Toxicity of Abamectin to Cockroaches (Dictyoptera: Blattellidae, Blattidae)

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ABSTRACT Abamectin was fed to German cockroaches, *Blattella germanica* (L.), in non-choice tests. LT_{50} and LC_{50} were estimated by probit analysis. The LT_{50} for the German cockroach ranged from 4.4 to 1.7 d for males, from 9.0 to 2.4 d for females, and from 4.4 to 1.6 d for nymphs for bait concentrations of abamectin between 0.0025 and 0.0500%. The LC_{50} of abamectin were 0.0110 and 0.0040% from males, 0.0240 and 0.0090% for females, and 0.0200 and 0.0080% for nymphs at 3 and 6 d, respectively. The LT_{50} values of 0.0550% abamectin bait were 3.4, 3.4, 2.4, 7.5, 2.9, and 4.5 d for *Periplaneta americana* (L.), *P. fuliginosa* (Serville), *P. brunnea* Burmeister, *P. australasiae* (F.), *Blatta orientalis* L., and *Supella longipalpa* (Serville). Although the bait was effective against various cockroach species, time to death for the larger species was longer than for the German cockroach. In preference tests in which male German cockroaches were allowed to feed on rat chow or abamectin bait, all died within 5 d of exposure to abamectin bait. Abamectin bait consumption was not significantly lower than that of untreated rat chow. Arena tests with 0.0550% abamectin bait resulted in 31-75% mortality of German cockroaches after 9 d, with most control being achieved by treating harborages with the bait. The hydramethylnon standard resulted in 65% mortality after 9 d.

KEY WORDS Insecta, abamectin, insecticide, bait

INSECTICIDAL BAITS have become one of the most effective and commonly used methods of cockroach control, particularly in over-the-counter products. Compared with residual sprays, baits offer the advantage of long residual activity, safe application within child-proof containers, and reduced odor (Cornwell 1976). The active ingredients used in baits can include compounds like hydramethylnon and abamectin, which have poor contact activity but are very active as stomach poisons (Rust 1986). Because baits can be placed in containers, insecticides that stain (e.g., hydramethylnon has a yellow color) can be applied indoors without concern. Use of baits also results in less environmental contamination and greater ease of application for the homeowner than other insecticide products (Rust 1986).

Abamectin (80% avermectin B1a, 20% avermectin B1b) is effective as a stomach poison against a broad spectrum of insect species such as ants (Glancey et al. 1982, Baker et al. 1985), lice (Barth & Preston 1985), clothes moths (Bry 1989), gypsy moth (Deecher et al. 1987), flies (Langley & Roe 1984, Miller et al. 1986, Rousch & Wright 1986, Campbell et al. 1987), termites (Su et al. 1987), and yellowjackets (Chang 1988). Strong & Brown (1987) reviewed the mode of action of avermectins and their effect on target and nontarget species of animals.

Abamectin cockroach bait (Avert, Whitmire Research Laboratories, St. Louis, Mo.) is a slow acting toxicant for control of German cockroaches, *Blattella germanica* (L.). Laboratory and field tests have demonstrated the efficacy of the product for control of the German cockroach (Ballard & Gold 1983, Wright & Dupree 1985). Rates of 76.5 ppm in the diet were required to produce mortality; lower concentrations inhibited mating and reproduction (Cochran 1985). Tanaka & Matsumura (1985) also found that low concentrations of avermectin caused failure of leg muscles of American cockroach, *Periplaneta americana* (L.), to respond to stimuli.

The objective of our study was to evaluate the toxicity of abamectin to the German and six other pest species of cockroaches. Because abamectin is a stomach poison and causes delayed toxicity, toxicity at various concentrations and times of treatment were determined for the German cockroach. Speed of kill for a 0.0550% bait was determined for the other species. In addition, the relative attractancy of the formulated bait and its ability to suppress populations of German cockroaches were assessed.

This article reports the results of research only. Mention of a proprietary product does not constitute an endorsement or a recommendation for its use by USDA.

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Materials aod Methods

Cockroaches. German cockroaches, *Blattella germanica;* Oriental cockroaches, *Blatta orientalis* L.; brown banded cockroaches, *Supella longipalpa* (Serville); American cockroaches, P. *americana;* Australian cockroaches, P. *australasiae* (F.); brown cockroaches, *P. brunnea* Burmeister; and smokybrown cockroaches, *P. fuliginosa* (Serville) were lightly anesthetized with CO. and removed from colonies maintained at the USDA-ARS Insects Affecting Man and Animals Laboratory, Gainesville, Fla. "Orlando normal" German cockroaches were used in our study. This strain is susceptible to insecticides (Koehler & Patterson 1986). Adults that had eclosed 3 d before testing and fourth- and fifth-stage nymphs were used. Males of the other species were removed from laboratory colonies and were of unknown age.

Chemicals and Baits. Baits were prepared by Whitmire Research Laboratories (St. Louis, Mo.). Seven concentrations of baits ranging from 0.0025 to 0.1000% (wt/wt) were formulated on a standard bait base. Laboratory rat chow (Purina, St. Louis, Mo.) was finely ground and used as a control diet. After the initial dose studies with German cockroaches, a 0.0550% (wt/wt) bait was used for all subsequent studies.

Mortality Tests. Thirty German cockroaches (10 male, 10 female, and 10 late-stage nymphs) were placed in glass utility jars (4.25 liter) that were lightly greased with a 2:3 (petrolatum/mineral oil) film to prevent escape. A souffle cup containing ::::::8g of bait was placed in each jar. Water was provided with a cotton-stoppered, water-filled plastic vial (20 ml; 5.5 by 2.5 cm inner diameter); harborage was a rolled corrugated cardboard strip (6 by 15 cm). Cloth covers were placed over each jar and secured with a rubber band.

German cockroaches were exposed to seven concentrations of abamectin baits (0.0025, 0.0050, 0.0075,0.0125,0.0250,0.0500, or 0.1000%) or the control (finely ground laboratory rat chow). Three jars were set up for each treatment. These tests were nonchoice and done at 50% RH and 25°C with a photoperiod of 12:12 (L:D). Numbers of dead cockroaches were recorded for each jar at 1, 2, 3, 6, 8, 10, 12, and 14 d of treatment.

Thirty male oriental, brownbanded, American, Australian, brown, or smokybrown cockroaches were placed in glass utility jars (4.25 liter) that were prepared as described above. Numbers of dead cockroaches were recorded for each jar at 1, 2, 3, 5, 7, 9, and 11 d of treatment.

Data were analyzed by probit analysis (Finney 1971) to estimate LC_{W} values for each day of treatment and LTso values for each concentration of bait. Significant differences in LT_{50} and LC_{50} values were determined by failure of 95% confidence intervals to overlap.

Preference Tests. Two plastic scintillation vial caps (2.2 cm diameter), one containing ::::::5g of 0.0550% abamectin bait and the other containing finely ground laboratory rodent chow, were placed in each glass utility jar (4.25 liter). Nylon screen (6.6 threads per cm) was placed on top of the powdered abamectin bait and rodent chow to prevent spillage. Water and harborage were provided as described earlier. Preference tests were conducted in a room held at 50% RH and 25°C with a photoperiod of 12:12 (L:D).

Before cockroaches were released, all experimental jars were placed in the laboratory for 48 h to allow the moisture content of the baits and rodent chow to equilibrate with the laboratory environment. Twenty male German cockroaches were then placed in each jar (lightly greased with a 2:3 [petrolatum/mineral oil] film to prevent escape). To check moisture changes in the baits, control jars with bait and rodent chow were set up without cockroaches. To check cockroach mortality, other control jars containing cockroaches were set up with laboratory rodent chow for food.

Masses (±0.1 mg) of the abamectin bait and laboratory rodent chow, and the number of dead cockroaches were recorded immediately before cockroaches were released and daily for 7 dafter release. Five jars for the treatment, three humidity control jars, and three untreated control jars were used. Daily consumption of food and bait by the cockroaches was corrected using the following formula:

$$CC = W_1(HC./HC_{I)} - W.,$$

where CC is the corrected consumption, WI is weight on day 1, W. is weight on day 2, HC_{I} is the average weights appropriate hUliJlidity checks (3 reps) on previous day, and *HC.* is the average weights humidity checks on current day. Adjusted food and bait consumption were analyzed by *t* tests ($P = 0.05$) (SAS Institute 1988).

Arena Tests. The inside walls of 11 aluminum arenas (120 by 120 by 30 em, three per treatment) were greased lightly with a 2:3 (petrolatum/mineral oil) film to prevent cockroach escape. Four cardboard harborages (4.5 by 8.5 cm inner diameter; Fonda, Union, N.J.) with holes (2 cm inner diameter) cut in the side were placed midway along the edge of each arena. German cockroaches (50 males, 50 females, and 280 nymphs) were placed into each arena.

The arenas were treated with 1.65% hydramethylnon bait trays (Combat, American Cyanamid, Clifton, N.J.), abamectin bait stations (20-30 g of 0.0550% [AI] abamectin) placed in a cardboard dish (2 by 8.5 cm inner diameter; Fonda), or 5 g of abamectin bait dusted into each cockroach harborage. Dishes that contained the abamectin or the hydramethylnon bait trays were placed opposite each other and an equal distance from a centrally placed chicken waterer (1 liter) in each arena. Dishes that contained laboratory rat chow were placed in a similar manner, but at a 90° orientation to the dishes containing the treated bait. Control arenas just received laboratory rodent chow. Are-

Table 1. LTso values (days) of German cockroaches fed abamectin at various bait concentrations

%	n	LTso, d	95% CI	Slope ± SE
		Males		
0.0025	30	4.358	3.233-5.214	3.355 ± 0.121
0.0050	30	4.633	3.674-6.053	2.462 ± 0.096
0.0075	30	3.336	2.539-4.263	1.892 ± 0.052
0.0125	30	3.282	2.704-3.917	2.842 ± 0.065
0.0250	30	2.675	2.326-3.059	5.819 ± 0.211
0.0500	30	1.685	1.439-1.936	5.256 ± 0.162
0.1000	30	1.692	1.562-1.824	5.261 ± 0.240
		Females		
0.0025	30	9.025	7.401-11.942	2.378 ± 0.D78
0.0050	30	5.230	4.433-6.066	3.306 ± 0.D78
0.0075	30	8.928	7.154-12.539	2.440 ± 0.085
0.0125	30	4.210	3.517-5.017	2.910 ± 0.068
0.0250	30	3.651	3.206-4.234	5.870 ± 0.174
0.0500	30	2.368	1.933-2.740	4.928 ± 0.200
0.1000	30	2.396	2.210-2.624	4.798 ± 0.311
		Nymphs		
0.0025	30	4.427	3.751-5.156	3.686 ± 0.089
0.0050	30	3.015	2.563-3.526	3,819 ± 0.092
0.0075	30	5.200	4.153-6.551	1.958 ± 0.052
0.0125	30	4.191	3.384-5.189	2.318 ± 0.059
0.0250	30	2.904	2.489-3.375	4.940 ± 0.170
0.0500	30	1.550	1.356-1.743	7.426 ± 0.212
0.1000	30	2.067	1.922-2.220	5,671 ± 0.321

Data were analyzed by probit analysis (Finney 1971). There was no control mortality.

nas treated with baits and the controls were replicated three and two times, respectively.

Numbers o'dead cockroaches in each arena were counted daily. Percent mortality was calculated, and arcsine square-root transformed data were analyzed by analysis of variance, and means were separated by Tukey's Studentized range test (P = 0.05) (SAS Institute 1988). This procedure was used to make pairwise comparisons of means while maintaining an experimentwise type I error rate of 5%.

Results and Discussion

The LTsoS for males, females, and nymphs of the German cockroach decreased from 4 to 9 d for 0.0025% abamectin bait to 1.5-2.3 d for 0.0500% bait (Table 1). Generally, LTsoS decreased with increasing concentrations of abamectin, up to 0.0500%. No significant decrease in LTsoS was found in baits concentrations >0.0500%, probably because of feeding deterrence. Therefore, a 0.0550% bait was used in additional studies. At 0.0500%, the LTso for abamectin was 1.68, 2.40, and 1.55 d for males, females, and nymphs, respectively. Cochran (1985) reported that German cockroach females fed avermectin Bl baits at >6.5 ppm exhibited high mortality at 10 d, and survivors failed to reproduce. The faster mortality times reported in our study are probably attributable to the higher concentrations (>10 times) of abamectin bait used.

Table 2. LCso values (%) of German cockroaches fed bait treated with abamect;n

Day	n	LCso, %	95% CI	Slope ± SE
		Males		
3	150	0.011	0.008-0.016	1.587 ± 0.021
6	90	0.004	0.001-0.006	2.258 ± 0.074
		Females		
3	120	0.024	0.018-0.038	2.045 ± 0.039
6	120	0.009	0.007-0.012	3.121 ± 0.069
		Nymphs		
3	120	0.020	0.012-0.032	1.517 ± 0.174
6	120	0.008	0.005-0.010	3.001 ± 0.005

Data were analyzed by probit analysis (Finney 1971). There was no control mortality.

Abamectin is a slow-acting toxicant that provides delayed toxicity to German cockroaches, with higher doses killing cockroaches faster. The speed of action for males (LTso = 1.68 d) is slower than that reported for chlorpyrifos (0.23-0.41 d; Appel 1990) and hydramethylnon (0.86 d at 1.65% bait; Appel 1990). However, the LT50 of abamectin is faster than that of sulfluramid (2.14 d at 1,000 ppm; Reid et al. 1990) and boric acid (5.06-7.63 d; Appel 1990). Both Reid et al. (1990) and Milio et al. (1986) demonstrated that sulfluramid and hydramethylnon provide delayed mortality of cockroaches that is dose-related.

Significantly higher concentrations of abamectin were required to kill German cockroaches at 3 d than 6 d (Table 2). The LCsoS of abamectin for males, females, and nymphs of the German cockroach were 0.0100-0.0240% at 3 d of treatment and 0.0040-0.0090% at 6 d of treatment. The LCsoS were generally significantly higher for females and nymphs than for males.

The LTsoS of abamectin for male American, smokybrown, brown, Australian, oriental, and brownbanded cockroaches were 3.3, 3.4, 2.4, 7.5, 2.8, and 4.5 d, respectively (Table 3). These values were significantly higher than those for the German cockroach. Differences in bait preferences and body size of these other species may account for these differences in LTsoS. Patterson & Koehler (1989) found that hydramethylnon baits could be

Table 3. LTso values (days) for cockroaches fed 0.0550% abamectin

Species	n	LTso. d	95% Cl	Slope ± SE
American	30	3.376	3.021-3.858	7.611 ± 0.741
Smokybrown	30	3.433	3.071-3.923	7.657 ± 0.741
Brown	30	2.427	2.022-2.794	5.177 ± 0.648
Australian	30	7.527	6.624-8.806	4.643 ± 0.491
Oriental	10	2.854	2.670-3.057	6.182 ± 0.403
Brownbanded	30	4.541	3.674-5.880	2.474 ± 0.181

Data were analyzed by probit analysis (Finney 1971). There was no control mortality.

Table 4. Consumption of 0.0500% abamectin bails and laboratory rat chow by male German cockroaches in choice tests

Treatment or food	Consumption (mg) on day				Total 7-d consumption, mg
	1	2	3	4	
Choice (Mortality)	0%	8%	58%	91%	100%
Abamectin bait	2.99a	3.63a	0.19a	O.35a	7.16a
Rat chow	4.36a	3.43a	0.92a	0.15a	9.61a
Control (Mortality)	0%	0%	0%	0%	0%
Rat chow 1	5.63a	6.31a	6.11a	2.75a	40.65a
Rat chow 2	3.22a	6.40a	15.33a	10.04a	69.94a

Treatment group means in the same column followed by the same letter are not significantly different ($P = 0.05$; Student's t test [SAS Institute 1988]).

used to suppress populations of peridomestic cockroaches, even though the time required to kill the larger cockroaches was> 16 d (Milio et al. 1986). Abamectin, like hydramethylnon, can kill the larger species of cockroaches and is a potentially useful product for suppression of peridomestic cockroaches.

Preference tests of German cockroaches for the abamectin bait compared with laboratory rat chow resulted in 100% mortality by the fifth day (Table 4). There was no control mortality. These mortality results compare favorably with mortality obtained using formulated baits that contain hydramethylnon and sulfluramid with this strain of cockroach under identical experimental conditions (T.H.A., unpublished data). The LT_{50} of abamectin bait in choice tests was 2.85 d (n = 100; 95% confidence interval, 2.722-2.981; slope ± SE, 9.122 ± 0.084). This LToo was significantly greater than the LT_{50} of a similar concentration of bait fed in nonchoice tests (1.68 d), but was not significantly different from the LT_{50} of a bait that was half the concentration (2.68 d for 0.0250% bait). This result would be expected if the bait was approximately the palatability of rat chow (rat chow is not highly palatable to German cockroaches).

Field performance of a bait may be adversely affected (Reierson & Rust 1984) if palatability is reduced. Therefore, relative palatability with respect to dietary alternatives is likely to be extremely important in bait performance for slow-acting oral toxicants. Over a 7-d period, male cockroach (groups of 20) consumption of abamectin bait (7.16 mg) was not significantly less than consumption of rat chow (9.61 mg). The total consumption (16.77 mg) of food in utility jars containing abamectin was less than consumption (110.59 mg) in the control jars over the same period. Reduced consumption in the treated groups was probably attributable to toxicity of abamectin. Similarly, Cochran (1985) reported reduced consumption of baits by female German cockroaches at bait concentrations >0.3 ppm; but he attributed the reduced consumption to toxicity rather than unpalatability or repellency.

Arena tests with 0.0500% abamectin and 1.65% hydramethylnon bait resulted in significant mortality of German cockroaches after 1-3 d (Table 5). Abamectin placed in bait dishes resulted in significantly lower mortality after 9d than abamectin placed in the harborage with the cockroaches. Abamectin provided faster mortality than the hydramethylnon standard from 1 to 3 d of treatment. After 5 d, the abamectin treatment placed in the harborage and the hyramethylnon bait stations resulted in significantly higher mortality than the abamectin placed in the bait station or the controls. After 9 d, abamectin placed in the harborage provided 75% mortality of German cockroaches, hydramethylnon provided 65% mortality, and abamectin placed in the bait station provided 31%

Table 5. Percent mortality of cockroaches in arena tests treated with 0.0550% abamectin or 1.65% hydramethylnon

Day	% Cumulative mortality, f ± SE			
	Control	Abamectin bait station	Abamectin in harborage	Hydramethylnon bait station
1	1.05 ± 0.52ab	4.74 ± 1.19a	0.13 ± 0.13b	1.47 ± 0.25ab
2	1.45 ± 0.66b	7.19 ± 1.80a	1.18 ± 0.40b	1.65 ± 0.23b
3	1.71 ± 0.66b	11.49 ± 1.52a	6.84 ± 0.79a	4.02 ± 0.38b
4	1.84 ± 0.53b	15.35 ± 1.84a	20.79 ± 6.32a	15.63 ± 1.57a
5	1.84 ± 0.53c	18.07 ± 1.49b	35.26 ± 8.42a	49.40 ± 2.87a
6	1.84 ± 0.53c	19.65 ± 1.36b	49.61 ± 8.28a	55.52 ± 2.61a
7	1.97 ± 0.66c	22.98 ± 2.43b	60.26 ± 8.16a	58.59 ± 2.77a
8	1.97 ± 0.66e	30.61 ± 6.00b	71.84 ± 6.05a	60.22 ± 2.60a
9	2.63 ± 0.53e	31.49 ± 5.65b	75.00 ± 4.74a	64.91 ± 2.61a

Means within a row followed by the same letter are not significantly different ($P = 0.05$; Tukey's Studentized range test [SAS Institute 1988]). $n = 6$ arena tests.

mortality, whereas control mortality was only 3%. Differences in percent mortality for hydramethylnon bait trays and abamectin bait stations was probably caused by differences in palatability of the bait base. Abamectin bait applied to the harborage resulted in higher mortality than the bait station due to the proximity of the bait to the cockroaches.

Abamectin is an effective toxicant for several species of cockroaches and has considerable potential for use in cockroach bait products. Its speed of kill is almost equal to that of sulfluramid and hydramethylnon and is definitely faster than boric acid. Baits formulated at 0.0550% do not repel German cockroaches, although palatability of currently available baits could be improved. However, cockroach populations can be effectively suppressed using currently available formulations. Application of the bait to cockroach harborages significantly improved performance so that mortality was equal to that produced by hydramethylnon.

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