

FOOD BAIT PREFERENCE IN GERMAN COCKROACH, *BLATTELLA GERMANICA* (L.) (DICTYOPTERA: BLATTELLIDAE)

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Abstract - The aim of this study was to investigate food bait preference in *Blattella germanica* (L.) cockroaches in relation to age and to compare their feeding preferences in several choice situations. Food choice presents two components: attractiveness measured by food type eaten first and feeding stimulation measured by mean duration of feeding on a food source. Comparisons between attractiveness of the food baits tested revealed that fipronil gel was more attractive than hydramethylnon, abamectin B1 gel or boric acid. Hydramethylnon gel had higher feeding stimulation potential than fipronil gel and fipronil gel was higher than boric acid. The feeding stimulation potentials of fipronil gel and abamectin B1 gel were similar. Age influenced feeding preference: small and medium-sized larvae preferred bread and chose bread first more often than fipronil gel whereas large larvae and non-gravid females showed no first choice preference but fed on fipronil gel for longer than on bread.

Key words - Food choice, gel baits, attractiveness, feeding stimulation

INTRODUCTION

Cockroaches are among the best known urban pests and many investigations aim at finding ways to eradicate them. A few years ago, a new generation of toxic gel baits appeared on the European market. Before that, pest control professionals used sprays which were not easy to apply and the habitants often found that the treatments were unpleasant or offensive. Ten years ago, toxic baits were rarely used by professionals because, not only most of the active components were not attractive, but they were often repellent (Rust and Reiersen, 1981). According to Rust *et al.* (1995), German cockroaches are repelled by most insecticides, especially when presented in bait form and this pest could not be controlled successfully with baits. Recent developments in bait technology involve mixing relatively slow-acting insecticides into a food base. However, since the new generation of toxic gels has arrived, insecticide spray applications are being rapidly replaced by more environmentally sound approaches, such as baits. Indeed, the use of baits results in less environmental contamination and greater ease of application than the other insecticide products (Rust, 1986). Cornwell (1976) defined a bait as a substance which incorporates an insecticide in an attractive and palatable food. To be efficient, gel formulations must be palatable and non-repellent, easy to consume and toxic in the amounts consumed (Appel, 1990).

The level of exploitation of a food resource depends on its own characteristics as well as the energy needs of the insect exploiter. One critically important factor is changes in feeding requirements of the exploiter in relation to its age or physiological state and a second factor is resource quality. Indeed, rhythms of food intake are related to sexual cycles in females, gravid females do not eat (Cochran, 1983) and moulting cycles, larvae have to eat at least once during each instar to moult and the peak of activity is near the middle of the instar (Kunkel, 1966; Dabouineau and Rivault, 1988; Valles *et al.*, 1996). Harborage-to-resource distance can also influence the frequency of feeding activity in cockroaches (Silverman, 1986). Attractiveness of a toxic bait must be evaluated in order to estimate its efficiency for the control of German cockroaches because this species locates food essentially by random search (Meisch and Howell, 1967) and exploits the first food source encountered (Rivault and Cloarec, 1991).

The aim of this study was to investigate food bait preference in *Blattella germanica* (L.) cockroaches in relation to age and to evaluate their preference between several baits. We tested different

age-classes of German cockroaches observing them in binary choice situations. Goliath® (fipronil) was tested against either bread or one of three other toxic baits: hydramethylnon, abamectin, or boric acid.

MATERIAL AND METHODS

Insects

Cockroaches used in our experiments were German cockroach, *Blattella germanica* collected in Rennes (France) and reared in the laboratory since 1987. In order to know if age influenced food choice, first, third and fifth instar larvae and non-gravid females were tested. These cockroaches came from an age-class serial breeding.

Tested baits

Four toxic baits were used in choice tests: fipronil gel (0.05%; commercialized as Goliath®, Rhône-Poulenc Rhodic, Lyon, France); hydramethylnon gel (2.15%); abamectin B1 gel (0.05%), and boric acid gel (33.3%). Cockroaches were also given a choice between fipronil gel and a usual attractive food, white bread (Reiersen and Rust, 1977).

Experimental set-up

Tests were performed in Petri dishes containing a folded cardboard shelter and water. One small first instar larva, one medium-sized third instar larva, one large fifth instar larva and one non-gravid female were placed in each test dish. This method allowed us to individualize each cockroach without having to mark them. Individuals were left to habituate to this set-up for 3 days. During this time, they were not fed in order to increase their hunger level and thereby optimize their response to the food choice on the day of the test. Fasting before a test does not influence their choice, Silverman and Selbach (1998) observed that males repelled by glucose preferred to die rather than eat any glucose. In our experiments, cockroaches were not forced to eat a bait when they did not want to.

Test dishes were placed in a room equipped with a high sensibility video camera (CCD Ikegami, 0.01 lux) fitted with a LED infra-red projector. Tests were carried out in complete darkness during the cockroach active phase. Just before a test, two small dishes containing the same quantity, 0.03 g, of two different food types were introduced into the test dish, through a hole in the lid. They were placed either side of the water source, approximately 10 cm from the shelter. Activity in this dish was video recorded from the beginning of the test until 10 minutes after the last cockroach began to feed. We tested four choices: fipronil gel versus bread, fipronil gel versus hydramethylnon, fipronil gel versus abamectin B1 gel and fipronil gel versus boric acid. In this paper, they are noted: fipronil gel / bread, fipronil gel / hydramethylnon, fipronil gel / abamectin B1 gel and fipronil gel / boric acid, respectively. As each cockroach was individualized we could measure the following parameters: the type of food chosen first by each cockroach and the time spent by each cockroach on each food source.

Data analysis

ANOVAs and Student t-tests were performed to evidence differences in feeding in relation to age of cockroach and type of food.

RESULTS

Influence of type of food and of age-class on total duration of food intake

An ANOVA computed without taking into account cockroach age-class revealed that total duration of feeding on both food types varied significantly with type of food in test choice ($F = 11.469$, $p < 0.0001$). Cockroaches spent significantly less time feeding when given the choice fipronil gel / boric acid than in the presence of the other choices. Total feeding duration did not vary significantly between the three other test situations: fipronil gel / bread, fipronil gel / hydramethylnon and fipronil gel / abamectin B1 gel.

To test the influence of age-class on total duration of food intake, an ANOVA on total duration of

food intake for each cockroach was computed without taking into account the type of food in test. This ANOVA revealed a highly significant age effect on duration of food intake ($F = 60.848$, $p < 0.001$). The following order was established: non-gravid females ate more than large larvae; these large larvae in turn ate more than small and medium-sized larvae (Fig. 1). This implies that we cannot compare directly mean feeding duration between age-classes on each food type to know if feeding preference varied with age. Because total feeding duration varied with age, a ratio was calculated to eliminate differences in the quantity of food eaten due to differences in age-class size. This ratio was obtained by dividing duration of feeding on each food type by total duration of feeding during the test for each individual.

Influence of age on the duration of food intake in relation to food type

Table 1. Feeding duration (\pm s.e. mean) on each food type, in each choice situation, in relation to the food eaten first. Legend: mean duration d_F : **F**, d_H : **H**, d_A : **A**, d_B : **B** and d_{bread} : bread, t is the calculated value of the Student test and p is the associated probability.

Choice situation	Food eaten first	Feeding durations in sec (\pm s.e. mean) and t-test results
F versus A	F	$d_F = 269.42 \pm 18.11$ sec; $d_A = 39.53 \pm 9.28$ sec $t = 9.765$; $p < 0.0001$
	A	$d_F = 77.19 \pm 17.6$ sec; $d_A = 269.19 \pm 23.51$ sec $t = 5.362$; $p < 0.0001$
F versus Bread	F	$d_F = 291.52 \pm 24.21$ sec; $d_{\text{Bread}} = 35.29 \pm 11.4$ sec $t = 8.849$; $p < 0.0001$
	Bread	$d_F = 68.66 \pm 14.01$ sec; $d_{\text{Bread}} = 300.59 \pm 29.22$ sec $t = 5.896$; $p < 0.0001$
F versus H	F	$d_F = 180.98 \pm 13.36$ sec; $d_H = 132.94 \pm 16.29$ sec $t = 1.975$; $p = 0.0526$
	H	$d_F = 57.35 \pm 13.43$ sec; $d_H = 274.62 \pm 26.45$ sec $t = 6.551$; $p < 0.0001$
F versus B	F	$d_F = 238.68 \pm 11.74$ sec; $d_B = 6.57 \pm 1.2$ sec $t = 19.851$; $p < 0.0001$
	B	$d_F = 236.4 \pm 48.71$ sec; $d_B = 52.5 \pm 12.97$ sec $t = 3.206$; $p = 0.0107$

ANOVAs were computed on these ratios to analyse the influence of age on the results of choice tests. In the presence of a choice between fipronil gel and another toxic bait (hydramethylnon, abamectin B1 gel or boric acid), no modifications in food preference with age could be evidenced ($F = 1.354$, $p = 0.2610$; $F = 1.157$, $p = 0.3297$; $F = 2.459$, $p = 0.0671$, respectively). Therefore, feeding preference between these toxic baits does not depend on the age of the foraging individual and the age factor could be eliminated in these three situations and feeding duration for each type of food for the different age-

classes could be pooled and compared (Fig. 2). When presented a choice between fipronil gel and hydramethylnon, cockroaches spent significantly longer feeding on hydramethylnon than on fipronil gel. When presented a choice between fipronil gel and abamectin B1 gel or fipronil gel and boric acid, cockroaches spent longer feeding on fipronil gel. These comparisons of mean feeding duration gave the following order of preference: hydramethylnon was preferred to fipronil gel which in turn was preferred to abamectin B1 gel and boric acid.

An ANOVA on the choice ratios for fipronil gel / bread revealed significant differences ($F = 7.533$, $p = 0.0001$) and distinguished two groups of age-classes. The analysis of mean durations (Student t-test) showed that large larvae and non-gravid females spent significantly longer feeding on fipronil gel than on bread whereas, small and medium-sized larvae spent significantly longer feeding on bread than on fipronil gel (Fig. 3). Therefore, large larvae and non-gravid females preferred fipronil gel, whereas small and medium-sized larvae preferred bread.

Data for mean feeding durations showed that age influenced food choice between fipronil gel and bread. This difference in relation to age was not found in other choice situations. Comparisons between mean feeding durations showed that cockroaches ate hydramethylnon longer than fipronil gel and they ate fipronil gel longer than abamectin B1 gel and boric acid.

First choice

The results for first choice appeared to differ from those presented above. Fipronil gel was chosen first significantly more often in choice tests with hydramethylnon, abamectin B1 gel or boric acid, whatever the age-class of individuals (Fig. 4). However, in the presence of the choice between bread and fipronil gel, large larvae and non-gravid females showed no significant tendency to eat either food type, whereas first and third instar larvae chose bread first more often than fipronil gel. Baits ranked differently when feeding durations or first choices were considered. First choice results indicated that fipronil gel was more attractive than hydramethylnon, abamectin B1 gel and boric acid. Fipronil gel appears more attractive from a distance than the three competitor baits. For large larvae and adults, fipronil gel appears to be as attractive as bread, which is a common food, but bread is more attractive than fipronil gel for small and medium-sized larvae.

We tested the influence of the type of food chosen first on duration of feeding on the different food sources (Table 1). Results were similar for choices fipronil gel / bread and fipronil gel / abamectin B1 gel : in these tests cockroaches spent significantly longer feeding on the food they chose first. In the choice fipronil gel / boric acid, cockroaches fed on fipronil gel significantly longer, whatever the food type eaten first. Even if they chose boric acid first, which was rare, they ate more fipronil gel than boric acid. Moreover, feeding on fipronil gel lasted longer when it was in competition with boric acid than when it was in competition with another type of food ($F = 11.063$; $p < 0.0001$). In the choice fipronil gel / hydramethylnon, cockroaches spent longer feeding on hydramethylnon than on fipronil gel when they chose hydramethylnon first. However, when, as often the case, cockroaches chose fipronil gel first, total durations of feeding on fipronil gel or on hydramethylnon did not differ significantly. This may explain why feeding was longer on hydramethylnon than on fipronil gel although fipronil gel was chosen first more often. These results stress the importance of first choice on the quantity of food eaten. In most cases, cockroaches spent longer on the food type chosen first.

DISCUSSION

Depending on the parameters analysed, the four insecticide baits tested and bread ranked differently. In order to understand these apparent contradictions, we distinguished attractiveness from feeding stimulation. According to Dethier *et al.* (1960), an attractant causes an insect to perform directive locomotory responses toward a source of stimulation. When the source of stimulation is reached, a different behavior is released, this may be a consummatory act if the substance is perceived as a feeding stimulant. A feeding stimulant is a substance which elicits feeding. Attractiveness and feeding stimulation

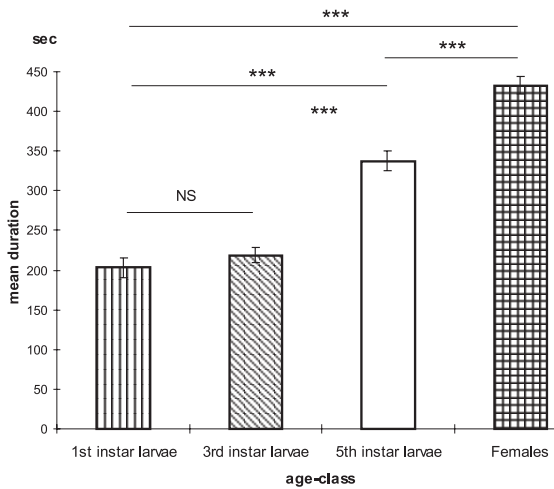


Figure 1. Feeding duration in relation to age. Bars represent mean (\pm s.e.) duration spent on each food type by cockroaches of each age-class. Durations are expressed in seconds.
Legend: *** = $p < 0.0001$; NS = no significant difference.

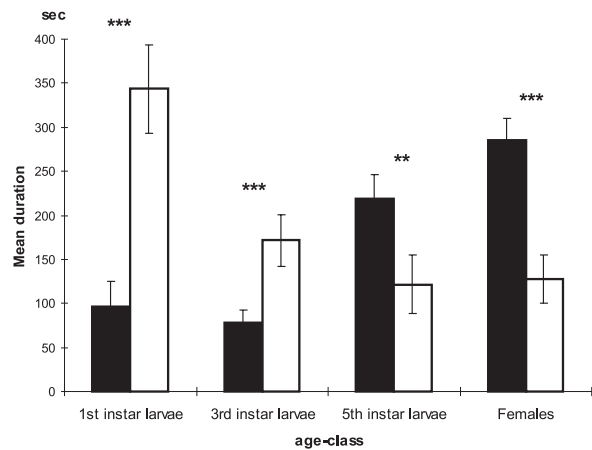


Figure 2. Feeding duration on food baits. Bars represent mean (\pm s.e.) duration spent on each food source in 3 choice situations: F/H, F/A, F/B. Durations are expressed in seconds.
Legend: *** = $p < 0.0001$; ** = $p < 0.01$

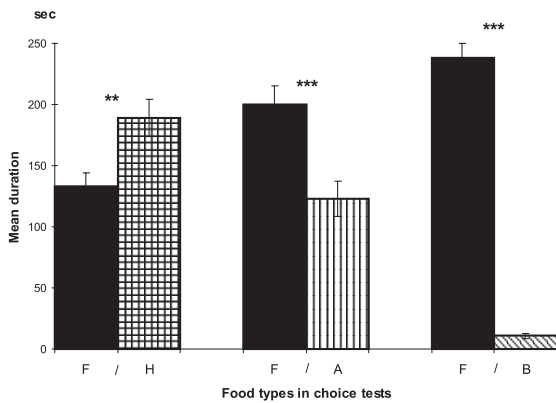


Figure 3. Feeding duration on F and bread in relation to age. Bars represent mean (\pm s.e.) duration spent on F (n) or on bread () by cockroaches of each age-class. Durations are expressed in seconds.
Legend: *** = $p < 0.0001$; ** = $p < 0.01$

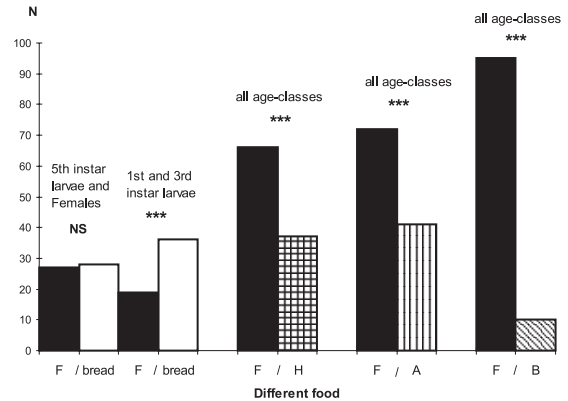


Figure 4. Number of times each type of food was chosen first for each choice situation. Bars represent the number of cockroaches that ate that food type first.
Legend: *** = $p < 0.0001$; ** = $p < 0.01$; NS = no significant differences; N = number of cockroaches choosing each food type first in each choice situation: F/bread, F/H, F/A, F/B.

induce two different types of activity but can be elicited by the same substance. Our data analysis distinguished attractiveness of a bait from its level of feeding stimulation. Attractiveness was measured by first choice whereas feeding stimulation was measured by duration of feeding on each type of food. The first food eaten was considered to be the most attractive, whereas the longest feeding durations were observed on the most stimulating food sources. Tsuji (1965, 1966), working on different constituents of rice bran and on some carbohydrates, showed that an attractive substance need not be a feeding stimu-

lant and that a feeding stimulant can be unattractive. Only a few of the compounds he found to be attractive were also feeding stimulants. In German cockroaches, the attractive effect of a rice bran extract was due to its neutral fraction whereas the feeding stimulant effect was attributable to both the neutral and acidic fractions. That means that some constituents of rice bran are feeding stimulants but are not attractive. Our results concerning the choice between fipronil gel and hydramethylnon can be interpreted in the same way. Fipronil gel appeared more attractive than hydramethylnon because fipronil gel was chosen first more often, but when feeding duration was taken into account, hydramethylnon seemed to be more stimulating than fipronil gel. Although Kaakeh *et al.* (1997) reported that another food bait containing hydramethylnon, the same active ingredient as in hydramethylnon, was as attractive as fipronil bait, their experimental design made it impossible to evaluate attractiveness and feeding stimulation separately. Differences in feeding stimulation can perhaps be explained by differences in texture between baits. hydramethylnon dried up quickly, whereas fipronil gel retained its moist aspect for a long time. Cockroaches may not like this clammy aspect. Appel and Benson (1996) found that bait texture was a critical factor in toxicity, presumably as a function of feeding stimulation.

Fipronil gel is more attractive than abamectin B1 gel but their feeding stimulant efficiencies seem to be similar. In this choice situation, cockroaches always spent longer on the food type they chose first. If a cockroach that chose abamectin B1 gel first did not find it stimulating, it would have moved to the fipronil gel dish because this bait is attractive. As this was not the case, this suggests that there were not differences in feeding stimulation level between these two baits. Furthermore, a high level of feeding stimulation has been reported for baits containing abamectin (Cochran, 1985).

Boric acid was very rarely chosen first and feeding durations on boric acid were always very low. Furthermore, in the fipronil gel / boric acid choice situation, total feeding times were lower than those in the other situations, this suggests that boric acid inhibits feeding. boric acid is not attractive and not an efficient feeding stimulant. Tests with food baits containing boric acid (active ingredient of boric acid) indicated that this molecule is repellent (Strong *et al.*, 1993).

The results of choices between fipronil gel and bread raised questions concerning the perception of the toxicity of baits by cockroaches of different age-classes: large larvae and non-gravid females remained longer on fipronil gel than on bread but their first choices revealed no real preference for either food type, whereas small and medium-sized larvae preferred bread to fipronil gel and chose bread first more often than fipronil gel. One hypothesis that could explain these changes in choice in relation to age is the variation of the ratio between amount of toxicant and individual size, small and medium-sized larvae are smaller than a 0.03 g drop of fipronil gel. Therefore, they may be able to detect the toxicity of baits and then to avoid it. They probably perceived its toxicity all the better as the test dish was a confined environment. Our results can be compared to Rust and Reiersen (1981) experiments showing that unaltered food attracted cockroaches more than baits did. Therefore, we can infer that the insecticide contained in fipronil gel, fipronil, is less repellent than molecules available on the market in 1981.

Finally, in relation to the parameter analysed, the ranking of the different food baits tested varied and did not always reflect the real efficiency of the bait. For example, the average level of feeding stimulation of fipronil gel does not affect its efficiency: fipronil kills German cockroaches in nanogramme quantities per insect (Valles *et al.*, 1997). Therefore, even if cockroaches eat only a very little, they will die. In addition, a drop is not eaten completely by the first cockroaches that find it, some bait remains for the following cockroaches. On the other hand, fipronil gel was the most attractive bait, that means foraging cockroaches can find it easily in their home range, whereas hydramethylnon and abamectin B1 gel, that seem to be less attractive, have to be found on a more random basis. According to Cornwell's definition (1976), boric acid can no longer be considered a bait because it is repellent and deterrent.

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