Relationship Between Insecticide Resistance and Performance in Choice Tests of Field-Collected German Cockroaches (Dictyoptera: Blattellidae)

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ABSTRACT Topical application (LD) and time–mortality response (LT) methods were used to determine resistance levels of field-collected strains of the German cockroach, *Blattella germanica* (L.). LD_{50}s for chlorpyrifos were determined for seven strains. LT_{50}s and LT_{90}s with eight insecticides were determined for another three strains. Resistance ratios (RR) of >10 to chlorpyrifos (LD_{50}) were directly related to a significant decrease in activity in Ebeling choice-box tests. Using the LT method, the three field-collected strains were shown to possess zero to moderate resistance at the RR_{50} level (0.9–5.3) to organophosphates, moderate to high resistance to (1.4–>21.0) to carbamates, moderate to high resistance (4.3–20) to cypermethrin, and high resistance (>17–>35) to synergized pyrethrins. When the three field-collected strains were tested in choice boxes, RR_{50}s of 1.2–2.2 for chlorpyrifos and 2.5–5.3 for diazinon directly related to significantly lower efficacy. Low-level propoxur resistance (RR_{50} of 1.4–2.3) also reduced choice-box efficacy, but an RR_{50} of 0.9–1.3 for acephate did not reduce its performance. Cypermethrin deposits used in choice tests killed cockroaches exhibiting RR_{50}s as high as 20 in the lethal time test, perhaps because resistance mechanisms could not detoxify the exceptional activity of the active ingredient formulated as a wettable powder. Because they were repellent, residual deposits of pyrethrins resulted in poor efficacy in choice tests with either susceptible or field-collected strains. Strains with low-level physiological resistance as measured by the time–mortality response method survived insecticide exposure in choice-box tests to certain organophosphate and carbamate insecticides, indicating that these compounds would not be effective in the field.

KEY WORDS *Blattella germanica*, insecticide resistance, choice test

INSECTICIDE RESISTANCE in the German cockroach, *Blattella germanica* (L.), has been widely documented but there has been limited mention of the effect of resistance on control. In several instances cockroaches collected where insecticide applications failed to provide control have been shown to be resistant to insecticide (Barson & McCheyne 1978, Rust & Reierson 1978, Schal 1988). It is often presumed that control failures appear as high levels of resistance are reached. The degree of resistance of a field strain is often expressed in terms of a resistance ratio (RR), a comparison of the dose or time required to kill a percentage of the field strain with the dose or time required to kill the same percentage of a susceptible strain. Barson & McCheyne (1978) reported that two field strains of cockroaches which were collected where bendiocarb failed to provide control had resistance ratios of 5.6 and 6.2 (LT_{50}, time–mortality response method), both strains surviving 60-min exposure on residual deposits of 110 mg bendiocarb/m^2. Susceptible cockroaches succumbed on deposits of 8.5 mg/m^2. Rust & Reierson (1978) found that a 14-fold RR (LD_{50}, topical application) to diazinon resulted in the decreased performance of diazinon deposits against that strain of cockroach in choice boxes. The progeny of cockroaches surviving repetitive application of insecticide in public housing were resistant to bendiocarb, chlordane, diazinon, malathion, and propoxur (Nelson & Wood 1982). Ballard et al. (1984) observed that 10-fold resistance (topical application) to chlorpyrifos resulted in a measurable decrease in the level of cockroach control. Schal (1988) reported that chlorpyrifos failed to reduce German cockroach populations significantly in apartments he examined, even though the RR (LT_{50}) of progeny of survivors was very low (1.34). However, no attempt has been made to use laboratory techniques to determine the effect

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of insecticide resistance on control or for predicting threshold levels of control.

The Ebeling choice box provides a method of determining the potential performance of insecticides and a way to establish threshold levels of resistance. The objectives of this study were to determine the relationships between levels of insecticide resistance among field-collected *B. germanica* and the performance of insecticides in laboratory choice-box tests and to predict field performance based on the results of those tests.

Materials and Methods

Test Insects. Live German cockroaches collected by cooperators in 1985–1986 were sent to University of California, Riverside, from the following facilities where control failures with registered pesticides were suspected: a hospital in New York City (HNY); an apartment in New York City (26F); a restaurant in Tacoma, WA (TW); an apartment in Tacoma, WA (TA); an apartment in Santa Ana, CA (T-37-8); a bakery in Downey, CA (ABB); and a mess hall at a military base at Twenty-Nine Palms, CA (290C). At least 50 cockroaches, with no regard to sex or stadia, were collected from each site, and >200 were collected from some. These cockroaches were reared in 3.9-liter glass jars provisioned with dry Purina dog chow (no. 43850; Ralston Purina, St. Louis, MO), water and cardboard shelter until there were sufficient numbers to test, usually within three generations. Cockroaches were also collected from a mess hall on a military base in Kentucky (K851) in January 1986, an apartment complex in the Republic of Panama (B2616) in September 1986, and an apartment complex in Indiana (B1002) in October 1986. These collections were reared in plastic or polycarbonate jars provisioned with dry Purina Rodent Laboratory chow no. 5001, water, and cardboard harborage. Nymphs were removed and reared separately from the parental stock so there was no mixing of generations. Rearing and testing were completed in three generations.

The sensitivity and reaction of the field-collected cockroaches were compared with two susceptible laboratory strains of *B. germanica*. The Orlando normal strain (USDA) was used for time–mortality tests and the UCR strain (provided >25 years ago from Orlando normal) was used for topical tests. Both susceptible strains were used in choice-box tests. We have been unable to detect any difference of insecticide sensitivity between these two susceptible strains.

Insecticides. Resistance ratios based on contact exposure and topical tests were determined with technical grade insecticides diluted in acetone. Because formulated insecticides are used to control *B. germanica* under field conditions, we used commercial formulations and registered application rates in choice boxes. A series of representative insecticides was used in the study. The carbamates included bendiocarb (technical and Ficam W, 76% wettable powder) and bendiocarb plus pyrethrins synergized with piperonyl butoxide (9.6:1.0:2.5, Ficam Plus) (NOR-AM Chemical, Wilmington, DE.) and propoxur (technical and Baygon 1.5 emulsifiable concentrate [EC], Miles, Kansas City, MO). Organophosphates included acephate (technical and Orthene PCO II, Chevron Chemical, San Francisco, CA); chlorpyrifos (technical and Dursban LO 4EC, DowElanco Chemical, Indianapolis, IN); diazinon (technical and Diazinon 4EC, CIBA-GEIGY, Greensboro, NC); and propetamphos (technical and Safrotin 4EC, Sandoz, Basel, Switzerland). The pyrethrins synergized with piperonyl butoxide (1:10) was Pyrenone (EC 60–6, Fairfield American, Newark, NJ) and the pyrethrins synergized with piperonyl butoxide (1:2) and MGK-264 (1:3.3) was Pyrocide (McLaughlin Gormly King, Minneapolis, MN). The pyrethroid tested was cypermethrin (technical and Demon 40WP, ICI Americas, Wilmington, DE).

Resistance Determinations. The insecticidal activity of each insecticide against adult male cockroaches was determined by topical application or by a jar exposure method (Burden 1974). Topical applications were made with an ISCO model M microapplicator (Instrument Specialities, Seward, NE). Cockroaches anesthetized with CO_2 were treated with 1 μl acetone solution of chlorpyrifos. A 27-gauge needle (Becton, Dickinson, Rutherford, NJ) on a glass tuberculin syringe was used to place a microdroplet of solution on the ventral aspect of the penultimate abdominal segment. Six to ten cockroaches were treated with each of five to seven concentrations of chlorpyrifos that provided between 10 and 90% kill; this was replicated three to five times. Treated insects were placed in glass jars (0.95 liter) provisioned with food, water, and harborage and the number dead or moribund was counted 24 h after treatment. The insects were considered dead if they could not right themselves within 2 min of being turned upside down. Mortality was analyzed by probit analysis and the dose of chlorpyrifos (μg) to produce 50% mortality by 24 h (LD_{50}) was determined (Raymond 1985).

Contact exposures were conducted with glass jars (473 ml) treated with acetone solutions. Cockroaches were confined in the jars by a 2:1 mixture of petroleum and mineral oil applied to the inner lip. A 2.5-ml acetone solution of insecticide was swirled to dryness over the inner surface of each jar until the acetone evaporated, resulting in a uniform deposit over the inside surface of the jar. Concentrations of organophosphates and carbamates were selected to ensure complete knockdown of the susceptible strain within 90 min. Concentrations of pyrethrins and cypermethrin were the highest that could be applied and still obtain data adequate to calculate a probit line for the susceptible strain.

Ten adult male cockroaches (7–14 d old) were exposed in each treated jar. A time–dose response plot was calculated from the data. Cockroaches were considered knocked down (KD) when they were lying on their dorsum and unable to right themselves. The number of cockroaches KD was recorded at 2.5-min intervals for the first 15 min, 5-min intervals for the duration of the first hour, 10-min intervals during hour 2, 15-min intervals during hour 3, and 30-min intervals during hours 4–7. The number KD at 24 h was also recorded.

Contact exposure tests were made on three different days with a total of 12 replicates, the exception being that in those strains where an LT_{50} was not attained within 7 h, only nine replicates were used. Data from the replicates were pooled and analyzed by probit analysis (at U.S. Army Environmental Hygiene Agency) using a computer program modified from Daum (1970). For those strains or treatments that were clearly heterogeneous with a distinctive plateau, regression lines were calculated for both subsets of the data (Daum 1970). Regression lines were not determined for strains or treatments that did not reach 50% KD within 7 h.

Resistance ratios (RR_{50} and RR_{90}) were calculated by dividing the LD_{50} or the LT values of the field strains by the corresponding dose or time values for the Orlando normal or UCR susceptible strains.

Choice-Box Tests. Residual deposits of insecticide were tested in choice boxes similar to those used by Ebeling et al. (1967). The sides of the boxes were constructed from pine drawer siding (30.5 by 9.5 cm) and each box had a tempered masonite floor. A wooden vertical panel divided the box into two equal compartments. The panel had a hole (1.3 cm diameter) near the top center that allowed cockroaches to move between compartments.

For these tests, insert panels of masonite (15 by 30.5 cm) were treated with 3 ml aqueous insecticide preparation spread uniformly over the panel with a camel's-hair brush and allowed to dry for 30 h. These panels were then placed in the bottom of the compartment which was then kept dark. Dog chow and a water jar were placed in the untreated light compartment. Both compartments were covered with transparent sheet lucite; the treated compartment also was covered with a piece of masonite to keep that compartment dark. Twenty adult male German cockroaches were released into the untreated compartment, and a cork placed in the partition hole was removed from the partition hole 3 h later, when the cockroaches settled. The cockroaches then had access to the dark compartment containing the treated insert. Untreated boxes were set up in similar fashion with each strain tested. The room in which the choice boxes were used was kept on a photoperiod of 12:12 (L:D) h. The test was replicated five times per strain. The number and location of live and dead cockroaches in the boxes were recorded for up to 14 d.

The association between the RR of chlorpyrifos (LD method) and the average percentage mortality in choice boxes at 14 d was analyzed with a Kendall's coefficient of rank correlation test (Sokal & Rohlf 1981). Using MSTAT (Microcomputer Statistical Program, Michigan State University, East Lansing), the percentage mortality data from choice boxes was treated with an arcsine transformation and analyzed with an analysis of variance (ANOVA), and means were separated by Tukey's honestly significant difference test. Day 14 was selected for analysis to allow sufficient time to account for slow-acting insecticides.

Results and Discussion

Based on the LT method, field strains K851, B2616, and B1002 had high levels of resistance to some insecticides. Their RR_{50} values ranged from >17 to >35 with synergized pyrethrins and 4.3 to 20 with cypermethrin (Table 1). On the other hand, the RR_{50}s of these three strains were fairly low with the organophosphates tested, ranging from 1.2 to 2.2 with chlorpyrifos, 1.7 to 5.3 with diazinon, and 0.9 to 1.3 with acephate. All three strains were >9-fold resistant to propoxur at the LT_{90} level, the slopes of the dose–response plots for propoxur being lower than for the susceptible strain. Deposits of propoxur failed to kill 100% of the cockroaches at 24 h. Similarly, low slope values found with the cypermethrin plots indicated much greater resistance differences at the LT_{90} level than at the LT_{50} level. Clearly, some cockroaches were extremely resistant to propoxur and cypermethrin.

According to Cochran (1989), RRs of 1.0–2.0 provided by the time–mortality response method (LT) indicate little, if any, resistance; values between 2.0 and 10.0 indicate moderate resistance; and RRs >10 indicate high levels of resistance. The basis for categorizing resistance ratios as low, moderate, and high depends upon the assay technique used (Brown & Pal 1971, Collins 1975). In comparative studies of insecticide resistance assays of German cockroaches, Collins (1975) found that the LT method provided consistently lower RR for diazinon and propoxur than did topical applications. Similarly, Milio et al. (1987) found that an LT_{50} resistance ratio of 1.99 was equivalent to 14.09 RR by the topical application method, suggesting that the LT test may not be particularly useful for organophosphate insecticides.

We used choice boxes in this study because for many insecticides choice boxes provide a reli-

Table 1. Comparison of resistance data of field-collected *B. germanica* determined by the time–mortality response method and performance of 1-d-old residual deposits at 14 d in choice boxes

Strain and insecticide[a]	*n*	Slope ± SE	LT_{50} Min (95% FL)	RR_{50}[b]	LT_{90} Min (95% FL)	RR_{90}[b]	% KD at 24 h	% Dead in choice box at day 14[c]
K851								
Chlorpyrifos	120	5.9 ± 0.2	120 (113–129)	2.2	198 (177–220)	3.2	100	15
Diazinon	120	5.7 ± 0.2	259 (239–279)	5.3	434 (377–499)	>7.4	100	48
Propetamphos	120	6.3 ± 0.2	79 (73–84)	1.3	125 (113–139)	1.7	100	82
Acephate	120	6.0 ± 0.2	67 (62–72)	1.3	110 (98–122)	1.5	100	75
Pyrethrins + MGK 264 1:3	90	—	>420	>35	>420	>21		0
Cypermethrin	120	1.1 ± 0.0	178 (159–199)	20	>420	>32	92	100
Propoxur	120	4.2 ± 0.2	32 (29–36)	1.4	>420	>14	93	57
Bendiocarb	90	6.7 ± 0.4	>420	>21	>420	>13	41	67
B2616								
Chlorpyrifos	120	7.0 ± 0.3	104 (97–111)	1.6	158 (143–176)	2.1	100	25
Diazinon	120	4.0 ± 0.1	131 (119–143)	2.5	276 (238–319)	4.2	100	77
Acephate	120	6.2 ± 0.3	52 (49–56)	0.9	84 (75–95)	1.0	100	92
Pyrethrins + PBO 1:2	90	—	>420	>21	>420	>5.0	74	7
Cypermethrin	120	1.2 ± 0.1	56 (47–67)	4.4	>420	>14	98	98
Propoxur	120	1.4 ± 0.1	290 (217–387)	9.9	>420	>11	52	7
B1002								
Chlorpyrifos	120	7.4 ± 0.3	78 (73–84)	1.2	117 (105–130)	1.4	100	28
Diazinon	120	5.8 ± 0.2	90 (84–97)	1.7	151 (135–168)	2.4	100	97
Acephate	120	4.9 ± 0.2	65 (60–71)	1.3	118 (105–134)	1.6	100	98
Pyrethrins + PBO 1:2	90	—	>420	>17	>420	>5.2	64	17
Cypermethrin	120	1.9 ± 0.1	67 (58–77)	4.3	323 (251–417)	9.3	100	100
Propoxur	120	3.5 ± 0.2	75 (71–79)	2.3	>420	>9	68	10
Orlando normal								
Chlorpyrifos	120	19.4 ± 1.2	54 (52–56)	—	63 (59–66)	—	100	100
Diazinon	120	19.7 ± 1.3	49 (47–51)	—	57 (53–60)	—	100	97
Propetamphos	120	14.2 ± 0.5	58 (57–60)	—	72 (68–76)	—	100	100
Acephate	120	9.1 ± 0.4	52 (51–54)	—	72 (69–79)	—	100	98
Pyrethrins + MGK 264 1:3	90	5.4 ± 0.3	12 (11–13)	—	21 (18–25)	—	100	—
Pyrethrins + PBO 1:21	90	2.5 ± 0.1	24 (21–28)	—	80 (65–99)	—	100	33
Cypermethrin	120	6.6 ± 0.2	9 (8–9)	—	13 (13–15)	—	100	100
Propoxur	120	11.7 ± 0.4	23 (22–26)	—	31 (28–34)	—	100	97
Bendiocarb	120	6.7 ± 0.4	20 (18–23)	—	32 (28–35)	—	—	100

[a] Insecticides prepared from technical material. Deposited 2.5 acetone solution to provide the following (μg(AI) per jar): pyrethrins, 125 (0.48 $\mu g/cm^2$); propoxur, 250; cypermethrin, 500; chlorpyrifos, diazinon, acephate, and bendiocarb, 1,250; propetamphos, 3,750.

[b] Resistance ratios (RR) calculated as ratio of LT of test strain/LT of Orlando normal strain.

[c] See Table 3 for complete choice-box data.

able estimate of field performance of sprays, dusts, and baits against German cockroaches (Ebeling et al. 1967, Rust & Reierson 1978, Appel 1990, Appel & Abd-Elghafar 1990). Choice-box data, however, must be carefully interpreted, especially when testing wettable powder (WP) formulations of extremely active ingredients such as pyrethroids. WP formulations prevent absorption of active ingredients into surfaces and are readily picked up by cockroaches that touch them. Momentary exposure to cypermethrin-treated surfaces or transfer of insecticide by contact with other cockroaches killed by cypermethrin may result in 100% kill of the cockroaches within 24 h (Schneider 1983). On the other hand, Rust & Reierson (1988) found that porous substrates, oils, and grease may dramatically reduce the contact activity of pyrethroids. As the rapid contact activity of pyrethroids increases, the likelihood of repellency increases. As concentration and contact activity decrease, repellency declines. Schneider & Bennett (1985) concluded that usefulness of laboratory tests in predicting repellency in field situations was limited, but they did not test the choice box under conditions as described by Ebeling et al. (1966). However, Rauscher et al. (1985) concluded that light and presence or absence of insecticides affect German cockroach distribution in choice boxes over time. Their tests indicated that chlorpyrifos was repellent, but the repellency they observed may have been attributable to treatment with a greater concentration of active ingredient. They used 50.8 mg (AI)/929 cm^2 instead of the normal 30.2 mg (AI)/929 cm^2 that Ebeling used in choice boxes (Ebeling et al. 1966). Appel (1990) found that choice-box performance indices designed by Rust & Reierson (1978) accurately predicted field performance. Although insecticides do not always perform as well under field conditions as choice-box data would suggest (Rust & Reierson 1988), we are aware of no instances in which insecticides have performed better in field trials than would be suggested by the choice-box test. Poor correlation with field results may be attributable to the

Table 2. Comparison of topically determined LD_{50} and efficacy of deposits of 0.5% chlorpyrifos EC against field-collected German cockroaches in choice boxes

Location	Strain	*n*	Topical application[a]			Topical RR[b]	% Dead in choice box at day		
			LD_{50}	(95% FL)	Slope ± SE		1	7	14
Laboratory	UCR	400	0.24	(0.215–0.262)	4.2 ± 0.44	—	98.3	100	
Hospital, NY	HNY	84	0.77	(0.574–1.000)	3.1 ± 0.69	**3.23**	73.3	93.3	98.3
Apartment, NY	26F	108	1.22	(0.998–1.498)	3.6 ± 0.59	**5.10**	38.7	81.7	96.7
Apartment, WA	TA	66	1.40	(1.087–1.936)	3.2 ± 0.81	**5.83**	80.0	100	
Apartment, CA	T-37-8	44	1.65	(1.241–2.108)	6.5 ± 1.41	**6.88**	5.0	95.0	98.3
Restaurant, WA	TW	84	1.96	(1.522–2.417)	3.6 ± 0.68	8.17	30.0	81.7	86.7
Bakery, CA	ABB	78	2.51	(2.003–2.966)	5.9 ± 1.34	10.46	31.7	68.3	78.3
Mess Hall, CA	290C	96	4.16	(3.359–6.010)	3.5 ± 0.79	17.33	1.7	10.0	78.3

[a] μg technical chlorpyrifos per male.
[b] Ratio of LD_{50} of field strain ÷ LD_{50} of UCR strain. Ratios in bold represent strains in which 0.5% chlorpyrifos EC would likely have provided good control in field situations.

use of susceptible cockroaches in the choice-box test, whereas resistant cockroaches are encountered under field conditions. We have reported (Rust & Reierson 1978) (and we have repeatedly found) that insecticides and formulations that do not kill >95% of the insects within 14 d in the choice box do not provide good control under field conditions. In summary, Ebeling choice boxes generally measure both the efficacy and repellency of an insecticide rather than only repellency (Rust & Reierson 1978, Rauscher et al. 1985). Choice boxes provide an extremely useful laboratory method to evaluate candidate blatticides.

In this choice-box study, 1-d-old deposits of 0.5% chlorpyrifos in choice boxes killed susceptible strains within 7–14 d but there was significant survivorship of some resistant insects (Table 2). There was a significant positive association between increasing RR with chlorpyrifos (LD, topical) and survivorship at 14 d in choice boxes ($\gamma = 0.732$, $n = 8$, $P < 0.02$). With LD $RR_{50} > 8$, mortality in the choice boxes fell to <90%. Cockroaches surviving the treatment represent a nucleus for reinfestation. This corroborates data by Ballard et al. (1984) indicating that a topical RR_{50} of 10 contributed to poor control with chlorpyrifos in field situations. Rust & Reierson (1991) reported RR_{50} (topical application) of 8–10 among 25 strains of German cockroaches randomly collected from 100 restaurants. These data suggested that resistance was widespread, treated populations were likely to recover quickly, and that alternate pest control strategies involving a change of insecticide use pattern were clearly warranted in these restaurants.

Compared with their effects on the Orlando normal strain, deposits of bendiocarb, chlorpyrifos, or propoxur provided significantly lowered kill of all three field-collected strains (Table 3). An $RR_{50} > 1.2$ for chlorpyrifos and >1.4 for propoxur by the LT method was associated with reduced efficacy in the choice-box tests. The performance of diazinon deposits decreased when the RR_{50} values exceeded 2.5. Deposits of 0.05% and 0.1% cypermethrin provided nearly complete kill with all strains, including the Orlando normal strain. Resistance ratios as high as 20-fold at the LT_{50} level did not decrease the performance of the residual deposits of cypermethrin. Schal (1988) reported that applications of cypermethrin in infested apartments provided excellent control despite RR_{50} of 4.51 by the LT method. However, Zhai & Robinson (1991)

Table 3. Performance of 1-d-old residual aqueous deposits of various insecticides against three field-collected strains of German cockroach in choice boxes

Insecticide, %	Formulation[b]	μg (AI)/cm^2	% Males dead (± SEM) at day 14[a]			
			K851	B2616	B1002	Orlando normal
Acephate, 1.0	SP	64.59	75 ± 5.8b-e	**92 ± 3.3abc**	**98 ± 1.7ab**	98 ± 1.7ab
Bendiocarb, 0.5	WP	32.29	67 ± 8.8c-f	20 ± 5.0gh	28 ± 4.4fgh	98 ± 1.7ab
Chlorpyrifos, 0.5	EC	32.29	12 ± 4.4gh	25 ± 2.9fgh	28 ± 13.5fgh	100a
Cypermethrin, 0.01	WP	6.46	**100a**	**98 ± 1.7ab**	**100a**	100a
Cypermethrin, 0.05	WP	3.22	**100a**	**97 ± 1.7ab**	**97 ± 3.3ab**	100a
Diazinon, 1.0	EC	64.59	48 ± 7.3d-g	77 ± 4.4a-e	**97 ± 3.3ab**	97 ± 1.7ab
Propetamphos, 1.0	EC	64.59	82 ± 1.7a-d	**95 ± 2.9abc**	**92 ± 6.7abc**	100a
Propoxur, 1.1	EC	71.04	57 ± 8.3d-e	7 ± 4.4h	10 ± 5.8h	97 ± 3.3ab
Pyrethrins + PBO	EC	310.00	17 ± 4.4gh	7 ± 1.7h	17 ± 4.4gh	33 ± 11.7e

[a] In columns and rows, percentages followed by the same letter are not significantly different ($P < 0.05$, Tukey's HSD); $n = 3$. Based on choice-box studies, only values in bold indicate treatments likely to provide good performance in field situations against that particular field strain.
[b] Formulations included soluble powder (SP), wettable powder (WP), and emulsifiable concentrate (EC).

found that applications of cypermethrin in apartments infested with populations with RR_{50} of 150 by the topical method failed to provide control. As expected, residual deposits of synergized pyrethrins failed to kill any of the strains, including the susceptible strain, because deposits were extremely repellent (Rust & Reierson 1978). Resistance to acephate and propetamphos was low in each strain and 1-d-old deposits provided 75–98% kill in choice boxes.

As evidenced by our results with propoxur and chlorpyrifos, the potential interaction of insecticide resistance and repellency dramatically reduces the level of resistance required for German cockroaches to escape lethal encounters. Bret & Ross (1986) found that resistance in a field strain decreased sensitivity and dispersal attributable to propoxur vapors. In addition, the amount of insecticide-induced dispersal was influenced by formulation and was also affected by the strain tested (Wooster & Ross 1989). Insecticide resistance increases the likelihood of survivorship after exposure to insecticide and increases the opportunity for cockroaches to learn to avoid toxic insecticide deposits. It is not uncommon for resistant strains to remain in the dark harborage of the choice box in close proximity to the treatment.

In pest management programs, treatment decisions are based on economic thresholds or aesthetic injury levels. However, insecticide resistance reduces the efficacy of insecticide treatments, thereby influencing the decision process by reducing the number of viable treatment options. For *B. germanica*, RR_{50}s at which insecticides fail to kill 95% of the cockroaches in choice boxes vary with insecticide and formulation. RR_{50}s (LT method) of 1.2–2.0 for chlorpyrifos, 2.5–5.3 for diazinon, and >1.4 for propoxur resulted in significantly decreased efficacy in choice boxes. These RRs represent levels at which the insecticide use pattern should be altered and alternate strategies considered. RRs vary according to the test method used; RRs based on topical application characteristically are considerably higher than those based on LTs. However, our study indicates that low levels of resistance, as determined by either method, may result in poor control under field conditions. Other factors such as the effect of substrates, temperature, and relative humidity on the activity of residual deposits can also be examined in choice-box tests. Such factors may dramatically reduce insecticidal activity. Choice-box tests and corresponding resistance ratio determinations for field-collected strains from a wide variety of places where resistance is suspected need to be made to determine appropriate alternative insecticides and formulations that will provide optimal levels of control.

For residual insecticide applications to be effective, cockroaches must encounter them long enough to acquire a lethal dose. Effective pest management strategies will need to incorporate information regarding cockroach behavior as well as insecticide resistance.

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