PERFORMANCE OF AVERMECTIN BAIT FORMULATIONS AGAINST THE GERMAN COCKROACH (DICTYOPTERA: BLATTELLIDAE)

ERIC P. BENSON AND ARTHUR G. APPEL
Department of Entomology, Auburn University, Auburn, Alabama, U.S.A. 36849-5413

Abstract—Commercial formulations of avermectin based baits were evaluated in laboratory and field studies against the German cockroach, *Blattella germanica* (L.). In continuous exposure tests with adult males, LT_{50}s ranged from ca. 2.5 to >200d for Roach Ender™ and an experimental aerosol gel formulation, respectively; dry formulations had lower LT_{50}s than water containing formulations. Moist formulations were preferred, however, by mixed populations in large arena tests. A powder formulation (Avert™) reduced cockroach trap catch in infested apartments more rapidly when applied at 50, rather than 12 sites, even when the same total bait was applied. When applied at ca. 50 sites, an aerosol formulation of Avert gel provided nearly an 80% reduction in trap catch. Other avermectin formulations provided significant, but not outstanding reductions in trap catch. Avermectin based baits can reduce German cockroach populations when properly applied.

INTRODUCTION

In recent years, one of the most common and effective methods for controlling urban pests has been the use of insecticidal baits (Rust 1986, Appel 1990). Some of the newest active ingredients for baits include avermectin (avermectin B1) and the closely allied abamectin (80% avermectin B1a, 20% avermectin B1b). Baits containing avermectin have been evaluated against a wide variety of urban pests including ants (Glancey *et al.* 1982, Baker *et al.* 1985), clothes moths (Bry 1989), termites (Su *et al.* 1987) and yellowjackets (Chang 1988).

For cockroaches, avermectin baits are available in both professional use Avert™ (Whitmire Research Laboratories, St. Louis, Mo., U.S.A.) and over-the-counter Roach Ender (Reckitt & Colman, Carlstadt, N.J., U.S.A.). Avert is available to pest control operators as a brown dust. Roach Ender has been formulated as a small solid bait block and protected in a child-resistant plastic station similar to that of Maxforce bait stations (The Clorox Company, Oakland, CA., U.S.A.). Avert has been effective in controlling German cockroaches, *Blattella germanica* (L.) in laboratory and field tests (Ballard & Gold, 1983, Wright & Dupree, 1985). Arena tests using Avert (0.055% abamectin) resulted in 31-75% mortality of German cockroaches after 9 d, with most control being achieved by treating harborages (Koehler *et al.*, 1991). Most significantly, avermectin is effective against cockroaches that have developed resistance to conventional insecticides (Cochran, 1985). The objectives of this study were to evaluate the toxicity of and preference for several avermectin bait formulations and to determine the effects of avermectin bait placement and formulation efficacy against German cockroaches in public-housing apartments.

METHODS AND MATERIALS

Laboratory Evaluations

Four avermectin bait formulations were evaluated for toxicity in continuous exposure tests. Three baits were manufactured by Whitmire Research Laboratories: standard Avert powder, a new Avert Gel, and a new Avert Aerosol formulation. The fourth bait evaluated was the containerized avermectin bait, Roach Ender™, manufactured by Reckitt & Colman Household Products.

Insecticide-susceptible German cockroaches were reared in plastic trash cans with cardboard harborage and maintained at 25±3°C, 50±12% RH, and a 12:12 (L:D) photoperiod. Ten adult male German cockroaches were confined in a 0.95-l glass jar with a piece of dog food, a moistened cotton wick, and a small piece of cardboard. The upper inside surface of the jar was lightly greased with petroleum jelly to prevent escape. In addition, cloth covers were secured with rubber bands over the openings. Approximately 1.5 g of one of the avermectin baits was placed in each jar.

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Control jars with only water and dog chow were also included. All treatments were replicated three times. Cockroach mortality was recorded at 12 h intervals for seven days.

Bait preference tests were with mixed populations of German cockroaches of ca. 300 individuals established in 5, 1.3 by 0.5 by 0.5-m white enamel painted boxes equipped with electrified barriers. An inverted 0.95-l cardboard ice cream container with three entrance slots was provided as harborage. Food and water were also provided. The cockroaches were allowed to acclimate in the boxes for 24 h prior to testing. Approximately 1-2 g of a bait formulation was placed into a preweighed 6 cm-diameter aluminum weighing pan. Bait mass was recorded and one of each of the four bait formulations was placed into a randomly selected corner of each of four boxes. Dog food was placed in all four corners of the fifth box as a control. All baits were weighed daily for four days. Bait consumption was corrected for mass changes from similar baits placed next to the boxes, but covered with coarse screen.

Field Evaluation

The Opelika Housing Authority, located in Opelika, Lee Co., Alabama, U.S.A., approximately 10 kilometers from the Auburn University campus, was used as the field study site. The design of this complex provided primarily two apartment units and eight apartment units. Sticky traps (**Mr. Sticky**) were used to monitor cockroach populations for both years. Ten traps were placed in the kitchen of each apartment: six traps in the cabinets around the kitchen sink, two in the pantry, and one each behind the stove and refrigerator. Traps were positioned such that they contacted a vertical surface such as a wall, or part of an appliance. Sticky traps were left in place for 7 days then returned to the laboratory for evaluation. For both the 1991 and 1992 trials, trap catches were evaluated pretreatment and 1, 2, 4, 8 and 12 weeks posttreatment. Following the pretreatment trapping, treatments were allocated to individual apartments based on trap catch so that the initial cockroach population size and distribution was approximately equivalent among treatments.

In the summer of 1991, 12 apartments were each treated with an entire tube (30 g) of the powder formulation of Avert. Six additional apartments were monitored as untreated controls. Of the 12 treated apartments, half received Avert applied at a total of 12 positions; similar to the directions to apply bait products in bait stations (e.g., Maxforce). For the 12 position application method, 11/12 of a tube (27.5 g) was applied in the kitchen and 1/12 (2.5 g) in the bathroom. In the kitchen, 2.5 g of bait was placed in the rear corners under the sink, behind the stove, behind the refrigerator, in upper cabinets, in lower cabinets and in a pantry or in a cabinet above the refrigerator. The bait in the bathroom was placed on the floor behind the toilet. The other 6 apartments received Avert in 50 application sites throughout the kitchen and bathroom. The 50 application sites were treated with approximately 1/50 of a tube or 0.6 g and included all of the sites used in the 12 location method.

In the summer of 1992, 18 apartments (6/treatment) were treated with either 68.0g of Avert pressurized gel (0.01% Abamectin), 68.0 g of Avert paste (0.01%) or 12 bait stations of Roach Ender (0.05% Avermectin). Six additional apartments served as untreated controls. Based on 1991, results, pressurized gel and paste formulations were placed at 50 locations.

Data Analysis

Mortality in the continuous exposure test was analyzed by probit analysis (SAS Institute 1985). Significance was based on nonoverlap of the 95% fiducial limits (CI). Bait preference was analyzed by chi-square tests where the mass corrected total consumption within a box was divided by four to serve as the expected value.

The mean number of German cockroaches caught and the corresponding mean percent reduction compared with the pretreatment population levels are reported for the various bait treatments. Data from the two years were analyzed separately. Analysis of variance (ANOVA) and least square means test was performed on the log reduction ratio among treatments at each week. Field trials were also analyzed by separate linear regressions on each treatment of $\log_{10}$ (number of cockroaches + 1) over time. To evaluate decline and any later increase is cockroach numbers, a quadratic or second order equation of the form: $y = a_1x + a_2x^2 + b$, where Y is the mean number of cockroaches, X is time in weeks, and a_1 and a_2 are the regression parameters, was used.

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Table 1. Toxicity of several formulations of avermectin baits to adult male German cockroaches. Times in h.

Treatment	n	LT_{50} (95% CI) h	Slope ± SEM
Avert gel	30	247.92(184.78-423.69)	1.86 ± 0.31
Avert aerosol	30	5690(963.1- 4.7 X 10^7)	0.83 ± 0.29
Avert powder	30	110.45(105.72-115.41)	9.56 ± 0.89
Roach Ender	30	60.89(56.61-65.10)	5.42 ± 0.44
Control	30	1408(353.5-2 X 10^5)	1.43 ± 0.51

Table 2. 1991 field experiment. Mean number of cockroaches (N) at weeks 0, 1, 2, 4, 8, and 12, and percent reduction (Pct) calculated as mean percent reduction of cockroach numbers per time for each treatment. Negative mean percent reductions indicate an mean increase in cockroach numbers. SE = Standard error.

Treatment		N_0	N_1	Pct_1	N_2	Pct_2	N_4	Pct_4	N_8	Pct_8	N_{12}	Pct_{12}
AVERT	Mean	347.50a	268.00	**13.71a**	183.83	**37.65a**	187.60	**31.93a**	241.00	**13.69a**	419.80	**-56.54a**
12	SE	117.37	78.43	13.98	54.92	14.99	63.85	21.32	79.26	24.33	128.29	45.73
AVERT	Mean	426.50a	141.00	**33.90a**	115.33	**46.26b**	119.83	**55.00a**	182.50	**33.96a**	288.83	**-0.36a**
50	SE	195.22	45.29	26.58	34.88	21.22	45.42	24.80	58.97	31.88	58.21	26.31
CONTROL	Mean	225.44a	202.75	**-26.75b**	175.25	**-23.69c**	192.50	**-17.99b**	180.38	**-35.45b**	253.00	**-69.18b**
	SE	77.19	72.38	25.31	60.81	25.43	67.17	27.26	60.45	40.98	89.31	51.03

[a]Means within a column followed by different letters are significantly different at P = 0.05.

Regression approaches essentially eliminate numerical comparisons among treatments, but do show if treatments had significant effects on cockroach populations.

RESULTS AND DISCUSSION

Toxicity and Preference

LT_{50}s ranged from 60.9 h (2.54 d) for Roach Ender to 5690 h (237.1 d) for the experimental Avert aerosol bait (Table 1). The dry avermectin formulations were signi-ficantly more toxic to adult male German cockroaches than were the moist formulations. The LT_{50} of Avert powder in this study (4.60 d) was almost identical to the 4.63 d found by Koehler et al. (1991). The low toxicity of the experimental Avert aerosol bait was likely caused by the presence of mold which developed on the surface of the deposit after only a few days. The covered glass jars probably retained sufficient amounts moisture to promote mold growth.

There was no difference in dog food consumption by mixed-stages of German cockroaches among the four corners of the control box indicating no bias due to bait position. Pooled over all test days, moist baits were significantly (χ^2 = 7.82, df = 1; P > 0.01) preferred to dry baits in all boxes. Appel (1992) found greater toxicity with moist Maxforce gel than with dryer pastes especially when provided harborage. Because water is a major component of moist baits, consumption can be affected by molds, bacteria, and various hydrophilic chemicals. In addition, the physiological and reproductive status of individual cockroaches affect feeding preferences and thus affect consumption and toxicity of baits (cf. Koehler *et al.* 1991) and other toxicants (Abd-Elghafar *et al.* 1990).

1991 Field Study

Mean pretreatment trap counts ranged from 225.44 to 426.5 for the control apartments and the Avert 50 location apartments, respectively (Table 2). There were no significant differences in mean pretreatment trap counts among treatment groups (P > 0.05). The results of the test in Table 2 are expressed as both mean number of cockroaches and as percent reduction of pretreatment trap counts, calculated from the mean numbers of cockroaches per week. Both the Avert applied at 12 and 50 locations significantly reduced cockroach numbers compared with the control during the entire 12 weeks. There were no significant differences between the Avert treatments except at week 2

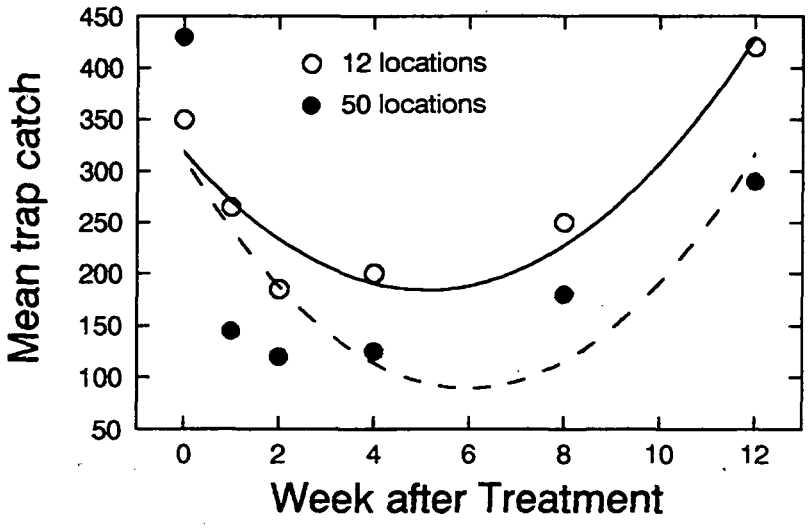

Fig. 1. Performance of Avert powder formulation applied at 12 and 50 locations in German cockroach infested apartments. Quadratic regressions through the data points only are shown.

where the Avert at 50 location apartments had a mean reduction in cockroaches of 46.26% compared with a 37.65% reduction in the Avert 12 apartments.

Neither of the two treatments exhibited significant $\log_{10}$(Number + 1) regressions. Regression diagnostics indicated that the poor fit of the simple model was due to the lack of sufficient parameters. That is, the number of cockroaches did not just decline over time, but declined and increased (Fig. 1). Analysis by a second order model produced the equation $Y = -56.5x + 5.47x^2 + 320$, with $r^2 = 0.92$ for the Avert 12 location treatment. For the Avert 50 location treatment, the second order model produced the equation $Y = -74.0x + 6.24x^2 + 307$, with $r^2 = 0.54$. These analyses indicate that Avert at 50 locations reduced the mean number of trapped German cockroaches most rapidly, as evidenced by the greatest negative a_1 regression parameter (-74.0), but the apartments also experienced the greatest rate of cockroach population recovery as seen by the greatest a_2 regression parameter of 6.24.

The 1991 field trials demonstrated that Avert powder can provide some limited control for German cockroaches for up to 8 weeks in heavily infested public housing apartments. Application of Avert in 50 sites overall provided greater control as well as reducing cockroach numbers more rapidly than Avert placed in 12 locations. However, the more rapid increase in cockroach numbers for Avert 50 may also indicate a more rapid depletion of available bait. In other words, the availability of more bait locations may be conducive to facilitating more cockroaches finding the bait but also depleting the bait in a shorter period of time. Similar loss of field efficacy at 12 weeks after treatment was found by Appel (1990) and correlated with the complete consumption or loss of bait in stations.

1992 Field Study

Mean pretreatment trap counts ranged from 350.33 to 418.83 German cockroaches per apartment for the Avert aerosol treated apartments and the control apartments, respectively (Table 3). There were no significant differences in mean pretreatment trap counts among the treatment groups ($P > 0.05$). During the this trial, the Avert products performed significantly better than Roach Ender until week 12. The Avert aerosol provided the best overall control with a range of control from approximately 60 to 80 percent.

For the $\log_{10}$(Number + 1) regression analysis, all the baits had significantly negative slopes (Table 4), indicating a reduction in cockroach trap catch. As in the other studies, cockroach numbers did fluctuate over time, though not as widely as the 1991 trial. Still a quadratic or second order equation was used to further evaluate these data. The Avert gel bait reduced the mean number of trapped German cockroaches most rapidly as evidenced by the greatest negative a_1 regression

Table 3. 1992 field experiment. Mean number of cockroaches (N) at weeks 0, 1, 2, 4, 8, and 12, and percent reduction (Pct) calculated as mean percent reduction of cockroach numbers per time for each treatment. Negative mean percent reductions indicate an mean increase in cockroach numbers. SE = Standard error.

Treatment		N_0	N_1	Pct_1	N_2	Pct_2	N_4	Pct_4	N_8	Pct_8	N_{12}	Pct_8	N_{12}
Avert Gel	Mean	357.50a	280.80	**42.64a**	260.00	**45.78a**	255.40	**37.28a**	167.20	**65.05a**	199.20	**52.46a**	199.20
	SE	127.93	102.06	14.82	102.64	13.86	79.03	18.67	67.02	11.44	84.55	18.09	84.55
Avert Aerosol	Mean	350.33a	164.00	**60.82a**	156.67	**64.69a**	73.83	**59.89a**	73.83	**79.11a**	61.00	**75.09a**	61.00
	SE	120.68	77.43	10.11	89.65	9.32	18.03	22.98	32.49	5.44	29.52	12.47	29.52
Roach Ender	Mean	402.00a	291.00	**19.16b**	326.50	**-0.33b**	253.17	**2.67b**	283.67	**14.03b**	222.50	**54.63a**	222.50
	SE	126.66	90.21	9.14	87.50	12.84	77.81	31.84	104.08	19.33	100.67	11.05	100.67
Control	Mean	418.83a	582.50	**-34.03c**	783.50	**-60.88c**	551.75	**-5.76b**	587.75	**-122.26c**	571.50	**-18.11b**	571.50
	SE	134.19	196.98	22.92	265.95	10.56	201.09	24.16	208.66	102.26	192.10	16.54	19.10

[a]Means within a column followed by different letters are significantly different at P = 0.05.

Table 4. 1992 field experiment. Regression statistics for $\log_{10}$(Number + 1) transformed data for each treatment over time. Mean number of cockroaches used in the analysis.

Treatment	Slope	Intercept	r^2	*F* value	P
AVERT GEL	-0.02	2.49	0.718	10.178	0.033
AVERT AEROSOL	-0.05	2.32	0.711	9.839	0.035
ROACH ENDER	-0.02	2.53	0.631	6.853	0.059
CONTROL	0.003	2.75	0.020	0.083	0.788

Table 5. 1992 field experiment. Regression statistics for each treatment over time utilizing a quadratic or second order model.. Mean number of cockroaches used in the analysis.

Treatment	Equation[a]	r^2
AVERT GEL	y = 338.93 - 336.28X + 2.03X2	0.90
AVERT AEROSOL	y = 284.90 - 63.69X + 3.89X2	0.80
ROACH ENDER	y = 360.06 - 23.52X + 1.11X2	0.65
CONTROL	y = 528.54 + 37.34X - 2.98X2	0.14

[a]y is the mean number of cockroaches and X is time in weeks.

parameter (-336.28) (Table 5). The Avert aerosol bait had the largest positive a_2 regression parameter (3.89), indicating the most rapid cockroach recovery among the avermectin treatments.

The 1992 field trials indicated that, again, avermectin baits placed in 50 locations provide better control earlier and as well providing a more rapid decrease in cockroach populations as indicated by trap catch. Between weeks 8 and 12, however, it is likely that baits have been consumed or are otherwise unavailable resulting in population increases. In both the 1991 and 1992 field trials only one application of each formulation was made to each apartment. Single applications are probably the most difficult test of any insecticide treatment as a professional pest control operator would visit and reapply treatments on usually a monthly basis, especially in public-housing or other highly infested accounts.

In conclusion, avermectin bait formulations are effective in controlling German cockroach infestations, especially when applied at a number of (at least 50) locations. Selection of the appropriate bait formulation for the conditions of a particular infestation, for example using dry formulations in a moist kitchen environment or using a moist formulation in dry wall void, can probably further increase bait performance.

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