ISSUES AFFECTING THE PERFORMANCE OF COCKROACH BAITS

J. SILVERMAN AND D. N. BIEMAN
The Clorox Technical Center, 7200 Johnson Drive, Pleasanton, CA 94588 USA

Abstract—Several issues were addressed which were thought to impact the performance of cockroach baits. These included responses to bait matrices such as speed-of-action, indirect toxicant uptake, physiological and behavioral resistance, and associative learning. Bait application approaches were also considered, leading to a discussion of a field method which reduced within-treatment variation, thereby providing better assessments of the intrinsic properties of cockroach baits.

INTRODUCTION

We are attempting, in this workshop, to identify themes common to both insect and vertebrate baiting. Although synanthropic social hymenoptera are certainly amenable to control with baits, closer parallels can be drawn between commensal rodents and domiciliary cockroaches, particularly the German cockroach, *Blattella germanica*. The German cockroach and commensal rodents display many similar biological and behavioral traits, and share characteristics such as random and opportunistic foraging, polyphagy, learning, and behavioral and physiological resistance, which affect bait development strategies. Consequently, the German cockroach will be the focus of this presentation.

Over the past 10 years, evidence for successful German cockroach control with insecticidal baits has renewed an interest in this insect control strategy. Reierson (1995) provides an excellent review of our current understanding of cockroach baits. Rather than restating that which is well documented, this discussion will focus on some of the more controversial issues pertaining to the properties of effective baits (intrinsic factors) and the recommendations given for their application (extrinsic factors). Intrinsic factors include physiological and behavioral resistance, learned avoidance, and the impact of coprophagy or secondary kill on cockroach populations. What happens *after* a bait is formulated and packaged is affected by extrinsic factors, such as where and how many baits are placed. We will address these topics both by reviewing existing literature and presenting new data.

Intrinsic factors

Cockroach baits consist of several components; active ingredient, food materials, binders, emulsifiers, and preservatives. The final bait product is typically packaged in child-resistant stations or dispensed in critical locations as gels, pastes, granules or dusts. It is generally agreed that the active ingredient should not be detected by the cockroaches, so that feeding proceeds unabated, and a lethal dose is obtained. Fast-acting contact blatticides tend to be the most repellent (Ebeling *et al.*, 1966). This relationship was expressed for baits (Appel, 1990; Rust and Reierson, 1981) and those bait toxicants which kill cockroaches relatively quickly perform poorer in field studies than slower acting insecticides. Hydramethylnon, abamectin and boric acid, generally regarded as non-repellent and slow acting toxicants, have provided significant cockroach reductions in field trials (Milio *et al.*, 1986; Appel, 1992; Appel and Benson, 1995). However, a close connection between performance and repellency and/or speed of kill has not been established. Studies evaluating a broad spectrum of bait actives, including those where repellent and speed-of-kill properties are not linked, could shed some light on this subject.

The relatively slow-acting, non-repellent, properties of some bait toxicants could result in the ingestion of a dose greater than that required to cause mortality. In laboratory studies, Hollingshaus and Little (1984) reported that hydramethylnon bait was consumed by B. germanica males at a level greater than 20X the lethal dose. One advantage of such overindulgence is the excretion of excess toxicant and its subsequent ingestion by coprophagous conspecifics. (Silverman

Proceedings of the Second International Conference on Urban Pests.
K.B. Wildey (editor). 1996

et. al., 1991; Wang *et al.*, 1995; Short *et al.*, 1994) have demonstrated horizontal toxicant transmission for hydramethylnon in cockroaches. Although it is agreed that hydramethylnon secondary transfer occurs in laboratory studies, there is some skepticism of its impact on field populations. Two field population reduction experimental protocols come to mind which could allow us to definitively assess the importance of coprophagy and secondary-kill on bait performance. The first would directly compare two equally effective toxicants which share similar characteristics, however, one treatment provides substantial secondary-kill in lab trials while the other lacks this property. Presently, we can think of no two toxicants that differ by this single criteria. A second design utilizes a very different approach: differential, stage specific access to a bait with secondary-kill properties. For example, a bait container might be devised, whereby one treatment would only permit large nymphs and adults access; the second treatment would allow bait access by the entire cockroach population. If population reduction estimates were the same for both treatments, we can assume that small nymphs denied direct access to the bait died due to indirect contact with the toxicant.

We completed an experiment which provided direct evidence that secondary-kill occurs in field populations of *B. germanica,* although the actual impact on control could not be inferred. Here, German cockroaches were trapped from an infested apartment, and approximately 700 adults were marked on the wings with an indelible ink. They were fed hydramethylnon bait, then released immediately into the apartment . Over the next 14 days, dead insects and those displaying symptoms of hydramethylnon toxicity were collected, extracted and assayed chromatographically for hydramethylnon. Of the unmarked cockroaches, 70% of the adults and 75% of the nymphs contained hydramethylnon, suggesting that hydramethylnon transfer between conspecifics may be significant. Investigations on the role coprophagy plays in the natural history of cockroaches may shed light on how important this phenomenon is in cockroach control.

As indicated above, repellency may compromise the performance of an active ingredient by reducing bait consumption. Reierson (1995) suggests that another phenomenon, learned avoidance, may affect bait performance by diminishing consumption, of baits which may actually contain insecticides not generally regarded as repellent. He refers to general examples of associative learning in cockroaches and proposes that a decline in bait performance may in some cases be explained by reduced, or no bait feeding, following an initial sublethal exposure. We tested this hypothesis by feeding a sublethal dose (1 mg of a 0.1% hydramethylnon bait=1 μg of hydramethylnon) to individual male *B. germanica.* Five hours after the initial dose, these same insects were exposed to one of four different pre-weighed baits (N=10): 1) The same bait used for pre-exposure (bait 1+0.1% hydramethylnon), 2) Bait 1 minus AI, 3) A second bait (bait 2+0.1% hydramethylnon) that differed from bait 1 by 75% of the components, 4) Bait 2 minus AI. Decreased feeding on baits 1–3 could be explained by learned avoidance towards the active ingredient, the bait base, or an interaction of the two components. The experiment was conducted using a laboratory cockroach strain as well as two field strains, both of which had been exposed to bait 1 (2% hydramethylnon) prior to retrieval from the field.

Although the Palatka strain consumed more overall, no differences between bait types for a given strain could be detected. Therefore, this experiment failed to demonstrate learned avoidance in *B. germanica.* Investigations of different insecticides, insecticide levels, bait types, exposure intervals or other variables may lend support to the learned avoidance hypothesis.

Table 1. Bait consumed by 3 strains of B. germanica 5 hrs after ingestion of a sublethal dose of bait 1 w/AI.

	Mean mg of Bait Consumed by Strain		
Bait	Orlando	Palatka	Puerto Rico
Bait 1 w/AI	0.87[a]	4.63[a]	1.01[a]
Bait 1 w/o AI	1.47[a]	3.73[a]	1.31[a]
Bait 2 w/AI	1.43[a]	4.72[a]	1.29[a]
Bait 2 w/o AI	1.44[a]	4.43[a]	1.09[a]

Means within a column followed by same letter are not significantly different (P=0.05; ANOVA).

Resistance is determined more by a cockroach's response to a bait matrix rather than how the bait is applied, therefore it will be considered as an intrinsic factor here. German cockroaches have been collected from a variety of locations which reveal a range of resistance ratios to a variety of insecticides used in bait products (Reierson, 1995; Cochran, 1995). Since topical assays were primarily performed, physiological resistance mechanisms are most likely involved. However, despite the evidence from laboratory bioassays, the impact of physiological resistance on bait performance in the field is poorly understood. Behavioral resistance to insecticides may also compromise the performance of bait products (Sparks *et al.*, 1989; Ross, elsewhere in these Proceedings). Recently, we described a unique resistance mechanism in the German cockroach, glucose aversion, whereby individuals containing the semi-dominant glucose aversion gene were selected for in the continuous presence of glucose-containing toxic baits (Silverman and Bieman, 1993; Silverman and Ross, 1994). In two Florida locations, repeated treatment with a glucose-containing toxic matrix over a five year period resulted in a change in bait performance from population reductions over 90% in 1983 to population increases of up to 39% in 1988. Removal of glucose from the bait formulation restored the performance characteristics of the bait. Subsequently glucose-averse phenotypes were discovered in a number of wide-ranging locations, including Torrance, California where Reierson (1995) had observed a gradual decline in the performance of glucose-based hydramethylnon baits over a period of ten or more years. Following the reformulation of baits without glucose, selection experiments have been conducted on a number of cockroach strains with no further indication of bait aversion (Ross pers. comm.). Behavioral resistance to inert ingredients adds another dimension to the overall resistance and bait performance picture.

Extrinsic Factors

There has been a fair amount of discussion on the importance of bait placement in cockroach control. It is generally believed that German cockroaches do not move great distances in search of food, and that best control is accomplished when bait is placed where cockroaches are likely to encounter it during foraging. Although it is generally agreed that *B.germanica* forage more or less randomly, and are apparently not capable of locating food over more than a few centimeters (Ebeling and Reierson, 1970), trapping is more effective when volatile food materials are used (Owens and Bennett, 1983, Reierson and Rust, 1984). Food, and especially water deprivation, increase cockroach activity and directed movement (Reierson, 1995), therefore improved trapping results with volatile food materials may be explained by a bias towards hungry and/or thirsty individuals. Since it appears that olfaction is used to locate food to some degree, it may not be absolutely critical to intercept cockroaches with baits placed along foraging routes. It is generally believed that cockroaches travel along edges, and therefore traps and baits placed at floor-wall junctions and in corners would be more effective. In fact, Ebeling *et al.* (1966), and Ebeling and Reierson (1974) were able to collect more cockroaches when traps were placed at these locations. In laboratory trials, Reierson and Rust (1984) found that twice as much food was consumed when it was placed next to cockroach harborage vs 18 inches away. Reierson (1995) concludes from these data and perhaps other observations, that "bait placed in the open, away from a wall is essentially non-effective because cockroaches are less likely to locate it".

In our field studies, we place bait trays in many different positions within sampling units. Ease of placement and security of attachment to the substrate, the chief factors among the logistical parameters, usually determine tray orientation. This results in bait trays being placed vertically, horizontally, upside-down, in corners, along edges, as well as away from corners and edges.

Cockroaches live in a world where food can materialize from anywhere, and they presumably have the mobility to procure it almost everywhere within their environment. Their world includes vertical and horizontal surfaces (right-side-up and upside-down) and everything in between. Food may become available from open packages, smears on cabinets, spills on counters and doors, and a myriad of other possibilities. We expect that cockroaches have evolved opportunistic foraging strategies to take advantage of the unpredictability of food location; they should find food wherever it turns up. As a corollary to this, the only requirement for successful application of palatable toxic baits is to place them in the vicinity of cockroaches; prescription placement is unnecessary. We designed field experiments to test the hypothesis presented above. We predicted that cockroaches would feed equally (1) at the "classic corner" (or edge) placements and locations away from corners (or edges), and (2) on a horizontal and vertical surfaces.

We tested the two predictions in two apartments (one for each prediction) in Salinas, Puerto Rico in February,, 1996. Apartments with obvious cockroach infestations were chosen. We treated the apartments with hydramethylnon bait trays. In "corner" vs "away from corner" studies, paired bait comparisons were not used, since bait in one tray may have guided cockroaches to the other tray. Instead locations with comparable population counts were used in this test, and placements were assigned randomly. Corner baits were placed in corners or along edges, while away from corner baits were placed 25 cm diagonally apart from corners, or perpendicularly away from edges, unless this procedure brought the bait closer than midway to an edge. If it was closer than midway to an edge, the placement was moved to the center (e.g. center of drawer) or center-line of a counter. We also compared bait trays placed in vertical and horizontal positions adjacent to each other. The mass of bait discs were measured before placement and after, at one day and at four or five days.

Cockroaches feed equally at corner placements and locations away from edges, and on horizontal and vertical surfaces, in the field, supporting our predictions. We would anticipate that efficacy trials would yield results consistent with these consumption data. Humans introduce food fortuitously into the cockroach environment. Cockroaches must find food quickly by moving in all directions and climbing at any angle, in order to thrive in their environment. Humans may respond quickly to accidental introductions of food and try to remove it (e.g. closing an open package, or wiping up smears and spills). A cockroach whose foraging strategy only led it along edges would be a hungry cockroach, and would lose out to individuals with more resourceful foraging adaptations. Therefore it does not appear that the precise placement of a bait in a corner or against an edge would be critical for success.

What we and others (Bennett *et al.*, 1984; Reierson and Rust, 1984) do believe is critical for maximal bait performance is an adequate quantity of bait placed in most or all of the areas that cockroaches inhabit, and that monitoring be conducted to identify infested microhabitats! Yet, many investigators continue to sample populations and place bait in predefined locations, that may or may not have cockroaches. Containerized baits are typically placed in identical or nearly identical locations (generally 12) within every apartment in the study complex. Gel bait and powder bait formulations, dispensed from a syringe or tube, are applied to more locations, but generally the same spots in every unit. The apartment to apartment cockroach reduction variablity in many of these studies was generally large, making it impossible to statistically separate treatments, despite large numerical treatment differences.

We developed a German cockroach sampling and baiting procedure which decreases the variance substantially, allowing us to discriminate smaller differences in product performance. Two major changes distinguish this method from other procedures. (1) Sampling units are considered unique; number and positions of traps and baits differ. (2) Approximately 4 grams of bait was placed per baiting location within a unit. Cockroaches do not inhabit the same locations in every sampling unit. Taking this into account, this method calls for a systematic inspection of each unit setting traps in locations where live cockroaches are observed. To more accurately assess control, bait was placed within 10 cm of the trap location. An excess of bait per trap location was supplied to guarantee adequate baiting. From our experience, cockroaches frequently deplete the entire

Table 2. Effect of bait tray placement in corner vs 25 cm away from wall, and horizontal vs vertical tray placement, on bait consumption by *B. germanica* in apartment locations.

	Mean mg of Bait Consumed				
Placement (N=16)	1 Day*	5 Days*	Placement (N=17)	1 Day†	4 Days†
Corner	743[a]	1041[a]	Vertical	1255[a]	1469[a]
10" Away from Corner	778[a]	1091[a]	Horizontal	1410[a]	1503[a]

Means within a column followed by same letter are not significantly different (P=0.05; *=Mann-Whitney U test, †=Wilcoxon Signed Ranks test).

Table 3. Field performance of a hydramethylnon bait using two sampling and baiting strategies.

	% Reduction at 12 Weeks Post-treatment		
	N	Mean±SE	Median
Method 1	14	86.6±3.8	93.50
	9	34.1±28.7	81.10
	8	44.5±22.6	66.70
	18	29.9±37.2	91.90
Method 2	10	94.0±2.5	95.80
	7	99.2±2.5	99.60
	10	97.3±1.1	99.20
	7	97.1± 1.1	98.30

contents of bait trays during a study. We wanted the differences observed in performance to relate to bait treatment, and not to quantity. At first glance it may seem that much more bait was used in this procedure, but in many sampling units far less bait was used (as few as 2 trays). These changes in sampling increased efficacy, test accuracy and precision. Two sampling and baiting methods are compared below (Table 3) in eight separate field studies using the same hydramethylnon bait treatments. Method 1 involves the placement of 10 sticky traps and 12 bait trays in approximately the same location in each apartment. Method 2 employs a pre-inspection of each apartment to determine the number and locations of baits and traps needed to effectively reduce the cockroach population and monitor its reduction.

There is no overlap of the descriptive statistics between the tests employing the two methods. Method 2 decreased variance (greater precision) and yielded higher percent population reductions. These results were expected because units were sampled and treated according to the actual distribution of the cockroaches, and bait was always available.

CONCLUSION

Of the numerous topics related to insect baiting, we selected some of those that revealed parallels with vertebrate baiting. Our focus on the German cockroach was justified by this insect's close association with humans; a trait shared with commensal rodents. Some of the issues common to both synanthropic groups are physiological and behavioral resistance and bait shyness, as well as bait placement and population monitoring in bait efficacy trials. Physiological and behavioral resistance to bait toxicants have been documented for commensal rodents (Greaves and Rennison, 1973; Brunton *et al.*, 1993) and *B. germanica*. Behavioral resistance of *B. germanica* to foods, such as glucose, and other other bait inerts has not been reported in commensal rodents, however, mouse strains vary in their response to sweetness (Lush, 1991). Therefore, it is possible for a similar resistance mechanism to evolve in rodents. Rats are known to be capable of conditioned aversion (Pavlov, 1927) and to avoid rodenticides having associated illness with their toxic effects (Nachman and Hartley, 1975). Though it has been proposed as a possible reason for the decline in bait performance, we have not been able to demonstrate learned avoidance in cockroaches, and no other studies have been reported on this subject. Although bait placement along runways may be important in rodent control (Corrigan, 1994), and corner and edge placement has been assumed to facilitate cockroach control, we were unable to see a placement effect. However, appropriate usage of baits in cockroach infested homes has a major impact on population control.

REFERENCES

Appel, A. G. (1990). Laboratory and field performance of consumer bait products for German cockroach (Dictyoptera: Blattellidae) control. *J. Econ. Entomol.*, 83, 153–159.

Appel, A. G. (1992). Performance of gel and paste bait products for German cockroach (Dictyoptera: Blattellidae) control: Laboratory and field studies. *J. Econ. Entomol.*, 85, 1176–1183.

Appel, A. G., and Benson, E. P. (1995). Performance of abamectin bait formulations against German cockroaches (Dictyoptera: Blattellidae). *J. Econ. Entomol.*, 88, 924–931.

Bennett, G. W., Runstrom, E. S., and Bertholf, J. (1984). Examining the where, why and how of cockroach control. *Pest Control* 52, 42–50.

Brunton, C. F. A., Macdonald, D. W., and Buckle, A. P. (1993). Behavioural resistance towards poison baits in brown rats, *Rattus norvegicus*. *Appl. Anim. Behav. Sci.* 38, 159–174.

Cochran, D. G. (1995). Insecticide resistance. Rust, M. K. *et al.* eds. *Understanding and controlling the German cockroach.* Oxford, New York. 171–192.

Corrigan, R. M. (1994). Vertebrate and arthropod parallels in urban pest management. *Proc. Nat.Conf. Urban Entomol.* 55–70.

Ebeling, W., and Reierson, D. A. (1970). Effect of population density on exploratory activity and mortality rate of German cockroaches in choice boxes. *J. Econ. Entomol.* 63, 350–355.

Ebeling, W., and Reierson, D. A. (1974). Bait trapping silverfish, cockroaches and earwigs. *Pest Control* 42, 24, 36–39.

Ebeling, W., Wagner, R. E., and Reierson, D. A. (1966). Influence of repellency on the efficacy of Blatticides. 1. Learned modification of behavior of the German cockroach. *J. Econ. Entomol.* 59, 1374–1388.

Greaves, J. H., and Rennison, B. D., (1973). Population aspects of warfarin resistance in the brown rat. *Mammal. Rev.* 3, 27–29.

Hollingshaus, J. G., and Little, R. E. (1984). Comparative toxicologyof AC217,300 in various species of insects. *Pest. Biochem. Physiol.* 22, 337–345.

Lush, I. E. (1991). The genetics of bitterness, sweetness, and saltiness in strains of mice. In *Chemical Senses: Genetics of perception and communication* (Eds. Wysocki, C. J., and Kare, M. R.), Vol. 3, Dekker, New York, 227–243.

Milio, J. F., Koehler, P. G., and Patterson, R. S. (1986). Laboratory and field evaluations of hydramethylnon bait formulations for control of American and German cockroaches (Orthoptera: Blattellidae). *J. Econ. Entomol.* 79, 1280–1286.

Nachman, M., and Hartley, P. L. (1975). Role of illness in producing taste aversion in rats: Acomparison of several rodenticides. *J. Comp. Physiol. Psychol.* 89, 1010–1018.

Owens, J. M., and Bennett, G. W. (1983). Comparative study of German cockroach population sampling techniques. *Environ. Entomol.* **12**, 1040–1046.

Pavlov, I. (1927). Conditioned reflexes. Oxford University Press, Oxford, 430 pp.

Reierson, D. A. (1995) Baits for German cockroach control. Rust, M. K. et al. eds. *Understanding and controlling the German cockroach.* Oxford, New York. 231–266.

Reierson, D. A., and Rust, M. K. (1984). Insecticidal baits and repellency in relation to control of the German cockroach, *Blattella germanica* (L.). *Pest Management* 2, 26–32.

Rust, M. K., and Reierson, D. A. (1981). Attraction and performance of insecticidal baits for German cockroach control. *Int. Pest Contr.* 23, 106–109.

Short, J. E., Mosson, H. J., Worsley, J. L., and Edwards, J. P. (1994). Toxicity of hydramethylnon to *Blatta orientalis* L. by direct and indirect exposure, and effects of hydramethylnon baits against a mixed population of *Blatta orientalis* L. and *Blattella germanica* (L.) in a simulated domestic environment. *Proc. 1st Inter. Conf. Insect Pests Urban Environ.* Wildey & Robinson eds. 295–304.

Silverman, J., and Bieman, D. N. (1993). Glucose aversion in the German cockroach, *Blattella germanica. Journal of Insect Physiology.* 39, 925–933.

Silverman, J., and Ross, M. H. (1994). Behavioral resistance of field-collected German cockroaches (Blattodea: Blattellidae) to baits containing glucose. *Environmental Entomology.* 23, 425–430.

Silverman, J., Vitale, G., and Shapas, T. J. (1991). Hydramethylnon uptake by Blattella germanica (Orthoptera: Blattellidae) by coprophagy. *J. Econ. Entomol.* 84, 176–180.

Sparks, T. C., Lockwood, J. A. Byford, R. L., Graves, J. B., and Leonard, B. R. (1989). The role of behavior in insecticide resistance. *Pestic. Sci.* 26, 383–399.

Wang, C. H. Yang, H. T., and Chow, Y. S. (1995). The controlling effects of abamectin and hydramethylnon for the Australian cockroach, *Periplaneta australasiae* (F.) (Orthoptera: Blattellidae), in Taiwan. *J. Entomol. Sci.* 30, 154–163.