THE INFLUENCE OF BAIT STATIONS ON FEEDING BEHAVIOR IN *PERIPLANETA AMERICANA*

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Abstract—Aspects of the feeding preferences and behavior patterns of cockroaches, and the influence of environmental factors such as the delivery system may contribute to the efficacy of toxic baits for cockroach control. The research objectives were to evaluate the influence of bait stations on the feeding of adult and nymphs of *Periplaneta americana* (L.), and to relate these differences to preferences for feeding on exposed or containerized (stations) baits. A delivery system of plastic stations and exposed food was evaluated for their influence on the feeding of adults and nymphs of *P. americana*. Cockroaches were confined in aquaria supplied with harborage and water; food consisted of either rat chow, dog food, or toxic bait (hydramethylnon, 1.65% AI), and was available in exposed sites or unexposed in two different size plastic bait stations. Feeding behavior and preference varied depending on the sex and life stage of the cockroaches tested.

INTRODUCTION

The use of toxic baits has become an effective component of domestic and peridomestic cockroach control programs around the world (MacDonald *et al.*, 1987; Patterson and Koehler, 1989; Appel, 1990; Short *et al.*, 1993). The effectiveness of baits may depend on several factors: palatability of the food materials which results in the cockroach ingesting a dose sufficient to produce mortality; a toxicant that is not repellent or a feeding deterrent; environmental conditions such as temperature and humidity; and the feeding behavior of domiciliary cockroaches. As more information on these and other factors becomes available the efficacy of baits will increase.

A variety of material has been used as the food matrix in cockroach control baits, including common household substances such as sucrose, potatoes, chocolate, and bread (Herms, 1915; Miesch and Howell, 1967; Reierson and Rust, 1977). However, bait constituents have improved with information on general feeding behavior and the food preferences of cockroach species and their life stages (Tsuji, 1965; Ballard and Gold, 1982; Brenner and Patterson, 1988). Early baits for cockroach control were often home-made concoctions of a food matrix and slow acting toxicants such as boric acid, phosphorus, or arsenic (Herms, 1915). The availability of organophosphates and carbamates improved the efficacy of baits and led to commercial products for cockroach control (Lofgren and Burden, 1958; Eversole, 1971; Wright *et al.*, 1973). Further improvements in the food matrix and the toxicants (Silverman and Shapas, 1986; Koehler *et al.*, 1991) have resulted in baits becoming an accepted cockroach control strategy (Appel, 1992).

Aspects of the feeding behavior of cockroaches and the influence of environmental factors such as temperature and relative humidity may contribute to the efficacy of toxic baits. The nutritional requirements and quantitative feeding behavior of *Blattella germanica* (L.) (Gordon, 1959; Tsuji, 1965; Silverman and Bieman, 1993) and *Periplaneta americana* (L.) (Subbiah and Pandimuthu, 1981; Rollo, 1984; Rollo and Gunderson, 1984) influence bait consumption, and the competitiveness of baits with alternative household foods. The delivery of toxic baits to the household environment is typically in the form of tamper-proof containers to prevent access by nontarget organisms (children and pets). However, containerized delivery systems (stations) may affect the feeding behavior of the cockroach by limiting access, or introducing an obstacle between the target pest and bait.

The objectives of the research presented here were to evaluate the influence of bait stations on the feeding behavior of adults and nymphs of *P. americana*, and to relate these differences to the utility of containerized or exposed baits in American cockroach control programs.

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MATERIALS AND METHODS

Cockroaches

The American cockroaches used in all evaluations were taken from a laboratory colony established in 1990 from adults and nymphs collected in Roanoke, Va. Colony rearing conditions included 24 - 270 C, photoperiod of 12:12 (L:D), ambient relative humidity, and unlimited water and food (4% Mouse/Rat Diet 7001, Teklab, Madison, WI).

Test Arena

Glass aquaria (40×20×26 cm) were provided with harborage and water at one end, and a screen top to prevent cockroaches from escaping. Exposed and containerized baits were placed at the end of the aquaria opposite the harborage. Exposed baits were placed in circular trays (4×1.5 cm); the containerized baits were in small or large black, plastic stations (Combat, The Clorox Co., Pleasanton, CA). The small station (5×5×1 cm) had three access openings, and the large station (8×8×1.5 cm) had four; the width of the openings in both station were approximately 1.6 cm.

Food Site Preference Test

Cockroaches were permitted to acclimate to the aquaria for 24 h before baits were introduced. Baits were weighed before placement in the aquaria, and weighed periodically during the test, as were duplicates of the baits which were maintained as controls. Into each of the aquaria were placed either 10 adult males or females, 10 large male or female nymphs (7–8th instar) , or 40 mixed sex small nymphs (4–5th instar). Cockroaches were observed daily and mortality was recorded; dead cockroaches were removed from the aquaria during the test. Three replicates were done for each test.

The nontoxic baits evaluated were: rat chow pellets (4% Mouse/Rat Diet 7001, Teklab, Madison, WI), dog food pellets (Canine 21 Dog Formula, PMI Nutrition, Brentwood, MO), and the toxic bait was Combat (hydramethylnon 1.65% AI).

Three food site preference tests were conducted: 1) rat chow in the exposed location and in the large and small stations, and evaluated with adults, large and small nymphs; 2) rat chow in the exposed location and dog food in the large and small stations, and evaluated with adults and large nymphs; 3) rat chow in the exposed location and toxic bait in the small station, and evaluated with adults. Feeding sites were changed depending upon the feeding preferences demonstrated by the cockroaches. After sufficient time to become acclimated to the environment and weight changes in the food indicated that the different food sources were fully utilized, food sources were changed.

Feeding Behavior Test

To determine aspects of the feeding behavior for individual adult male and female cockroaches (n = 10), rat chow pellets stained with Sudan Red (Fat Red 7B, Sigma Chemical Co., St. Louis, MO) were used in the exposed location and in the large bait station. One test arena contained only the exposed location and two replicates were done using only the large bait station. After 7 d exposure to the stained baits, the cockroaches were dissected and examined for evidence of internal red staining.

RESULTS

Food Site Preference: Rat Chow Exposed and in Stations

Adults and large nymphs displayed similar feeding preferences in response to food location. When all food sources were present (exposed and containerized), feeding was predominately from the exposed location (Table 1). After the exposed source was removed from the aquaria and food was available only from the large and small stations, the small bait station was preferred Following removal of the small station, the large station was used as a feeding site. All food sources were utilized by the cockroaches, but feeding site preference changed depending upon which sources

were present. Only small nymphs showed no differential feeding with respect to exposed or unexposed baits.

All food sources available. When exposed and unexposed food was available, adults and large nymphs fed predominately from the exposed food. Total consumption for adult males and females from this exposed food was 873.5 and 1781.6 mg; and 19.0 and 108.2 mg from the stations, respectively (Table 1). Total daily consumption for males and females was 127.5 and 188.9 mg/d, respectively. Large male and female nymphs consumed 411.4 and 543.5 mg of the exposed food, and 110.2 and 7.3 mg of the food in the stations, respectively. Total daily consumption for large male and female nymphs was 52.2 and 55.1 mg/d, respectively.

Small nymphs utilized food from all sources. During the first 13 d of exposure, feeding was primarily from the small (133.1 mg) and large (160.0 mg) stations; with 67.5 mg consumed from the exposed source. During the 12 d of exposure, food consumption was nearly equal between all locations, with 332.5, 441.1, and 467.3 mg from the exposed, small station, and large station, respectively. Daily food consumption increased from 14.8 mg/d to 49.6 mg/d during the 25 d of the study.

Small and large stations available. In the presence of food only in stations, adults and nymphs fed predominately from the small station. Adult males and females consumed 686.4 and 1397.6 mg from the small station and 39.5 and 37.0 mg from the large station, respectively (Table 1). Daily food consumption was 72.6 mg/d for males and 130.4 mg/d for females. Large male nymphs consumed 518.4 mg from the small station and 267.1 mg from the large station; daily food consumption was 112.2 mg/d. Large female nymphs ate 624.7 mg from the small station and 43.8 mg from the large station; daily food consumption was 95.5 mg/d.

Large station available. In the presence of only the large station, adult males and females ate 506.4 mg (46.0 mg/d) and 897.5 mg (89.8 mg/d), respectively (Table 1). Large male and female nymphs consumed 726.8 mg (121.8 mg/d) and 414.7 mg (69.1 mg/d), respectively.

Food Site Preference: Rat chow Exposed and Dog Food in Stations

When another food source (dog food) was provided in the stations, feeding behavior changed depending upon the sex or life stage of the cockroach (Table 2). Adult males ate 827.4 mg of

Table 1. Food consumed and daily consumption rate by various life stages of American cockroaches presented rat chow in exposed and enclosed locations.

	Total food consumed (mg) and daily consumption rate (mg/d)				
Life stage	Exposed	Small station	Large station	Total	mg/d
Adult males	873.5	16.8	2.2	892.5	127.5
	–	686.4	39.5	725.9	72.6
	–	–	506.4	506.4	46.0
Adult females	1781.6	108.2	0	1889.8	188.9
	–	1397.6	37.0	1434.6	130.4
	–	–	897.5	897.5	89.8
Large male nymphs	411.4	11.3	98.9	521.6	52.2
	–	518.4	267.1	785.5	112.2
	–	–	726.8	726.8	121.1
Large female nymphs	543.5	0.2	7.1	550.8	55.1
	–	624.7	43.8	668.5	95.5
	–	–	414.7	414.7	69.1
Small mixed-sex nymphs	0	19.1	84.3	103.4	14.8
	67.5	133.1	160.0	360.6	27.7
	157.5	193.6	284.4	635.5	35.3
	332.5	441.1	467.3	1240.9	49.6

Table 2. Food consumed by various life stages of American cockroaches presented with rat chow in exposed and dog food in enclosed locations.

	Total food consumed (mg)		
Life stage	Exposed	Small station	Large station
Adult males	827.4	116.6	0
	–	878.9	7.9
Adult females	494.8	885.2	548.9
	1077.3[a]	132.4	114.9
Large male nymphs	248.1	152.6	19.1
Large female nymphs	729.5	196.3	54.8

[a]dog food

exposed rat chow and 116.6 mg of dog food from the stations. After the exposed rat chow was removed, 878.9 mg of dog food was consumed from the small station and 7.9 mg from the large station. Adult females consumed 494.8 mg of the exposed rat chow, 885.2 mg from the small station, and 548.9 mg from the large station. When the exposed food was changed to dog food, adult females ate 1077.3 mg of the exposed food, 132.4 mg from the small station, and 114.9 mg from the large station. Large male nymphs consumed 248.1 mg of the exposed rat chow, 152.6 mg from the small station, and only 19.1 mg from the large. Large female nymphs ate 729.5 mg of the exposed rat chow, 196.3 mg from the small station, and 54.8 mg from the large stations.

Food Site Preference: Rat chow Exposed and Toxic Bait in Small Station

The food utilization was unequal between adult males and adult females and this resulted in different mortality rates. When provided rat chow in exposed location and toxic bait in the small station, adult males ate 1438.5 mg of rat chow and 24 mg of toxic bait, and mortality after 12 d was 28%. Adult females consumed 796.0 mg of rat chow and 324.5 mg of toxic bit, and mortality after 12 d was 78%.

When the top covers were removed from the bait stations, making the toxic bait more accessible, there was little difference in the amount of food consumed by males and females. Adult males consumed 326.7 mg of toxic bait and 0 mg of rat chow, which resulted in 75% mortality in 7 d. Adult females consumed 415.4 mg of toxic bait and 14.7 mg of rat chow, which resulted in 86% in 7 d.

Feeding Behavior Test: Stained Rat Chow Exposed or in Large Station

When the stained rat chow was the exposed food, all adult males and females ate from this source. Upon dissection, their crops were found to contain red rat chow, and the gastric caecae appeared enlarged and stained pale red. When the stained rat chow was in the large station, 10 of the 20 males had evidence (internal staining) of feeding from the rat chow similar to the exposed feeding results, the remainder of the males showed no evidence of feeding. Of the 20 adult females, 6 had red internal staining similar to those from the exposed rat chow tests, 9 had slight indications of either previous or limited feeding, and 5 had no evidence of feeding.

DISCUSSION

The results of this research show that the feeding behavior of adults and large nymphs of American cockroaches changes in response to the kinds of food sources that are available in their environment, and with respect to location of those food sources (in stations or exposed). Adult males and females apparently do not readily enter stations to obtain food. These behavioral responses to food and toxic bait delivery systems may effect control programs that utilize baits as a control strategy for this species. They may reduce the effectiveness of bait stations to control the

major segments of American cockroach populations, specifically adult males, females, and large nymphs. Only small nymphs readily accepted and fully utilized the bait stations as feeding sites in this study. The suppression of pest populations of *P. americana* with the use of toxic bait stations may be delayed or prevented by the selective feeding behavior of adults and large nymphs.

When the bait station and the exposed site contained identical food types, such as rat chow or dog food, feeding occurred primarily on the exposed food. This indicates that for bait stations to be effective in reducing domestic and peridomestic populations of American cockroaches they must contain a bait (food) that is competitive with other food in the cockroaches' environment. Few adults and large nymphs will feed on the bait in the station, and suppression of the population may not be achieved if the bait in the station represents only an equally attractive source of food. Using a novel food (dog food vs. rat chow) in the station did not insure that cockroaches would utilize the station as a feeding site. Adult males restricted their feeding to the exposed food and consumed little of the food in the station, even when there was a novel food in the station. This also occurred when the station contained a highly desirable bait. Data indicates that there are some physical features of the station that may influence feeding behavior, and limit the time spent feeding or the amount of food consumed. All cockroaches fed from the stained rat chow when it was exposed. However, when the stained rat chow was only available from the large station, one-half of the adult males had no evidence of any feeding and the majority of the adult females either stopped feeding or limited their feeding.

It may be difficult to develop a consistently desirable bait given the diversity of foods which may be present in the domestic and peridomestic environment Failure to effectively control pest populations can be the result of the reluctance of key components of the population, such as adult females to feed from the station, regardless of the food it contains. For example, when food was available in both the exposed location and bait stations, cockroaches always fed from both sources regardless of the type of food available in the station. This suggests that control may be reduced because some cockroaches would continue to utilize the available, and perhaps more abundant, food sources that existed in the habitat before the bait stations were deployed. When no exposed sources of food were present and the opportunity to feed was restricted to the food in the stations, the adults either stopped eating entirely or there was limited or sporadic feeding from the stations. This amount of feeding may not be sufficient to reduce a pest population, because water alone is reported to be enough to sustain American cockroaches for over 40 days (Willis and Lewis, 1957). This raises the possibility that a cockroach control program based exclusively on bait stations may fail because of the cockroaches' reluctance to utilize the food in the bait stations, even when no other food source is available. When the tops of the stations were opened and the accessibility of the toxic bait was equal to the other (exposed) food , higher levels of mortality were achieved, and in less time than when the bait was enclosed. This confirms that access to food or bait is as important as the quality of the material.

Bait stations were made available for consumer and professional use containing a bait enclosed within a protective housing, and inaccessible to children or pets. In today's environment of heightened chemical awareness, a delivery system that was tamper proof or "child resistant" meets certain consumer-oriented objectives (Hainze, 1993). The research reported here suggests that enclosing the toxic bait in the station may have resulted in a reduction in it's effectiveness to control American cockroach populations. Insecticide formulation technology may be further developed to the extent that baits in stations will be highly competitive with all other possible food sources in the urban environment. What may be needed is refining of the delivery systems that are used to introduce those baits into a domestic or peridomestic habitat. For example, the data indicates that the new small design station is preferred as a feeding site over the large conventional station. Bait guns or syringes also offer alternative methods for bait application.

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