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# BAIT AVERSION BY GERMAN COCKROACHES (DICTYOPTERA: BLATTELLIDAE): THE INFLUENCE AND INTERFERENCE OF NUTRITION

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**Abstract** Bait consumption is a complex interaction of behaviors and physiology / biochemistry mechanisms. It starts with a single premise that the response to a shortage or an impending shortage of nutrients required for maintenance, growth and development. Shortages may be acute such as a daily requirement, or chronic where the nutritional requirement delays growth and development, resulting in continual attempts to overcome the shortage. Nutritional demand will depend internally on cockroach age, sex, and stage of development and externally on what nutrients are available, also the concentration, ingredient type, and location. Understanding nutritional status and nutrient availability is critical for ensuring that cockroaches will identify a bait as a food item, test the food item, and continue consumption until sufficient intake of toxin results in lethality. Failure to fully stimulate bait consumption will result in cockroaches surviving a sub-lethal dose, with possible changes in behavior(s) towards further consumption of bait. Continued failure may permit the genetic selection and amplified displays of aversion (or non-stimulation) in future generations.
**Key Words** Nutritional status, bait development

## INTRODUCTION

"The dose makes the poison" (Paracelsus) is a critical factor to successfully using insecticidal bait to control German cockroaches, *Blattella germanica* (L.) (Simpson et al., 1995; Jones and Raubenheimer, 2002). Ensuring proper delivery of a dose relies on the cockroach to detect and identify bait placements as food, to sample this food, and to continue consuming until enough active ingredient is ingested. For baits to be identified and accepted as food, appropriate nutrition must be offered to satisfy a cockroaches' need (or impending need) of nutrients required for maintenance, growth, and development. However, the situation is more complex that simply fulfilling physiological and biochemical appetite, because the development of bait aversion occurs despite our knowledge and abilities to provide complete diet materials. The possibility of sub-lethal dosing from diet mixing and other post-exposure behaviors may result in survival of individuals. Unfortunately, little is known about the impact of post-exposure foraging and diet selection behaviors, and whether surviving individuals simply do not identify the bait as a food item; actively reject one (or many) ingredient(s) in the bait; or simply express behaviors that promote nutrient dilution or increased selection of food from a diversity of sources. Despite employing baits for the past 20+ years to control German cockroaches, we are still in the infancy of understanding the mechanisms of how toxic nutrition interacts with this insect's biology and survival mechanisms, resulting in genetic selection and amplified displays of aversion (or non-stimulation) in future generations. And as our reliance continues for bait products to be the premier method of control, there are additional challenges to incorporating what we learn, and will learn, because of more basic constraints from manufacturing and application of bait products.

### Impact of Nutrition on Sub-lethal Dose

German cockroaches are omnivores and generalist feeders, able to consume a wide range of macronutrients (proteins, carbohydrates, fats), and micronutrients (vitamins, minerals, growth factors) from diverse sources. They have specific needs and preferences for consumption of both essential and non-essential nutrients (Gordon, 1959, 1968) and they have abilities to overcome nutritional deficiencies with mechanisms, such as cellulases for carbohydrate shortfalls (Jones and Raubenheimer, 2001), and uric acid conservation for protein deficiencies (Mullins and Cochran, 1975a, b; Clarebrough et al., 2000). Acceptable ranges for dietary protein of 11 to 40%, (Haydak, 1953; Noland and Baumann, 1951; McCay, 1938) and the ability to metabolize fat, in place of carbohydrates (Kells et al., 1999) allows for flexibility in diet selection. In addition to their ability to consume a variety of nutrients, German cockroaches have the ability to select nutrients based on their need and what

nutrients are available (Jones and Raubenheimer, 2001). Permitting flexible systems for contending with nutrient shortfalls provides potential for sub-lethal doses as cockroaches fulfill nutritional needs on a variety of food containing different qualities.

In search of food, German cockroaches tend to forage sequentially with distance (Rivault and Cloarec, 1991), but may increase exploratory behavior and travel greater distances in an attempt to obtain food when nutritionally stressed (Ballard et al., 1984; Silverman, 1986; Barcay and Bennett, 1991; Kells, 1998). Once suitable resources are found, German cockroaches increase efficiency in foraging activities (Demark et al., 1993). Associative learning mechanisms (as demonstrated in American cockroaches; Gadd and Raubenheimer, 2000; Sakura and Mizunami, 2001) may assist in spatially locating resource sites, and ensuring continued consumption of suitable food. Relative to the risk of bait aversion, there could be a risk of sub-lethal dosing through consumption of alternative foods, and dilution of the toxicant from foraging and diet selection activities that limit exposure to bait placements.

With flexibility in nutrient intake, abilities to search and select for nutrient shortfalls, baits must be formulated to complement current nutrition, offering materials not readily available, or be able to "out-compete" current food placements by offering highly attractive food to cockroaches. Both strategies require more extensive surveys of *in situ* nutritional status for both macro- and micro-nutrients, and follow up research using cockroaches reared on similar nutritional profiles. Nutrient surveys from a number of sites will be important to account for the variability in nutrient profiles among different habitats, such as restaurants, food processing, beverage processors, etc. Initial evidence to indicate poor nutrition in situ (Ross and Wright, 1977; Sherron et al., 1982) was confirmed, at least in residences (Kells et al., 1999). If cockroaches in the field (in situ) are nutritionally stressed, current information derived in the laboratories utilizing cockroaches continually fed an "enriched" laboratory diet may produce artifactual data relative to diet consumption and nutrient selection. With previous exposure to an enriched diet (such as rat chow), German cockroaches bias nutrient consumption toward carbohydrates (Kells, 1998). When provided a diet simulating macronutrient availability in residential areas (Kells et al., 1999), German cockroaches select items containing protein. Though the nutrient self-selection concepts are very important, taking advantage of nutrient shortfalls and appetites for scarce nutrients will maximize "first-time" consumption and reduce the risk of sub-lethal dosing. Also, determining nutritional concentration will be important for ensuring sustained bait consumption during the initial dose, without feeding stoppage from satiation.

Post-bait exposure on cockroach biology is another important area requiring further study. Once a toxicant is ingested, there is a race between the toxicant's ability to affect physiology long enough to cause irreversible moribundity, versus the cockroach's ability to detect something is wrong and attempt a defense against this toxicity including: regurgitation, increased movement through gut, and increased detoxification. Behavior following bait consumption by individuals, or interactions with conspecifics are unknown with many baits (and active ingredients), especially actives where there is no contact toxicity or the toxicant is slow acting. The main mode of all active ingredients is to disrupt homeostasis by affecting specific target sites, so behavioral and physiological abilities of maintaining homeostasis may be very important in reacting to a sub-lethal dose. Once a cockroach has survived a sub-lethal dose, resulting behaviors may cause cockroaches to actively avoid bait placements, or actively search for other food sources. These behaviors could be complex, such as the cockroach feeling "sick" and retreating to quieter areas, a behavioral mechanism observed in other animals (cats and dogs). The behaviors could be based on very simple mechanisms. For instance, to maintain homeostasis related to hydration, cockroaches may start foraging for sources of water and move away from bait placements. Further consumption of water and non-toxic sources of food may result in further dilution of bait.

**Bait Manufacturing and Application**

The formulation and application of bait products is the second part of nutrition that may impact bait aversion risks. While research attempts to capture those nutrients that will initiate cockroach feeding and stimulate continued consumption, the basics of developing a bait product into marketable form and the method of presenting the bait in the field situation are fundamental steps requiring further support from research. The business elements of bait production, marketing and purchasing strategies, and human behavior play a critical role in the presentation of baits to cockroaches. From my experience in the pest control industry, as well as interactions with bait formulators, I have found some critical human behaviors and business practices that increase risk of bait aversion.

In the pest control industry, many companies tend to limit purchase of stock to one or few bait products at a time as a result of purchasing, stocking, and training concerns when dealing with multiple products. Limiting the number of different bait products purchased allow for quantity buying, reducing per item cost. Limiting stocks of different brands provides for simplicity in what Technicians carry in their trucks and their knowledge on application protocols. Different baits carry different restrictions and it is advantageous from a liability standpoint to limit what rules Technicians have to follow when applying product. Should different baits be available, there is a challenge in training Technicians to identify nutritional parameters / restrictions that would give one bait an advantage over another. In a majority of cases, nutritional profiles of cockroach baits are simply not available to Technicians, even if they could identify locations requiring a carbohydrate enriched bait, versus a protein based bait. Typical industry practices lead to a reliance on a“primary bait” for routine use and a backup product for times when the primary bait appears to fail. Unfortunately, continued and repeated use of the same bait directly contravenes proper practices of resistance management.

Application of bait in a cockroach habitat is another critical part of avoiding a sublethal dose. German cockroaches tend to forage sequentially with distance, sampling food as they proceed (Rivault and Cloarec, 1991), and adjusting consumption depending on nutritional quality and dilution (Jones and Raubenheimer, 2001). Unless bait formulations “out-compete” existing food available to cockroaches, applications of bait distant from cockroach harborages may increase the risk of sub-lethal dosing, as cockroaches sample other (non-toxic) items. Habitats supporting infestation provide complexity and depth making it difficult for placement of bait close to areas where cockroaches typically harbor. Sanitation and clutter in the environment increase risks (Durier and Rivault, 2002; Lee and Lee, 2000), though interactions between these and nutritional quality require further study.

From marketing bait products and cost control requirements, the bait formulation industry has tended toward single brands of cockroach bait. Unless an insect is so selective, to the point that certain bait nutrients are ignored at times (as with Pharoah ants, *Monomorium pharaonis*), the formulation industry will typically produce singular types of bait, with a consistent nutritional profile promoting cost of production, ease of use, and diversity of targeted habitats. Fewer products result in more efficient bait production, fewer ingredients to acquire and manage, fewer concerns with quality control, and shelf life stability. Costs of key nutrients, such as protein, can contribute a substantial cost of production and supply stability of these ingredients may also play a role. While presumed minor by research standards, these processing concerns play a major role in management of bait production and availability, and future research in aversion prevention and management should keep this business model in mind.

## CONCLUSION

Maximizing attraction and first-time consumption of a bait will prevent a sub-lethal dose and delay (or avoid) bait aversion of products. Future research on how to avoid sub-lethal dosing through defensive and learning measures will be important. Much is known about nutrition and cockroach biology, but there is a critical lack of information from in-field nutritional status accounting for variability in nutrient availability and response of cockroaches to this nutrition. Information is deficient regarding cockroach behavior in response to consuming toxic nutrition, especially the behavior expressed in their attempts to maintain homeostasis.

Bait development must consider a combination of complexity in the habitat, and be able to complement (or out-compete) current resources. The business of developing and deploying baits is a constraint to managing aversion resistance through the desire to maintain simplicity in providing a few baits that can be applied in a diversity of habitats. Continuous surveys on aversion resistance may be required to track future aversion development and to prevent loss of baits by making changes before full aversion occurs. Perhaps changes to nutritional profile and ingredient types should be planned and programmed as an evolutionary necessity during the marketing life of a bait product. From our experience with resistance management with spray insecticides, varying active ingredients is a standard practice. However, decisions are necessary regarding whether variety in nutrition should occur at the same time resulting in multiple products available, or in serial fashion with the introduction of new baits as aversion develops. With continued reliance on baits to control cockroaches, we have opportunities to develop new active ingredients, but face more challenges in incorporating new food ingredients into a marketed bait.

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