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Toxicity of fipronil to German and American cockroaches

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Abstract

Topical and oral toxicity of fipronil, compared to chlorpyrifos, was determined for the German cockroach, *Blattella germanica* (L.), and American cockroach, *Periplaneta americana* (L.). Fipronil and Combat bait matrices were evaluated for their attractancies to both species. In the topical toxicity tests, LD50's of fipronil, at 72 h after topical application, were 0.03 and 0.02 μg/g for adult *B. germanica* and *P. americana*, respectively. Fipronil was significantly more toxic than topically applied chlorpyrifos (LD50's were 0.06 and 0.16 μg/g for *B. germanica* and *P. americana*, respectively). The oral toxicity of fipronil and chlorpyrifos in Petri dish experiments, against both species, was affected by stage (for *B. germanica*), diet concentration, and feeding assay. Fipronil caused higher mortality of *B. germanica* than chlorpyrifos in two feeding assays (continuous and abbreviated). Both compounds were equally toxic to adult males of *P. americana* at all rates. Fipronil caused higher nymphal mortality than chlorpyrifos 48–72 h after exposure in both feeding assays. In large population chamber tests, fipronil bait was more effective and faster in killing *P. americana* than Raid and Combat. LT50's were 0.8, 2.4, and 7.6 d for fipronil, Raid (a.i. = chlorpyrifos), and Combat (a.i. = hydramethylnon) baits, respectively. Mortality reached 96.5, 93.4, and 84.6%, respectively, at the end of the 14 d test. In the bait attractancy tests, both strains of *B. germanica* were attracted similarly to fipronil and Combat bait matrices. *P. americana* were attracted more to fipronil than to Combat bait matrix or to other alternative foods.

Introduction

Methods for the control of cockroaches include crack and crevice treatments, baseboard sprays, aerosols, foggers, and baits. The use of toxic baiting in the control of cockroaches has a long and varied history (Frishman, 1982). Toxic baits containing phosphorous, boric acid, and other compounds were most effective against *Periplaneta* spp. (such as the American cockroach, *Periplaneta americana* [L.]) and other large peridomestic cockroach species (Cheng & Campbell, 1940; Lofgren & Burden, 1958), but the more prevalent German cockroach, *Blattella germanica* (L.), was not successfully controlled with these products. Varying levels of control in the use of baits in the control of *B. germanica* and *P. americana* have been reported with chlorpyrifos, sulfluramid, abamectin, boric acid, hydramethylnon, and other baits (Lund & Bennett, 1978; Rust & Reierson, 1981; Reierson et al., 1983; Reierson et al., 1983; Milio et al., 1986; Hagenbuch et al., 1988; Appel, 1990, 1992; Reid et al., 1990; Brenner & Pierce, 1991; Koehler et al., 1991; Appel & Benson, 1995; Kaakeh & Bennett, 1996). Use of baits results in less environmental contamination and greater ease of application than other insecticide products (Rust, 1986). However, effective bait formulations must be palatable and thus nonrepellent, readily available, and toxic in the amounts consumed (Appel, 1990).

The insecticidal properties of fipronil [(±)-5-amino-1-(2,6-dichloro-a,a,a-trifluoro-*p*-tolyl)-4-trifluoromethyl-sulfinylpyrazole-3-carbonitrile] were discovered by Rhone-Poulenc Agro in 1987 at Ongar, UK (Hatton et al., 1988; Colliot et al., 1992). This

phenylpyrazole insecticide is neurotoxic which blocks the transmission of signals by the inhibitory neurotransmitter gamma-aminobutyric acid (GABA) (Colliot et al., 1992; Cole et al., 1993; Moffat, 1993). Fipronil was reported to be a highly effective insecticide, utilizing a low-dose technology, against both piercing-sucking and chewing agriculturally important insect pests, and can be delivered via soil, foliar, bait or seed treatment applications (Colliot et al., 1992; My, 1994). However, no information is presently available on the toxicity of fipronil to *B. germanica* and *P. americana*.

In this study, the biological activities of fipronil, compared to those of chlorpyrifos, were determined against *B. germanica* and *P. americana*. Our objectives were to (1) determine the topical toxicity of fipronil against adult *B. germanica* and *P. americana*, (2) determine the oral toxicity of fipronil against males and 4th instars of both cockroach species, and (3) evaluate untreated, fipronil and Combat bait matrices for their attractancy to both cockroach species.

Materials and methods

Test insects. Cultures of *B. germanica* were maintained on a 12:12 (L:D) h photocycle at $27 \pm 1\,^{\circ}$C and 60% r.h., and were provided with an unlimited supply of water and food (Teklad-Rodent Diet # 8604; Taklan, Madison, WI, USA). The Johnson Wax (JWax) strain of *B. germanica* was isolated from a field population before the widespread use of synthetic organic insecticides and is susceptible (Koehler & Patterson, 1986). Assays with *P. americana* utilized a field-collected strain that was maintained in the laboratory, by A.G. Appel, Auburn University, Alabama, USA.

Topical toxicity. Toxicity of fipronil and chlorpyrifos was determined by topical application. Adult males of *B. germanica* (1–2 wk old) and *P. americana* (age not known) were used because their weight and physiology are more uniform compared to nymphs or adult females (Appel et al., 1983). Insecticide applications were made with an Arnold Automatic Microapplicator (Burkhard, Ricksmanworth, England) equipped with a 1 ml glass syringe. Technical grade fipronil (96.8% [a.i.]; Rhone-Poulenc, Research Triangle Park, NC, USA) or chlorpyrifos (99.0% [a.i.]; DowElanco, Indianapolis, IN, USA) were applied after dissolving in spectrophotometric grade acetone. One μl of insecticide solution was placed onto the intercoxal spaces of the ventral mesothorax of cockroaches briefly anesthetized with CO_2 to facilitate handling. After treatment, cockroaches were placed in groups in 100-mm plastic Petri dishes for observational purposes and supplied with a water vial.

For lethal dose (LD) determinations, groups of test insects were treated with a series of 8 insecticide concentrations (1, 2, 3, 4, 10, 20, 30, and 40 ppm) for *B. germanica* and 7 concentrations (40, 100, 400, 600, 800, 1000, and 4000 ppm) for *P. americana*. Control cockroaches were treated with acetone alone. Each concentration (and control) was replicated 3 times (10 *B. germanica* per replicate and 4 *P. americana* per replicate). Mortality was observed at 6, 24, 48, and 72 h following treatment.

LD50's for fipronil and chlorpyrifos were estimated by probit analysis (SAS Institute, 1990) to determine insecticide toxicity; indication of significant differences were determined by non overlap of the 95% fiducial limits (FL). Dose was expressed as weight of insecticide (μg)/average weight of an adult male (g). Incidences of control mortality were automatically corrected by Abbott's (1925) transformation.

Oral toxicity – Petri dish bioassay. Diets containing varying concentrations (% w/w) of active ingredient (1000, 500, 250, and 100 ppm for *B. germanica* assays; and 10 000, 5000, 2500, and 1000 ppm for *P. americana* assays) were prepared by finely grinding the laboratory diet and reconstituting this media (5 gm) with an acetone solution (3 ml) of insecticide and water (6 ml). The resulting mixture was pressed into a Plexiglas mold and dried in a fume hood for 24 h to yield pelleted diets ($\simeq$ 100 mg per pellet) of the desired concentration (% a.i. on weight basis). In all studies, controls were run using diets prepared as above but using an acetone blank and water to reconstitute the diet. After preparation, all test diets were stored (at 5 °C) for 24 h before use in glass Petri dishes lined with filter paper and containing moisture absorbing cotton balls.

Ten adult males or 4th instar nymphs of *B. germanica* (4 individuals for *P. americana*) were placed in a plastic box ($19 \times 13 \times 10$ cm high) with the sides lightly greased with a 30:70 petrolatum:mineral oil mixture. The lids were ventilated to prevent escape of the cockroaches. A water vial, tent cardboard harborage (21 cm^2) and a single pellet of the test diet (2 pellets for *P. americana*) were placed in each box. Insects used in this bioassay were starved for 24 h before testing. Two exposures were conducted in this study. In one

group, the insects were allowed a continuous exposure to the toxic diet. In the other, insects were provided with toxic diet for 24 h, and were then provided non-toxic food for the duration of observations (8, 16, 24, 48 and 72 h). Each concentration-by-exposure combination was replicated three times. Percentage of mortality, as described by four factors (insecticide, feeding assay, stage, and diet concentration) at each observation interval, was calculated. Arcsine-transformed data were analyzed by analysis of variance (SAS-ANOVA procedures), and means were separated by the test of least significant differences (LSD; $P = 0.05$; SAS Institute, 1990).

Oral toxicity – Population chamber bioassay. The efficacy of formulated fipronil (0.05% fipronil; Rhone-Poulenc, Research Triangle Park, NC, USA), Combat Roach Killing System (1.65% hydramethylnon; The Clorox Company, Pleasanton, CA, USA), or Raid Roach bait (0.528% chlorpyrifos; SC. Johnson and Sons, Racine, WI, USA) was determined in large population chambers with *P. americana*. These studies were conducted in a 11- by 14.5 m room, with a controlled environment of 27 °C and 50% r.h. Incandescent and fluorescent lamps, mounted in the ceiling 5.8 m overhead, were set to a photoperiod of L12:D12.

Test chambers were constructed of approximately 2 cm thick particle board (1 m^2 surface area) with a white painted surface. To this floor, Plexiglas^{TM} sheets (38 cm high by 6.4 mm thick) were fastened to form the walls. All wall and floor junctures were seamed with latex caulk to form tight, escape-proof seals. Arenas were made escape-proof by application of an impassable barrier of petrolatum and mineral oil (1:2) to the arena walls. This barrier was applied to within 1–2 cm of the chamber floor to prevent test insects from climbing the arena walls, thereby forcing all exploratory behaviors to the arena floor and the arena's provisions.

Refugia were restricted to one harborage unit (fashioned of tempered masonite panels) positioned in one corner of the chamber (Figure 1). The harborage unit consisted of stacks of panels separated by 20 mm spacers, thus providing 250 cm^2 of horizontal surface space. Populations were provisioned with abundant food and water so as not to restrain growth. Water (cotton-stoppered, 25 ml vials), and food (Wayne rodent blox) were positioned in the opposite corner of the chamber. Test populations were established in chambers by releasing 35 large nymphs (average of 0.8 g each) and 15 mixed adults (average of 0.8 g each), and allowing them 24 h to acclimate before treatments began.

After the acclimation period and initial census, the toxic baits were placed between the water vial and the laboratory food (Figure 1). Four toxic tablets of each bait were glued to the inverted lid of a Petri dish. The bottom of the Petri dish, covered from inside with foil, was placed on the top of the inverted lid to make a bait station.

Each treatment was replicated three times, in a completely randomized design. In daily observations, beginning the day after insect release in the chambers, the dead individuals were counted, classified by age (nymphs or adults), and removed from the arenas. Numbers and age classes of lethally affected cockroaches were recorded cumulatively. Daily percentage of cockroach mortality was corrected for control mortality using Abbott's (1925) formula. Corrected mortalities were analyzed by probit analysis, and LT50 in each treatment was estimated. Non overlap of 95% FL's were used to determine significant differences. Additionally, analysis by day among treatments was conducted to determine comparative efficacy. Daily cockroach mortalities at selected days after baiting (at 3, 7, and 14 d) were analyzed by ANOVA and means were separated by LSD test $P = 0.05$; SAS Institute, 1990).

Bait attractancy. Evaluation of the bait matrix attractancy to *B. germanica* and *P. americana* was conducted in a 90 cm diameter confinement with varying food stuffs (water, untreated laboratory diet, and jelly) and two candidate baits bases (fipronil and Combat) distributed in a 75 cm circular array (Figure 2). Adult cockroaches (25 individuals per sex) were released, and offered harborage, laboratory diet and water in the center of the arena, at least 24 h prior to the test's beginning.

All tests were conducted at night (1800 to 2200 h) under infrared illumination. Beginning 1 h into the scotophase, the number of foraging cockroaches at each food or bait matrix location was recorded at 10 min intervals for 120 min. Three replicates were conducted for each species. Data were converted to an attractancy ratio for each candidate bait matrix by dividing the total number of cockroaches at each bait matrix by the total number of cockroaches at the laboratory diet.

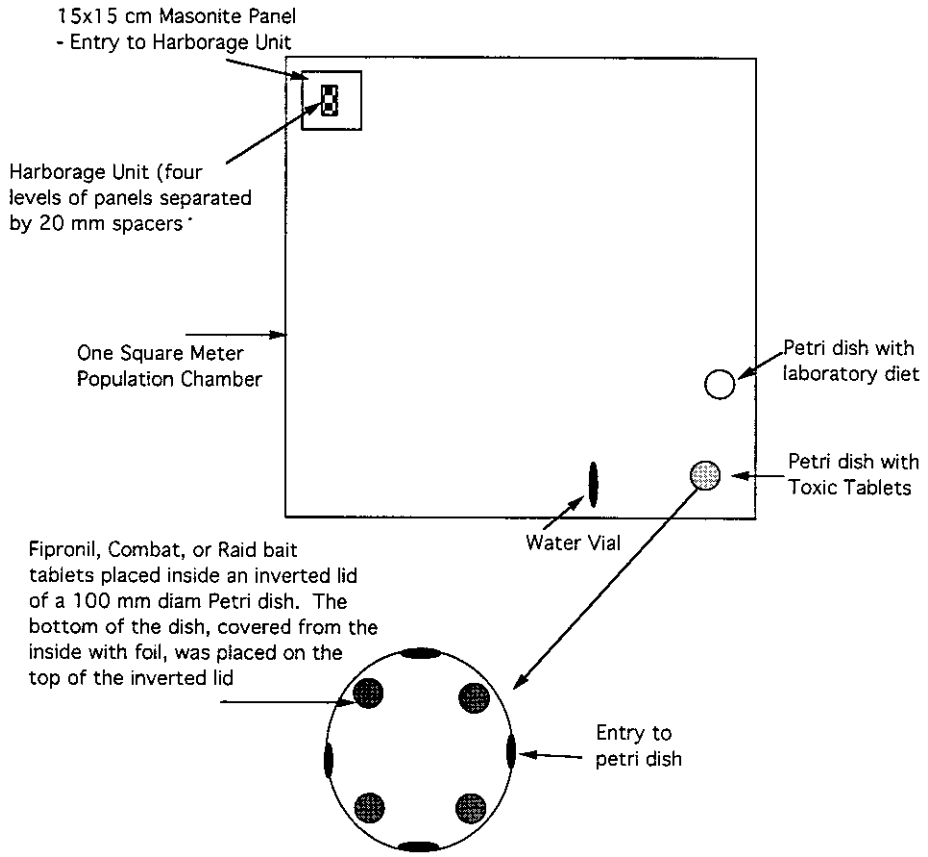

Figure 1. Population chamber layout for the toxicity tests of fipronil, Raid, and Combat baits to *B. germanica* and *P. americana.*

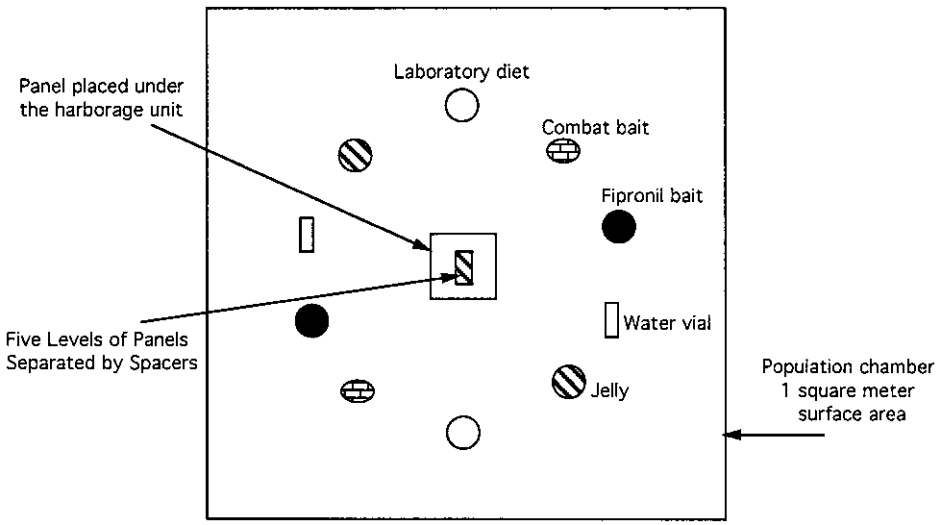

Figure 2. Population chamber layout for fipronil and Combat bait matrix attractancy test.

Results and discussion

Topical toxicity. LD50's at selected times after topical application of fipronil and chlorpyrifos on *B. germanica* and *P. americana* are shown in Table 1. At 72 h after application, fipronil was more toxic than chlorpyrifos to *B. germanica* (0.03 μg/g versus 0.06 μg/g). At all times after applications, fipronil was significantly more toxic to *P. americana* (i.e., smaller LD50 values) than topically applied chlorpyrifos. At 72 h after application, the LD50 of fipronil and chlorpyrifos were 0.02 and 0.16 μg/g, respectively. No mortality was recorded in either *B. germanica* or *P. americana* control groups.

Oral toxicity – Petri dish bioassay. The overall results of the four-factor analysis of variance for comparing the dietary toxicity of fipronil and chlorpyrifos against *B. germanica* are summarized in Table 2. Stage, followed by insecticide, were the most significant main effects in the model. Comparison of the percentage of total experimental variation for the percentage of mortality revealed that stage accounted for more experimental variation (32.4 and 30.7% at 24 and 72 h after exposure, respectively) than all other main effects. In general, feeding patterns of males and nymphs differ markedly (DeMark, 1988), but the bait active ingredient may affect each stage differently (Reierson, 1995). This may be related to size differences, metabolism and physiology. Koehler et al. (1993) and Valles et al. (1996) have also shown that *B. germanica* nymphs are considerably more tolerant of insecticides than adult males (i.e., stage dependent effect). The mechanism responsible for this phenomenon was due to enhanced detoxification (Valles et al., 1996). Among the remaining main effects, feeding assay described the least experimental variation (1.8%) at 24 h; diet concentration described 6.1% at 72 h.

The comparative effectiveness of fipronil and chlorpyrifos baits are presented in Table 3 for each cockroach species, feeding assay, diet concentration, and stage. Overall, fipronil caused 100% and 80 to 100% mortality in adult males and 4th instars *B. germanica*, respectively, at the end of the 72 h test period. Chlorpyrifos caused 87 to 100% and 47 to 100% mortality in adults and 4th instars of *P. americana*.

The overall results of the four-factor analysis of variance comparing dietary toxicity of fipronil and chlorpyrifos in *P. americana* are summarized in Table 2. Insecticide, followed by diet concentration and feeding assay, were the most significant main effects in the model at 72 h after treatments. Comparison of the percentage of total experimental variation for the percentage of mortality revealed that insecticide and rate explained more of the experimental variations (24.4 and 40.1%, and 51.1 and 21.4% at 24 and 72 h after exposure, respectively) than the other significant main effects. Also, among the main effects, stage described the least experimental variation (0.4 and 0.5% at 24 and 72 h, respectively). This indicates that the efficacy of fipronil did not differ significantly among adult males and 4th instar stages.

The dietary activity of fipronil and chlorpyrifos, against *B. germanica* and *P. americana* were compared at various time periods for each diet concentration in both feeding bioassays (Table 3). Both compounds were toxic to adult males at all concentrations. Fipronil caused significantly higher nymphal mortality than chlorpyrifos 48–72 h after exposure in both feeding bioassays.

Oral toxicity – Population chamber bioassay. Fipronil was more effective and faster in killing *P. americana* than Raid Roach and Combat baits (Table 4). The speed of kill in this test ranked (ascending LT50) as follows: fipronil $<$ Raid $<$ Combat, and these LT50's were significantly different from each other (no overlap in 95% FL).

The differential rate of kill was detected by ANOVA of percentage (nymphs and adults) cumulative mortality 1 d after baiting (Table 4). fipronil-induced mortality was significantly ($P < 0.05$) higher than those caused by Raid and Combat. At the end of the 14 d test period, the percent mortality increased sharply and reached 96.5, 93.4, and 84.6 for fipronil, Raid, and Combat baits, respectively. The percent mortality for control cockroaches at day 1, 3, 7, and 14 was 3.3, 6.7, 8.0 and 8.7, respectively.

Bait attractancy test. Figure 3 presents the cumulative mean number of foraging *P. americana* and *B. germanica* on fipronil and Combat bait matrices, and alternative foods. *P. americana* were attracted more to fipronil than to Combat bait matrix or other alternative foods. The attractancy ratios (bait:laboratory diet) for fipronil and Combat bait matrices were 2:1 and 1.5:1, respectively. *B. germanica* were attracted similarly to fipronil and Combat bait matrices. *B. germanica* attractancy ratios for fipronil and Combat matrices were 1.3:1 and 1:1, respectively.

In this study, fipronil bait base was attractive to both cockroach species. Differences in percentage mortal-

Table 1. Topical toxicity of acetone solutions of fipronil and chlorpyrifos to *B. germanica* and *P. americana*

Cockroach species	Strain	Insecticide	Time (h)	X^{2a}	Slope ± SE	LD50[b]	95% FL	
B. germanica	JWax	Fipronil	6	91.4*	4.5 ± 2.3	0.36	–0	– 0
			24	12.4*	3.0 ± 0.5	0.12	0.01	– 0.17
			48	24.9*	2.4 ± 0.7	0.04	0.01	– 0.07
			72	11.4*	6.8 ± 1.4	0.03	0.02	– 0.04
		Chlorpyrifos	6	7.3	0.9 ± 0.3	7.74	2.10	– >100
			24	4.5	0.8 ± 0.2	1.60	0.74	– 9.37
			48	13.2*	0.6 ± 0.2	0.28	0.07	– >100
			72	14.6*	0.1 ± 0.1	0.06	0.02	– 0.11
P. americana		Fipronil	6	0.7	2.6 ± 0.5	0.15	0.10	– 0.21
			24	3.3	2.0 ± 0.4	0.08	0.05	– 0.12
			48	0.5	3.0 ± 0.9	0.03	0.02	– 0.05
			72	0.0	16.0 ± >100	0.02	–0	– 0
		Chlorpyrifos	6	2.9	8.5 ± 1.9	0.33	0.28	– 0.37
			24	4.1	8.3 ± 1.9	0.32	0.27	– 0.36
			48	1.3	10.5 ± 2.6	0.29	0.25	– 0.32
			72	13.2*	2.9 ± 0.9	0.16	0.02	– 0.35

[a] Pearson's X^2 goodness of fit test (SAS Insitute, 1990). Excessively large X^2 values have failed this test and are indicated by an asterisk (*). A *t*-value of >1.96 (2.45–2.64) was used to compute the fiducial limits. For each time after topical application, the number of observations (time intervals x no. of insects) included in the regression analysis (from which LD_{50}values were calculated) was 240 for *B. germanica* and 84 for *P. americana*.
[b] μg/g expressions for all dosage estimators. LD50 with overlapping 95% CL are not significantly different. Diet concentrations evaluated for *B. germanica* were 1, 2, 3, 4, 10, 20, 30, and 40 ppm. Diet concentrations evaluated for *P. americana* were 40, 100, 400, 600, 800, 1000, and 4000 ppm.

Table 2. The overall full-model ANOVA (with insecticide, feeding assay, stage, and diet concentration as the main effects) for *B. germanica* and *P. americana* mortality at selected time after treatment in the dietary toxicity bioassay

Cockroach species	Source		24 h			72 h		
		df	F	P[a]	%TEV[b]	F	P	%TEV
B. germanica	Insecticide	1	41.9	**	29.3	27.6	**	12.6
	Feeding Assay	1	0.3	ns	0.2	33.0	**	15.1
	Stage	1	46.3	**	32.4	67.0	**	30.7
	Diet Concentration	3	4.0	*	8.4	4.4	**	6.1
P. americana	Insecticide	1	39.1	**	24.4	121.5	**	40.1
	Feeding Assay	1	6.4	*	4.0	48.2	**	15.9
	Stage	1	0.7	ns	0.4	1.5	ns	0.5
	Diet Concentration	3	27.3	**	51.1	21.7	**	21.4

[a] ns, *, and ** indicate non-significance and significance at the 5 and 1% levels, respectively.
[b] %TEV = percentage of total experimental variation = (source sum of square/model sum of square) × 100.

Table 3. Comparison of dietary activity of fipronil (Fip.) and chloropyrifos (Chl.) at different toxic-diet concentrations against adult males and 4th instar nymphs of *B. germanica* and *P. americana* in an abbreviated (Abb.) or continuous (Cont.) feeding assay

Species	Diet Conc. (ppm)	Feeding bioassay	Insecticide	% mortality of males					% mortality of 4th instars				
				8	16	24	48	72 h	8	16	24	48	72 h
B. germanica	100	Abb.	Fip.	7	17	100	100	100	0	20*	77	80	87
			Chl.	0	3	67	90	90	0	0	77	80	80
		Cont.	Fip.	0	33**	100**	100	100	3	17	57	87	100
			Chl.	0	0	57	97	100	0	7	37	80	100
	250	Abb.	Fip.	0	100	100	100	100	0	20**	67	77	80
			Chl.	0	7	30	83	87	0	0	47	47	47
		Cont.	Fip.	0	100**	100	100	100	0	17**	57	77	93
			Chl.	0	0	53	90	100	0	0	40	70	87
	500	Abb.	Fip.	13	100**	100	100	100	0	20	70	87	93
			Chl.	0	3	70	90	100	0	7	67	73	73
		Cont.	Fip.	0	100	100	100	100	3	17	63	90**	100*
			Chl.	0	3	77	97	100	0	3	30	57	87
	1,000	Abb.	Fip.	27*	100**	100	100	100	0	37*	70*	90**	93**
			Chl.	0	3	77	93	97	0	33	50	57	57
		Cont.	Fip.	13.3	100**	100	100	100	3	23	87	90	90
			Chl.	0	0	100	100	100	0	10	53	67	87
P. americana	1,000	Abb.	Fip.	0	0	8	42	42	0	0	17	58*	58**
			Chl.	0	0	8	25	33	0	0	0	17	25
		Cont.	Fip.	0	0	17	50	50	0	8	25	83	92*
			Chl.	0	0	8	42	42	0	0	8	33	42
	2,500	Abb.	Fip.	0	0	17	42	42	0	0	25	50	58
			Chl.	0	0	17	33	42	0	0	8	17	33
		Cont.	Fip.	0	0	17	50	67	0	8	33	92**	100**
			Chl.	0	0	8	42	60	0	0	8	33	42
	5,000	Abb.	Fip.	0	8	50	58	75	0	17	50**	83*	83*
			Chl.	0	0	33	50	58	0	0	8	25	33
		Cont.	Fip.	0	25	58	75	83	0	33	75**	100**	100**
			Chl.	0	17	50	75	75	0	0	17	42	50
	10,000	Abb.	Fip.	0	0	42	67	75	0	8	50**	75*	92
			Chl.	0	0	33	42	50	0	8	17	33	42
		Cont.	Fip.	0	13	63	88	88	0	17	58*	100**	100**
			Chl.	0	8	42	67	75	0	0	25	42	58

* or ** indicates significant differences between insecticides at the 5 and 1% levels, respectively, for each strain, diet concentration and feeding bioassay.

ity for fipronil and Combat baits to *P. americana* was probably caused by differences in palatability (i.e., bait attractancy and acceptance) of the bait. If the bait base is most attractive to the target pest species, some species specificity can be achieved so that risks to nontarget organisms are reduced (Reid et al., 1990). Therefore, the use of toxic baits may be compatible with environmentally sound integrated pest management programs.

Most insecticides are repellent to *B. germanica*, especially when offered in bait (Reierson, 1995). However, based on the high percentage of mortality at the end of the 14 d test period in large population chambers, the three baits were not repellent to both cockroach species and some had good acceptance (i.e., fipronil and Combat in the bait attractancy test). Good acceptance has also been reported for baits containing abamectin (Cochran, 1985), sulfluramid and hydramethylnon (Reid et al., 1990).

Table 4. Speed of kill (LT50) and percentage of mortality in mixed-age groups of *P. americana* fed fipronil, Raid, and Combat baits

Bait (% a.i.)	n[a]	χ^{2b}	Slope ± SE	LT50[c]	95% FL	% Mortality at day[d]			
						1	3	7	14
Fipronil (0.05)	700	7.9	1.7 ± 0.2	0.8	0.5–1.1	46.0 a	88.0 a	95.3 a	96.5 a
Raid Roach (0.528)	700	2.2	1.7 ± 0.2	2.4	1.9–2.8	28.0 b	55.4 b	78.6 b	93.4 ab
Combat (1.65)	700	41.3*	3.3 ± 0.5	7.6	6.4–8.9	3.3 c	9.8 c	39.3 c	84.6 b
F						24.4	178.7	103.4	5.3
P						< 0.01	< 0.01	< 0.01	0.04

[a] Number of trials included in the regression analysis.
[b] Since the χ^2 is small ($P < 0.100$), fiducial limits were calculated using a *t*-value of 1.96. The large χ^2 (value with asterisk) is not caused by systematic deperature from the model; at value of 2.11 were used in computing fiducial limits.
[c] Number of days before death of 50% of the test population following exposure to toxic baits.
[d] Means in the same column followed by the same letters are not significantly different (LSD test; $P > 0.05$).

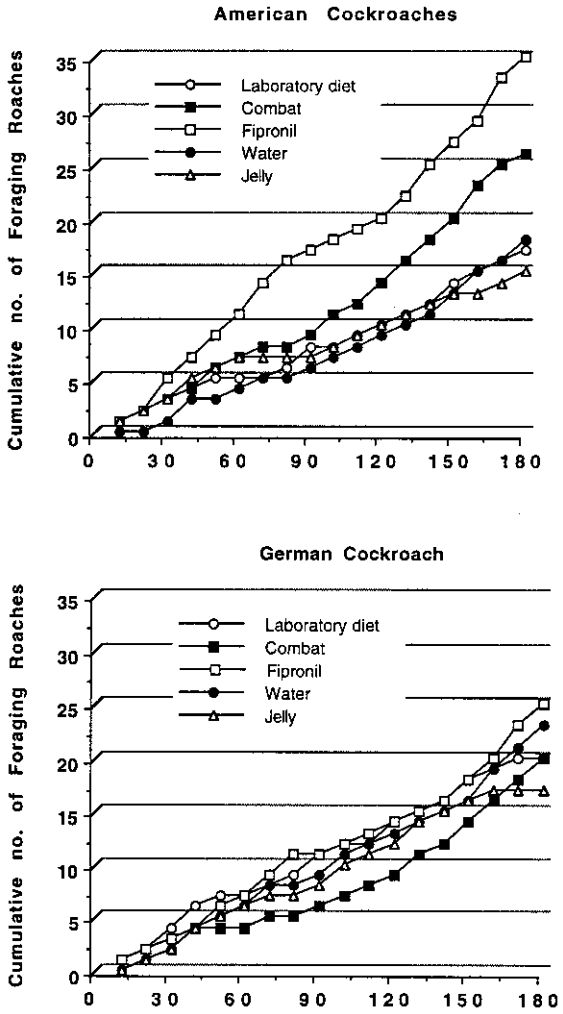

Figure 3. Attraction of *B. germanica* and *P. americana* to fipronil and Combat bait matrix in the presence of alternative foods.

Fipronil is an effective toxicant for *B. germanica* and *P. americana* control and has considerable potential for use in baits. However, cross resistance between dieldrin and fipronil in *Drosophila* conferred by earlier selection with dieldrin (Cole et al., 1995) may indicate a phenomenon (Kaku & Matsumura, 1994) that could occur in *B. germanica.* Additional research to test fipronil against dieldrin resistant *B. germanica* may be necessary to fully understand if the cross resistance will occur.

In conclusion, the insecticidal properties of this compound make it well-suited for the control of cockroaches in an urban setting. Based on our characterization of the activity of fipronil, this compound can be effective as a toxic bait against *B. germanica* and *P. americana* in field settings, provided that effective application rates and formulations are economically feasible. Further research to develop treatment strategies for the inclusion of fipronil in integrated cockroach management programs would be worth considering.

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References

Abbott, W. S., 1925. A method of computing the effectiveness of an insecticide. Journal of Economic Entomology 18: 265–267.

Appel, A. G., 1990. Laboratory and field performance of consumer bait products for German cockroach (Dictyoptera: Blattellidae) control. Journal of Economic Entomology 83: 153–159.

Appel, A. G., 1992. Performance of gel and paste bait products for German cockroach control: laboratory and field studies. Journal of Economic Entomology 85: 1176–1183.

Appel, A. G. & E. P. Benson, 1995. Performance of abamectin bait formulations against German cockroaches (Dictyoptera: Blattellidae). Journal of Economic Entomology 88: 924–931.

Appel, A. G., D. A. Reierson & M. K. Rust, 1983. Comparative water relations and temperature sensitivity of cockroaches. Comparative Biochemistry and Physiology 74A: 357–361.

Brenner, R. J. & R. R. Pierce, 1991. Seasonality of peridomestic cockroaches (Blattoidea: Blattidae): mobility, winter reduction, and effect of traps and baits. Journal of Economic Entomology 84: 1735–1745.

Cheng, T. H. & F. L. Campbell, 1940. Toxicity of phosphorus to cockroaches. Journal of Economic Entomology 33: 193–199.

Cochran, D. G., 1985. Mortality and reproductive effects of avermectin B1 fed to German cockroaches. Entomologia Experimentalis et Applicata 37: 83–88.

Cole, L. M., R. A. Nicholson & J. E. Casida, 1993. Action of phenylpyrazole insecticides at the GABA-gated chloride channel. Pesticide Biochemistry and Physiology 46: 47–54.

Cole, L. M., R. T. Roush & J. E. Casida, 1995. *Drosophila* GABA-gated chloride channel: Modified [^{3}H]EBOB binding site associated with Ala^{302} $\longrightarrow$ Ser or Gly mutants of *Rdl* subunit. Life Sciences 56: 757–765.

Colliot, F., K. A. Kukorowski, D. W. Hawkins & D. A. Roberts, 1992. Fipronil: A new soil and foliar broad spectrum insecticide. Brighton Crop Protection Conference (Pest and Diseases 1992), pp. 29–34.

DeMark, J. J., 1988. Effects of chitin synthesis inhibitors on nymphal and oothecal stages of the German cockroach, *Blattella germanica* (L.). M.S. thesis, Purdue University, West Lafayette, IN, (USA).

Frishman, A., 1982. Cockroaches. In: A. Mallis (ed.), Handbook of Pest Control. 6th ed. Franzak & Foster, Cleveland, Ohio, USA pp. 101–154.

Hagenbuch, B. E., P. G. Koehler, R. S. Patterson & R. J. Brenner, 1988. Peridomestic cockroaches (Orthoptera: Blattidae) of Florida: their species composition and suppression. Journal of Medical Entomology 25: 377–380.

Hatton, L. R., D. W. Hawkins, C. J. Pearson & D. A. Roberts, 1988. Derivatives of N-phenylpyrazoles. E. P. Patent 295117.

Kaakeh, W. & G. W. Bennett, 1996. Speed of action in Siege and Maxforce gel baits (1995). In: A. K. Burditt (ed.), Arthropod Management Tests, vol. 21. Entomological Society of America, Lanham, MD, USA, pp. 391–392.

Kaku, K. & F. Matsumura, 1994. Identification of the site of mutation within the M2 region of the GABA receptor of the cyclodiene-resistant German cockroach. Comparative Biochemistry and Physiology 108C: 367–376.

Koehler, P. G. & R. S. Patterson, 1986. A comparison of insecticide susceptibility in seven nonresistant strains of the German cockroach, *Blattella germanica* (Dictyoptera: Blattellidae). Journal Medical Entomology 74: 678–680.

Koehler, P. G., T. H. Atkinson & R. S. Patterson, 1991. Toxicity of Abamectin to cockroaches (Dictyoptera: Blattellidae, Blattidae). Journal of Economic Entomology 84: 1758–1762.

Koehler, P. G., C. A. Strong, R. S. Patterson & S. M. Valles, 1993. Differential susceptibility of German cockroach (Dictyoptera: Blattellidae) sexes and nymphal age classes to insecticides. Journal of Economic Entomology 86: 785.

Lofgren, C. S. & G. S. Burden, 1958. Tests with poison baits against cockroaches. Florida Entomologist 41: 103–110.

Lund, R. D. & G. W. Bennett, 1978. Evaluation of Bolt bait. In: K. A. Sorensen (ed.), Insecticide and Acaricide Tests, vol. 3. Entomological Society of America, College Park, MD, USA, pp. 176–177.

Milio, J. F., P. G. Koehler & R.S. Patterson, 1986. Laboratory and field evaluation of hydramethylnon bait formulations for control of American and German cockroaches (Orthoptera: Blattellidae). Journal of Economic Entomology 79: 1280–1286.

Moffat, A. S., 1993. New chemicals seek to outwit insect pests. Science 261: 550–551.

My, J., 1994. Nine new insecticides and acaricides. Cultivar-Paris 357: 57–58.

Reid, B. L., G. W. Bannett & S. J. Barcay, 1990. Topical and oral toxicity of sulfluramid, a delayed-action insecticide, against the German cockroach (Dictyoptera: Blattellidae). Journal of Economic Entomology 83: 148–152.

Reierson, D.A., 1995. Baits for German cockroach control. In: J. M. Owens, M. K. Rust & D. A. Reierson (eds.), Understanding and Controlling the German Cockroach. Oxford University Press, Oxford, pp. 231–265.

Reierson, D. A., M. K. Rust, A. M. VanDyke & A. G. Appel, 1983. Control of German cockroaches with amidinohydrazone bait, In: A. C. York (ed.), Insecticide and acaricide tests, vol. 8. Entomological Society of America, College Park, MD, USA, p. 54.

Rust, M. K., 1986. Managing household pests. In: G. W. Bennett & J. M. Owens (eds.), Advances in Urban Pest Management. Van Nostrand Reinhold, New York. pp. 335–386.

Rust, M. K. & D. A. Reierson, 1981. Attraction and performance of food materials in insecticidal baits for German cockroach control. International Pest Control 23: 106–109.

SAS Institute, 1990. SAS User's Guide: Statistics. SAS Institute, Cary, NC, USA.

Valles, S. M., S. J. Yu & P. G. Koehler, 1996. Biochemical mechanisms responsible for stage-dependent propoxur tolerance in the German cockroach. Pesticide Biochemistry and Physiology 54: 172–180.