Evaluation of Attractants for Monitoring Populations of the German Cockroach (Dictyoptera: Blattellidae)

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ABSTRACT Lures that are used to attract German cockroaches, *Blattella germanica* (L.), to traps were compared in olfactometer assays in the laboratory and in trapping experiments in cockroach-infested homes and a swine farm. In olfactometer assays, AgriSense GP-2 was the most attractive lure, followed by peanut butter, and distiller's grain. Other lures, including Trapper tablet; Victor pheromone, a crude fecal extract that ostensibly contains *B. germanica* aggregation pheromone; and Victor food lure elicited upwind orientation from <50% of the test insects. Peanut butter and distiller's grain were equally attractive in trapping experiments in swine production barns and they captured significantly more cockroaches than the GP-2 tablet or the Victor pheromone lure; the commercial lures failed to attract significantly more cockroaches than the unbaited control traps. When tested against blank controls, cockroaches preferred to rest in shelters that contained the aggregation pheromone-based lure (Victor), but this lure was the least attractive to cockroaches in olfactometer assays. These results do not support claims that commercial crude fecal extracts attract cockroaches to traps, and they highlight a need for developing more attractive lures for detection of cockroaches and for monitoring populations.

KEY WORDS *Blattella germanica*, attractants, baits, traps

MANY REDUCED-RISK APPROACHES for controlling cockroach populations are based on attracting cockroaches to traps, insecticide baits, and onto surfaces treated with residual insecticides or biological control agents. Pest monitoring, a central tenet of integrated pest management (IPM), also requires the deployment of effective attractants. Yet, commercially available traps and baits have a limited range over which they attract cockroaches and probably fail to lure cockroaches out of deep refuges. Trap catch therefore may be highly dependent upon location effects within an infested structure, and traps may fail to accurately estimate the prevailing cockroach population (Wright and Dupree 1983, Ross and Brett 1989, Schal and Hamilton 1990, Nalyanya 1995).

Extensive research has been conducted on food-based lures and synthetic odorants with the aim to incorporate them into cockroach control tactics. Among them, fatty acids and esters (Tsuji 1966, Wileyto and Boush 1983), cyclohexylalkanoates and *n*-alkylcyclohexaneacetates (Sugawara et al. 1975, Wileyto and Boush 1983), and tetrahydropyran esters (Pandey et al. 1994, 1995) have been evaluated. In addition, various household food materials (Tsuji 1965, Reierson and Rust 1977, Rust and Reierson 1981, Ballard and Gold 1982) and insecticide baits (Rust and Reierson 1981, Scharf et al. 1994; G.N. unpublished data) have been evaluated for attractiveness to cockroaches. Most of these lures, however, are mediocre attractants, and results from these studies have been inconsistent.

The lack of effective attractants for deployment in traps is probably the single most significant factor contributing to the abandonment of population monitoring efforts and a reliance on scheduled applications of insecticides in indoor environments. Effective attractants and efficient traps should increase the reactive distance of cockroaches to traps and thus enhance the sensitivity and accuracy of the decision-making component of IPM programs. We conducted laboratory behavioral assays and trapping experiments in the field to evaluate the relative attractiveness of several lures that are used in cockroach traps.

Materials and Methods

Insects. An insecticide-susceptible strain of *Blattella germanica* (L.), originally obtained from American Cyanamid (Princeton, NJ), was used in these experiments. The colony was maintained at 27 ± 1°C, ambient relative humidity, and a photoperiod of 12:12 (L:D) h, and was provided with water and Purina Rat Chow No. 5012 (Purina Mills, St. Louis, MO) ad libitum. In the laboratory tests, 10- to 20-d-old adult male cockroaches were used.

Lures and Traps. The following lures that are commercially used in cockroach traps were evaluated: Trapper (Bell Laboratories, Madison, WI), Victor pheromone and food lures (Woodstream Industries, Lilitz, PA), and the GP-2 tablet (AgriSense, Fresno, CA). Several other foods were evaluated for attractiveness, including peanut butter (Jif, Proctor and

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Gamble, Cincinnati, OH), distiller's grain (Jack Daniels, Lynchburg, TN), and feces-contaminated filter paper, containing *B. germanica* aggregation pheromone (Ishii 1970).

The trapping efficacy of the Trapper and Victor traps was compared. The Trapper trap is tent-shaped (18.5 cm long, 4 cm wide, 4 cm high) with ≈120 cm^2 of adhesive surface area. In our field experiments, this trap was divided into its three component traps (≈40 cm^2 each) and used with the supplied (170 mg attractant tablet, Trapper lure). The Victor pheromone roach trap is box shaped (14 cm long, 10 cm wide, 1.7 cm high) with ≈77 cm^2 of adhesive surface area and a laminated plastic pheromone dispenser glued to the ceiling of the trap. According to the manufacturer, the lure contains the crude extract of cockroach feces, containing *B. germanica* aggregation pheromone (Gerhet and Chang 1997).

Laboratory Experiments. *Choice of Shelter Assays.* Two different assays were designed to investigate the short-range attraction of cockroaches to the pheromone dispenser in the Victor trap and its arrestant activity. In the arrestant assay, we predicted that cockroaches would preferentially rest in shelters containing the aggregation pheromone. Shelters were made of inverted paper Dixie cups (Norwalk, CT, 9.5 cm diameter, 5 cm high, Steltenkamp et al. 1992) with four holes cut in the rim to facilitate entry. Victor pheromone lures were taped to the inside bottom of the cups and control cups received blank dispensers (gift from Woodstream). The control and pheromone cups were inverted symmetrically at opposite ends of a plastic cage (55 cm long, 30 cm wide, 21 cm high) the inner walls of which were treated with a thin layer of petroleum jelly to prevent cockroaches from escaping. Twenty adult male German cockroaches were released in the cage and provided with water and a pellet of rat chow. Their choice of shelter was recorded 24 h later, in the photophase, and the experiment was replicated five times.

A second shelter preference assay investigated the attraction of cockroaches to a Victor pheromone dispenser that they could not contact. The pheromone and a blank control dispenser were placed in petri dishes (60 mm diameter, 15 mm high) with fine-mesh screened lids to prevent cockroaches from contacting the dispenser. The petri dishes were placed under Dixie cups at opposite ends of a cage and the choice of shelter was recorded after 24 h.

Olfactometer Assays. Two-choice olfactometers were used for the behavioral assays. Each olfactometer consisted of a Plexiglas tube (54.5 cm long, 3.2 cm i.d.) with a 15 cm long divider sealed vertically in the upwind end. A tube cage (15 cm long, 3.2 cm i.d.) with a swivel metal screen gate was used to introduce cockroaches into the downwind end of the olfactometer. Sixteen such olfactometers were connected to a vacuum pump that provided a linear air velocity of 25 cm/s through each tube; the tubes were exhausted outside the building. Fluorescent lights covered with red photographic safety filters placed 60 cm below and above the olfactometers facilitated observation in the dark. Lures were aired in the fume hood for 15–20 min before dispensing ≈350 mg of each lure into a 0.5-ml microcentrifuge tube (cut to a height of 1.5 cm) that was used to dispense the odorants in the olfactometers. A strip of the Victor pheromone dispenser (1 by 3 cm) was cut and fit into each tube. A single male cockroach was placed in each olfactometer for ≈30 min to acclimate to the airflow and thereafter only quiescent insects were used in the assays. The gate was opened carefully and the lure introduced upwind. A response was considered positive when the test insect ran out of the cage to the end of the olfactometer tube, contacting the lure within 3 min. Each dispenser was used in no more than seven assays to preserve the concentration of odorants. A fresh naïve male was used in each assay and each kind of lure was tested separately on 25–30 cockroaches. The olfactometer tubes were subjected to the 25 cm/s airflow between tests and cleaned with detergent solution every 4–5 d.

Field Experiments. Two trapping studies were conducted, one in apartments managed by the Raleigh Housing Authority and the second in the farrowing barns of a cockroach-infested swine farm in Sampson County, NC.

Trapping in Apartments. To select apartments, seven traps (six in the kitchen and one in the bathroom) were placed in each apartment for 48 h. Apartments with a minimum of 20 cockroaches were selected for the study and only those locations within the apartments where cockroaches were trapped were used in later studies. Traps and lures were compared using a paired trapping procedure. A pair of traps (control and baited traps) were placed in each of the sites, ≈0.5 m apart. After 24 h the traps were retrieved and replaced with fresh traps, which were also left in place for 24 h. To minimize the effect of trap location, the positions of the new traps were reversed relative to the previous day.

The first experiment was conducted to determine the attractiveness of the Trapper lure, so Trapper trap with and without its lure were compared (six apartments). The second experiment was designed to evaluate the attractiveness of the Victor pheromone lure. Because Victor traps without dispensers could not be obtained, the pheromone dispenser from the Victor pheromone trap was carefully removed from the trap, stapled to the inner surface of a Trapper trap and compared with an unbaited Trapper trap (12 apartments). The third experiment compared the attractiveness of GP-2 tablet and Victor pheromone lure (12 apartments) using a similar procedure as in experiment 1. Because GP-2 is formulated as a ≈750-mg tablet, the tablet was carefully divided into pieces of ≈170 mg, comparable to the weight of Trapper tablets. Finally, the Victor roach trap with its pheromone lure was compared with the Trapper trap with its tablet (14 apartments). Each site within each apartment was considered a replicate, and a minimum of 30 replications were made per comparison.

Trapping in the Swine Barns. To investigate the attractiveness of the AgriSense GP-2 tablet, the Victor pheromone lure, and several gel baits, trapping was

conducted in rooms (15 m long, 13 m wide) in farrowing barns of a cockroach infested swine farm. Mason jars (0.95 liter) wrapped in a 12-cm cotton sleeve to facilitate cockroach entry, were used as traps. Petroleum jelly was spread on the inner lip to prevent cockroaches from escaping. Traps were baited with a single GP-2 tablet (≈750 mg), Victor pheromone (1 dispenser), 750 mg of peanut butter, or 750 mg of distiller's grain. Lures were placed in small petri dishes (60 mm diameter, 15 mm) with screened lids which permitted odorant emission while preventing trapped cockroaches from contacting the lures. The experimental design was a randomized complete block. Baited traps were deployed for 24 h 1 m apart on the floor along the cockroach-infested walls of farrowing rooms. Trap location was randomized along each wall (block) and 10 walls were used concurrently.

Data Analysis. Olfactometer assays were analyzed by Ryan's test. Assays for choice of shelter in two-choice preference assays were analyzed by the chi-square test at $\alpha = 0.05$. Student's paired t-test was used to analyze trap catches of paired traps in apartments. Because few adult males and females were captured in apartments, the sum of all cockroaches (males, females, and nymphs) per trap was used in the analyses and only trapping sites with a mean trap catch of two or more cockroaches per day were included in the analysis. Mean trap catch per location per day for each trap type or trap and lure combination was computed. Trap counts from the pig farm were square-root transformed and analyzed by PROC GLM (SAS Institute 1996). LSMEANS/PDIFF was used to compute the mean trap catch and to separate differences among the lures. The data analyzed from the swine farm is a subset of a larger data set from a study in which other lures were evaluated. To use this subset of data, correlation coefficients of trap catch between the control and lures, and between pairs of lures were computed. The correlation coefficients were highly variable and mostly insignificant suggesting that there was poor association among the various treatments.

Results

Shelter Preference Assays. In the contact arrestant assays, all the cockroaches preferred the shelter containing the Victor pheromone lure over the control shelter ($\chi^2 = 10.0$, df = 1, $P < 0.001$) (Fig. 1A). Similarly, in short-range attractant assays, where the dispenser was screened from the cockroaches, significantly more males preferred the shelter with the lure than the control shelter ($\chi^2 = 6.74$, df = 1, $P < 0.001$) (Fig. 1B).

Olfactometer Assays. In the behavioral assays, upwind orientation responses were highly dependent upon the presence of an attractant lure (Fig. 2). All the lures that were tested except Victor food and Victor pheromone were significantly more attractive than the control ($P < 0.05$). Of the commercial lures tested, the GP-2 tablet elicited the highest and significantly more responses ($P < 0.05$) than any other commercial lure or cockroach contaminated filter papers. Male

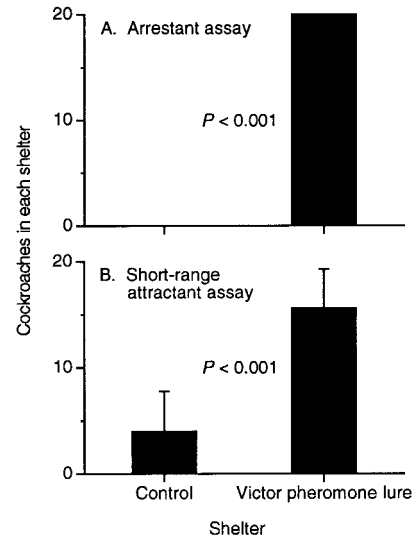

Fig. 1. Arrestant and short-range attractant assays of the Victor pheromone dispenser. Columns represent mean + SE number of cockroaches in each shelter. Chi-square test was used to compare the results to the expected 50:50 distribution ($n = 5$ replicates with 20 cockroaches each).

response to peanut butter and distiller's grain was not significantly different ($P > 0.05$), but peanut butter attracted more cockroaches than all the commercial lures, except GP-2 (Fig. 2).

Trapping in Apartments. Paired assays in apartments partly confirmed our olfactometer results. Trapper traps with GP-2 lure captured significantly more cockroaches than Trapper traps with Victor pheromone ($t = 3.62$, df = 38, $P < 0.001$) (Fig. 3C). However, Trapper traps with or without the Trapper lure trapped equal numbers of cockroaches ($t = 0.77$, df =

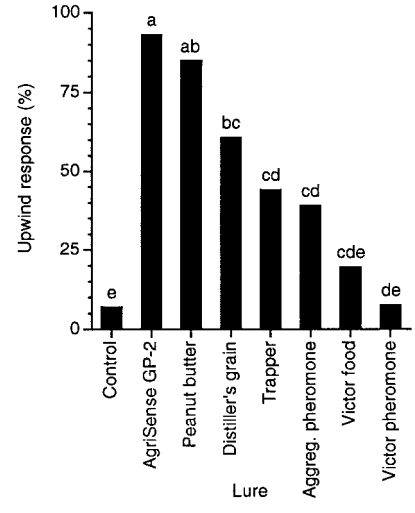

Fig. 2. Upwind orientation responses of male German cockroaches to various lures in olfactometer assays. Columns with different letters are significantly different (Ryan's test, $P < 0.05$; $n = 25$–30 cockroaches per lure).

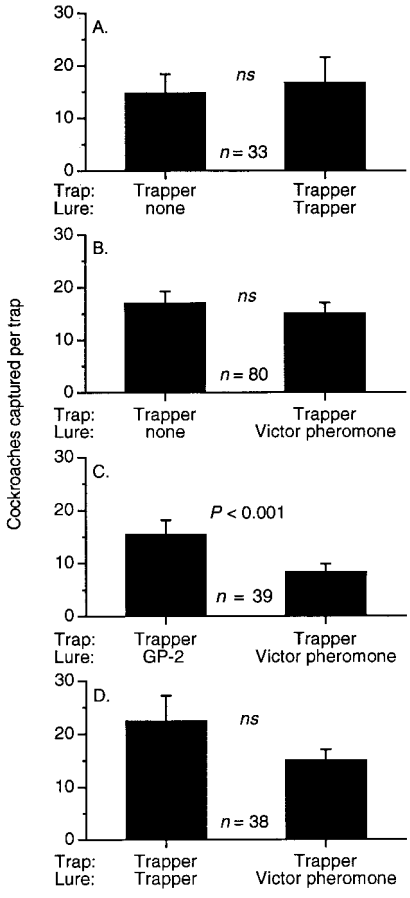

Fig. 3. Trap catches of German cockroaches in apartments using two types of traps and three lures. Columns indicate mean (+ SE) (*ns*, not significantly different by Student's paired *t*-test, $P > 0.05$).

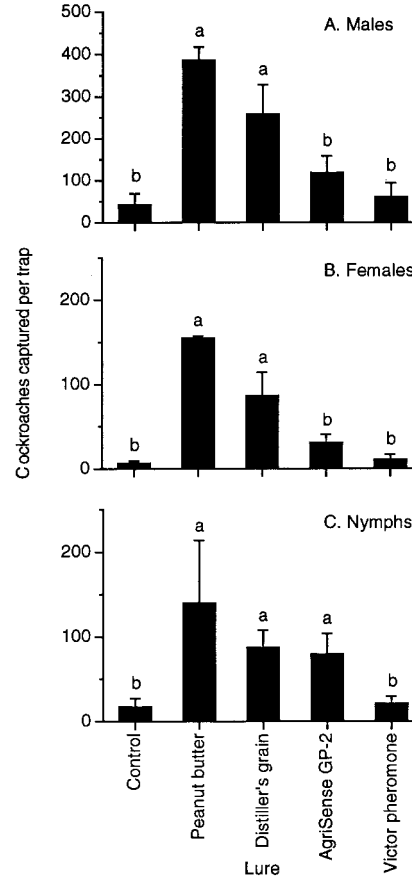

Fig. 4. Comparative trap catches of German cockroaches in swine barns by using several lures. Columns indicate mean + SE and those with different letters are significantly different from each other (LSMEANS, $P < 0.05$; $n = 10$).

32, $P > 0.05$) (Fig. 3A), suggesting that the lure was less effective in the field. Similarly, there was no significant difference in trap catch between Trapper traps with or without the Victor pheromone lure ($t = 1.72$ df = 79, $P > 0.05$) (Fig. 3B), indicating that the pheromone-based lure failed to enhance trap catch in the field. And finally, no significant difference was found in the mean trap catch per day of Trapper traps containing the Trapper lure and the Victor trap containing the Victor pheromone lure ($t = 1.976$, df = 38, $P > 0.05$) (Fig. 3D). However, apartments contained relatively low cockroach populations and the heterogeneity of kitchens delimited the paired traps to <0.5 m apart. We therefore expanded these assays to a highly infested swine farm.

Trapping in Swine Barns. There were significant differences in the number of cockroaches trapped by different lures ($F = 30.16$; df = 4, 146; $P < 0.001$) (Fig. 4). The block by bait interaction was significant ($F = 4.67$; df = 32, 146; $P < 0.001$), suggesting that cockroach distribution was uneven among the barn walls and along each of the walls. There were also significant differences in the numbers of trapped males, females and nymphs ($F = 24.69$; df = 8, 146; $P < 0.001$), but the stage by bait interaction was not significant ($F = 1.03$; df = 8, 146; $P > 0.05$). According to LSMEANS/PDIFF analysis, only peanut butter and distiller's grain consistently lured significantly more males, females, and nymphs than the blank control and other lures (Fig. 4). The GP-2 lure also attracted and trapped more nymphs than the blank control. In contrast, there were no significant differences between Victor pheromone lure and the blank control in their attractiveness to nymphs and adults.

Discussion

Several important inferences may be derived from our data. First, the olfactometer results and the differential attractiveness of the baits in the field indicate that all stages of *B. germanica* perceive and orient toward the source of food odors and other olfactory cues over some distance. These findings are in contrast to the generally held view that *B. germanica* does not respond in a consistent fashion to any attractant and that no lure attracts cockroaches from a distance of

more than a "few" centimeters (Meisch and Howell 1967, Rust and Reierson 1981, Owens 1995, Reierson 1995). Second, not all lures used in cockroach control are equally attractive, and indeed the most attractive baits that we found were "off-the-shelf" foods (e.g., peanut butter) and industrial by-products (distiller's grain). And third, claims of attractiveness attributed to some commercial lures cannot be supported by either laboratory or field results.

Some of the lures that we tested were attractive to cockroaches in both olfactometer assays in the laboratory and in trapping assays in the field. The stage by bait interaction was not significant in the field, indicating that any given lure was equally attractive to immatures and adults. In laboratory olfactometer assays AgriSense's GP-2 tablet, peanut butter, and distiller's grain elicited responses from >50% of adult males. Trapper lure outperformed the blank control but was not significantly more attractive than Victor food or pheromone lures, which in turn failed to attract more cockroaches than the blank control (Fig. 2). Peanut butter and distiller's grain were highly attractive to cockroaches in swine barns (Fig. 4), whereas GP-2 and Victor pheromone were not significantly more attractive than the blank control. However, GP-2 trapped significantly more nymphs than Victor pheromone lures and the control. Interestingly, the GP-2 lure was highly attractive in olfactometer assays and in apartments, but it failed to trap significantly more adults than the blank control traps in the swine barns. We suspect that the use of mason jars as traps probably favored trapping adults, as indicated by the relatively fewer nymphs that were captured (Fig. 4). In adhesive traps, which are more commonly deployed in pest control programs, more nymphs than adults are generally captured, and we would therefore expect better efficacy from the GP-2 lure under these conditions. Indeed this was the case as shown by trapping results from apartments where adhesive traps were used. The difference in attractiveness of this lure could also be due to strain differences in olfactory response (G.N., unpublished data).

The data we obtained in apartments failed to discriminate between most of the paired treatments. The Trapper trap was no better with the Trapper lure than without it, and it was no better with the Victor pheromone lure than without it (Fig. 3). Likewise, the Trapper trap plus its lure was no different from the Victor trap with its pheromone lure. In contrast, Trapper trap with GP-2 was significantly more attractive than Trapper trap with Victor pheromone lure. These apartments contained relatively few cockroaches and the relatively poor lures that were tested failed to contribute significantly to the traps. Nevertheless, results with GP-2 suggest that a more potent lure can enhance trap catch.

Scharf et al. (1994) reported that GP-2 was repellent to cockroaches, in marked contrast to our finding that it elicited responses from >90% of the males in olfactometer assays. Peanut butter elicited upwind responses from 84% of the cockroaches in our assays, but Rust and Reierson (1981) did not find it to be as attractive. Such discrepancies may be due to differences in cockroach strains, lure formulations, and in methodology for evaluating attractants. Although behaviorally discriminating bioassays are required to distinguish the component behaviors that result in a positive response (Kennedy 1977, Sakuma and Fukami 1985), most field assays of lures, including our own, are based on trapping assays that fail to discriminate between orientation behavior and trap efficiency.

The Victor pheromone lure contains an extract of German cockroach feces, which includes the aggregation pheromone. However, this lure was not significantly more attractive to cockroaches than a blank control in either olfactometer (Fig. 2) or in field experiments (Fig. 4). It is important to note that to evaluate its attractiveness, we tested the lure independently of the Victor trap in which it is normally deployed. The trap may be highly effective, but from our data we must draw the conclusion, in contrast to previous studies (Kaakeh and Bennett 1997a, 1997b), that high trap catch with Victor traps cannot be attributed to its aggregation pheromone lure. Also, relatively low responses to the Victor food lure (Fig. 2) would suggest that neither lure contributes substantially to the capture efficiency of this trap.

The aggregation pheromone contains both attractant and arrestant components and cockroaches respond to the attractants by olfaction (Sakuma and Fukami 1985) and to the arrestants by contact chemoreception (Sakuma and Fukami 1991). Although it is apparent that the Victor pheromone lure is only minimally attractive in olfactometer bioassays, it appears to function as a short-range attractant and arrestant in cage bioassays (Fig. 1). Cockroaches clearly preferred shelters that contained the pheromone lure over control shelters. Why do Victor pheromone dispensers fail to attract cockroaches? It is possible that the attractant components of the lure volatilize at a high rate or are lost during extraction, handling, or storage. Indeed, Sakuma et al. (1997) caution of the extremely high volatility of several amines they isolated as cockroach attractant aggregation pheromones. However, recent assays using a locomotion compensator treadmill conclude that carboxylic acids, both highly volatile and some less volatile components, elicit the attractant-aggregation response (Scherkenbeck et al. 1999). Clearly, more bioassay-guided chemical characterization is needed before these materials can be used in pest control operations.

Potent lures are needed to meet the challenges of trapping cockroaches in detection, monitoring, and pest reduction efforts. The attractants and baits in current use are thought to be relatively ineffective (Ballard and Gold 1982, Gold 1995), yet some of the lures assayed in the field significantly increased trap catch (Fig. 4) and presumably would enhance the correlation between trap catch and infestation level. Moreover, similar studies with food-based baits (GN, unpublished data) and with pheromone- and food-baited traps (Liang et al. 1998) confirm that some lures can significantly enhance trap catch. Clearly, cockroaches respond to odorant lures from a distance.

Food stuffs like peanut butter, bread, and distiller's grain, as well as various baits elicited more responses in the laboratory, and trapped more cockroaches than did unbaited traps in the field. These findings imply that even currently deployed lures can detect and monitor infestations, and a concerted research effort to discover more potent attractants should yield more effective cockroach lures.

Tremendous advances are being made in the discovery and implementation of semiochemicals in IPM in field crops (Jones 1998), forestry (Borden 1993), and stored products (Burkolder 1990, Phillips 1997). Notwithstanding, semiochemicals have not been used in cockroach control, probably because of difficulties in their characterization and identification. The sex pheromones of several species have been tested under field conditions (Bell et al. 1984, Schal 1992, Liang et al. 1998), but have not been used in practical pest management. Crude fecal extracts containing aggregation pheromones have shown promise in field studies aimed at reducing repellency of contact insecticides (Rust and Reierson 1977a, 1997b), and in laboratory assays of baits (Miller et al. 1996), but their deployment as attractants appears to be less impressive (current study). Nevertheless, efforts to integrate pheromone and food lures in cockroach population management are certain to optimize trap catch, as with *Supella longipalpa* (Liang et al. 1998).

It appears that insecticide baits are relatively effective cockroach control tactics, even when as few as 12 bait stations are used per apartment (Reierson 1995). It would seem that if traps were baited with attractive lures, if their trapping efficiency were significantly enhanced, and if they were deployed in a similar manner as baits, then theoretically, the efficacy of the two tactics should be the same. Assuming equally effective lures, both traps and baits should be encountered by equal numbers of cockroaches, and the horizontal transmission of bait active ingredient (Silverman et al. 1991; Kopanic and Schal 1997, 1999) notwithstanding, their efficacy should be similar. The great disparity between the efficacy of these two cockroach control tactics highlights the need to better understand the chemical ecology of the cockroach, develop better lures, and design traps that retain captured cockroaches.

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