center of each square and seeded with ten 2-d-old larvae (five replicates of each treatment). Each cup was covered with muslin secured with a rubber band and held in a room with temperature and humidity controlled at 27°C and 80% RH for 30 d.

Fleas were then stimulated for adult emergence by exposure to CO_2 and shaking (El-Gazzar et al. 1986), frozen, and the numbers of successfully emerged adults were counted; mortality was determined by failure of adult emergence. Carpets were sampled at monthly intervals for 7 mo, i.e., until all samples had been used. Five replicates of each treatment or control were tested per month.

Statistical Analysis. The mean number of adult fleas emerging per treatment was analyzed by analysis of variance (ANOVA) (SAS Institute 1988), and monthly treatment means were separated using Tukey's Studentized range test ($P = 0.05$ [SAS Institute 1988]). Results are presented as percentage survival of fleas to adult emergence. Mortality data in pyriproxyfen treatments were corrected using Abbott's (1925) formula and analyzed by probit

Table 1. Residual effectiveness of insect growth regulators on carpet ($n = 5$)

Treatment	% ± SEM survival at month after treatment						
	1	2	3	4	5	6	7
Control	70.0 ± 4.5a	80.0 ± 6.3a	74.0 ± 2.5a	90.0 ± 7.7a	94.0 ± 4.0a	66.0 ± 6.0ab	90.0 ± 3.2a
Fenoxycarb (0.6%)	0 ± 0b	4.0 ± 4.0c	2.0 ± 2.0d	10.0 ± 5.5cd	22.0 ± 10.7c	4.0 ± 4.0d	0 ± 0d
Methoprene (0.075%)	0 ± 0b	38.0 ± 8.0b	52.0 ± 10.7ab	48.0 ± 5.8b	70.0 ± 3.2ab	68.0 ± 3.7a	70.0 ± 7.1a
Pyriproxyfen (0.01%)	6.0 ± 4.0b	18.0 ± 5.8bc	30.0 ± 3.2bc	18.0 ± 7.3bc	42.0 ± 5.8bc	28.0 ± 7.3bc	30.0 ± 5.5b
Pyriproxyfen (0.025%)	2.0 ± 2.0b	10.0 ± 4.5bc	30.0 ± 6.3bc	16.0 ± 5.1bc	18.0 ± 4.9c	24.0 ± 6.8c	22.0 ± 8.0bc
Pyriproxyfen (0.05%)	0 ± 0b	18.0 ± 3.7bc	10.0 ± 0cd	4.0 ± 2.4cd	14.0 ± 7.4c	2.0 ± 2.0d	10.0 ± 4.5bcd
Pyriproxyfen (0.075%)	0 ± 0b	18.0 ± 6.6bc	4.0 ± 2.4d	0 ± 0d	16.0 ± 8.1c	4.0 ± 4.0d	4.0 ± 2.4cd
Pyriproxyfen (0.15%)	0 ± 0b	20.0 ± 5.5bc	4.0 ± 4.0d	0 ± 0d	14.0 ± 5.1c	2.0 ± 2.0d	2.0 ± 2.0d

Means within a column followed by the same letter are not significantly different ($P = 0.05$; Tukey's Studentized range test [SAS Institute 1988]).

Table 2. Estimated LC_{50} rates of pyriproxyfen residues aged on carpet over 7 mo

Month	n	Slope ± SEM	LC_{50}[a] (95% CI)	χ^2
1	250	1.989 ± 0.245	0.00223 (0.00023–0.00452)	1.303
3	250	1.405 ± 0.173	0.00932 (0.00002–0.02160)	14.587
5	250	1.378 ± 0.127	0.00744 (0.00344–0.01078)	1.725
6	250	1.662 ± 0.207	0.00905 (0.00001–0.02029)	17.042
7	250	1.373 ± 0.087	0.00565 (0.00288–0.00852)	3.494

[a] LC_{50} expressed as a percentage.

analysis (Finney 1971) to determine LC_{50} values for each month. Significant differences were determined by nonoverlap of 95% CI. These data were also analyzed for each tested rate to determine the age of pyriproxyfen residue that would give 50% mortality of exposed larvae (LT_{50}).

Results and Discussion

Survival of cat flea larvae in all insect growth regulator treatments was significantly lower than in the control 1 and 2 mo after treatment (Table 1). Control survival was 66–94% over the 7-mo period. El-Gazzar et al. (1986) reported 85–94% pupation from larval cat flea medium. Perhaps carpet reduces larval survival compared with sand (El-Gazzar et al. 1986) or filter paper (Silverman et al. 1980) because of abrasion or volatile chemicals remaining from carpet manufacture.

Larval survival in the fenoxycarb treatments was significantly (F = 17.57; df = 7, 32; P = 0.0001) different from control survival for the 7 mo of the test. Survival ranged from 0 to 22%, with 0% at 1 and 7 mo. Survival was highest at 5 mo, with 22%.

Survival of fleas exposed to methoprene ranged from 0% at 1 mo to 70% at 5 and 7 mo. Survival of fleas on methoprene-treated carpet was significantly lower (F = 119.41; df = 7, 32; P = 0.0001 and F = 17.57; df = 7, 32; P = 0.0001) than survival of control fleas at 1 and 2 mo. However, by the third month, survival in the methoprene treatment was not significantly different from that in the control treatment.

Fenoxycarb and methoprene have comparable toxicities in laboratory tests (El-Gazzar et al. 1986), but performed differently in this test on carpet. One reason may be that the tested rate of fenoxycarb was 8-fold that of methoprene.

Percentage survival of fleas exposed to the lowest rate of pyriproxyfen (0.01%) ranged from 6% at 1 mo to 42% at 5 mo. At 0.025%, survival ranged from 2% at 1 mo to 30% at 3 mo; for 0.05%, survival ranged from 0% at 1 mo to 18% at 2 mo; for 0.075%, survival ranged from 0% at 1 and 4 mo to 18% at 2 mo; and for the high rate of 0.15%, survival ranged from 0% at 1 and 4 mo to 20% at 2 mo.

Table 3. Estimated age of pyriproxyfen residues to produce 50% mortality of exposed flea larvae

Pyriproxyfen rate	n	Slope ± SEM	LT_{50}[a] (95% CI)	χ^2
0.01%	350	1.096 ± 0.179	10.570 (infinite)	24.7
0.025%	350	1.110 ± 0.264	18.334 (infinite)	44.2

[a] Duration in months.

Monthly LC_{50} rates of pyriproxyfen ranged from 0.00225% at 1 mo to 0.00932% at 3 mo. There were no significant differences in pyriproxyfen LC_{50} values of any of the months (Table 2) based on overlap of 95% CI, indicating that the lowest rate tested (0.01% pyriproxyfen) killed >50% of exposed larvae up to 7 mo after treatment. The LT_{50} value revealed that the lowest rate of pyriproxyfen (0.01%) had a half-life of 10.6 mo; that of the next rate, 0.025%, was >18 mo (Table 3). The estimated persistence at the rates tested is likely longer than the 7-mo duration of the test.

Although the tested rate of methoprene (0.075%) was within the same range as the pyriproxyfen rates, results with methoprene were not comparable with those of the other insect growth regulators. Although other insect growth regulators have been investigated for their volatility (Atkinson et al. 1992), methoprene is the only one known to translocate or move from the point of application (Donahue and Young 1992). Thus, the small carpet sample we used probably acted as a point-source dispenser of methoprene for the entire room in which it was stored, with methoprene continually diffusing from it, attempting to achieve equilibrium.

These results indicate that fenoxycarb and pyriproxyfen have extended residual activity when applied to carpet. The long residual of insect growth regulators on carpet is in contrast to the results obtained with the traditional organophosphate and carbamate insecticides tested on carpet, where most compounds gave acceptable control for <2 mo (Koehler et al. 1986, Rust and Reierson 1988). Rust and Reierson (1988) found that, in general, the trend of insecticide efficacy against adult cat fleas was organophosphates > carbamates = synergized pyrethrins > pyrethroids, but Koehler et al. (1986) found that of the seven insecticides they tested, only microencapsulated diazinon (1.0%) and chlorpyrifos (0.5%) provided mortality that was significantly higher than that in the untreated control 3 wk after treatment. Osbrink et al. (1986) found only limited (52–63%) residual activity on 1-d-old deposits of the five adulticides they tested,

and no activity when the deposits were tested at day 7.

Carpeting, although the most common surface treated for flea control, is perhaps the most difficult substrate to treat effectively with an insecticide (Koehler et al. 1986, Byron 1987). Carpet has been described as a refuge for fleas in which they may avoid exposure to an insecticide (Osbrink et al. 1986). The increased surface area of the carpet matrix prevents penetration of insecticides into the nap and reduces the active ingredient per unit area (Rust and Reierson 1988, Anonymous 1990). The prolonged residual activity of the insect growth regulators in our study provides an effective alternative to organophosphate and carbamate insecticides.

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