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by

Linda Anne Ncherne
ACKNOWLEDGMENTS

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BAIT AVERSION AND ORAL TOXICITY OF INSECTICIDES IN A FIELD STRAIN OF GERMAN COCKROACH

By

Linda Anne McHerne

August 2006

Control of German cockroaches is again becoming a severe problem. The usual method of control is the use of gel baits. In order for a bait to be effective, it must be palatable, attractive, highly toxic, and provide secondary kill through coprophagy or necrophagy. Currently, strains of German cockroach exist that are not being controlled by gel baits. It is unknown if this can be attributed to physiological or behavioral aversion. Daytona field strain German cockroach, was collected from an area that had reported control failure using gel bait in Daytona, FL. To determine if Daytona field strain was behaviorally averse to gel baits, Daytona field strain and Orlando susceptible strain were given choice test using six different commercially available gel baits. Daytona field strain exhibited feeding deterrence to three of the most common gel baits used: Avert, Maxforce and Maxforce FC, as well as DPX-MP062-411a; however, Orlando susceptible strain exhibited no feeding deterrence. In both strains, there is positive correlation between consumption and mortality. Bait aversion caused decreased
consumption of three commonly used gel baits; however there were two formulations that overcame aversion.

Physiological resistance was evaluated through an oral toxicity assay where active ingredient was fed to Daytona field strain and Orlando susceptible strain cockroaches on breadcrumbs. Daytona field strain exhibited low resistance ratios to a new chemical, indoxacarb (3.5 LD$_{50}$ and 4.4 LD$_{90}$) and moderate to high resistance ratios to fipronil (9.4 LD$_{50}$ and 36.9 LD$_{90}$). When using a palatable gel bait formula, Daytona field strain ingested 1.5x more fipronil than necessary to kill 90% of the population. Due to evolving physiological resistance, palatable bait formulations may not control German cockroaches in the future.

The ability of fipronil and indoxacarb to cause secondary mortality was evaluated on Daytona field strain and Orlando susceptible strain cockroaches. Cockroaches were offered insecticide treated nymphs as a food source both with and without a food choice. Necrophagy occurred in both choice and no choice tests for both strains. Significant mortality from ingestion of fipronil treated nymphs only occurred in the no choice test for both strains; whereas significant mortality from ingestion of indoxacarb treated nymphs occurred in both choice and no choice tests for both strains; however it occurred more rapidly in the no choice test.

Overall, there have been significant control problems in the field when using the most common gel baits. Control failures are due to the combination of physiological resistance and behavioral resistance, but can be overcome with the use of other formulations of gel baits or new active ingredients. Control will be more effective when sanitation is used in conjunction with gel baits.
CHAPTER 1
INTRODUCTION

The German cockroach, *Blattella germanica* (L.), has adapted to cohabiting with the human species. Throughout the years, various methods and chemicals have been used to try to control this pest. While results were as varied as the method of control, most treatments were ineffective. The first chemical treatments that really reduced cockroach populations and effected control were spray formulations used in the 1950s; more chemical formulations were developed in the next two decades. Ultimately, all of these chemicals became obsolete because, within about five years of exposure, the German cockroach became physiologically resistant (Cornwell 1976).

Introduction of baits in the late eighties greatly reduced concerns about physiological resistance. These baits contained new classes of chemicals that were so toxic that a lethal dose of active ingredient was delivered in one meal (Wang et al. 2004), apparently preventing the development of physiological resistance. It seemed to work as these new baits were effective at controlling the German cockroach. In a couple of years, bait formulas and applications changed from dry baits contained in a plastic case placed in a couple of random locations to gel bait formulations that were placed drop-wise in many small spaces near harborages and foraging areas; which was even more effective at cockroach control. In the past ten years, control failures have been reported from areas where gel baits had been used extensively. It was determined that these failures were the result of cockroaches refusing to consume the bait. This behavioral aversion was initially determined to be due to glucose within the gel bait matrix. Although the problem of
glucose aversion was overcome, failures were still reported. Currently, the exact cause of behavioral aversion is unknown.

For my studies, a field strain of German cockroach was isolated from an area that had reported control failures. Control failures are due to decreased mortality, which has many possible sources. Chapter 3 evaluates the field strain collected to determine to what extent gel baits are feeding deterrents and to determine if decreased consumption of gel bait affects mortality.

Because the effectiveness of new classes of chemicals must be determined, two of the six gel baits tested in Chapter 3 contain a new chemical, indoxacarb. Chapter 4 evaluated oral toxicity of indoxacarb, in both a susceptible strain and a field strain of German cockroach. One of the benefits of highly toxic chemicals contained in gel baits is that they can cause mortality in cockroaches that did not directly ingest the gel bait. Additionally, in chapter 4, secondary mortality due to necrophagy was evaluated in both a susceptible strain and a field strain of German cockroach.

Behavioral changes in German cockroaches that cause them to eschew gel baits that once were effective is as important a survival strategy as physiological resistance. The role of consumption of toxic gel baits cannot be understated. Consumption is what allows the active ingredient to have an effect, not only on primary mortality, but on secondary mortality as well. Documenting and understanding behavioral changes in cockroaches is the first step towards effecting new control measures.
CHAPTER 2
LITERATURE REVIEW

Biology

German cockroaches, *Blattella germanica* (L.) (Blattaria: Blatellidae) are hemimetabolous, having only three life stages: egg, nymph, and adult. When the young emerge as first stage nymphs, they are no longer dependent on their mother and must find a way to acquire nutrition and water. Larger cockroaches accomplish this by foraging. Because first stage nymphs are very small and therefore easy prey for other insects, including other cockroaches, survival dictates they find another way. Their survival strategy stems from their gregarious nature. Instead of foraging outside the harborage, they remain sequestered inside the harborage (Silverman, et al, 1991) consuming the excrement of other cockroaches; a process known as coprophagy (Durier and Rivault 2000b, Gahlhoff et al. 1999; Kopanic et al. 2001). As they mature, coprophagy decreases as foraging and scavenging methods increase. As with other insects, German cockroaches grow by the process of molting. The time between molts is known as a stadium. German cockroaches undergo 6-7 stadia and take an average of 103 days to mature into an adult. This time frame is dependent many factors such as temperature, nutritional status, and strain (Cooper and Schal 1992).

Nymphs are dark brown in color with a large tan spot on their pronotum. They range in size from approximately 1.5 mm newly emerged to 1.6 cm as adults. Adults are light brown in color and have two dark stripes on their pronotum extending longitudinally down the body under the wings. The male has a tapered abdomen while the abdomen of
the female is rounded (Ebeling 1975). Although both sexes possess wings, they are incapable of flight.

When a female German cockroach emerges as an adult, it takes many days to become sexually active (Schal et al. 1997). When they do become sexually active, they often mate multiple times, although one mating is usually sufficient to fertilize all their eggs (Schal et al. 1997). This mated female produces, on average, 30-40 eggs per oothecal case (Willis et al. 1958). Adult females survive approximately 6 months and produce 4-6 broods in their lifetime (Schal et al. 1997). They are oviparous; however, they carry their ootheca until just prior to hatching (Schal et al. 1997). This gravid cycle lasts approximately 21-28 days (Schal et al. 1997) during which time the females eat sparingly or not at all (Schal et al. 1997, Ross 1993).

**Habitat**

German cockroaches have a world-wide distribution and, in addition to domiciles, can be found in restaurants (Rust and Reierison 1991), hospitals (Elgderi et al. 2006, Kitae et al. 1995), and even aboard naval vessels (Flynn and Schoof 1971). They are usually found in kitchens, bathrooms, or other areas where water is readily available. They are nocturnal scavengers capable of living off human waste foodstuffs (i.e. crumbs, residues on dishware, etc). During the day they usually remain sequestered in harborages. A harborage is any enclosed area allowing them protection to breed and survive. In homes this is often cabinetry, appliances, wall voids, or any clutter (boxes, stored goods, garbage, etc). This ability to sequester in very small spaces is often the mechanism for new infestation as introduction of cartons, boxes, or other materials harboring German cockroaches is transported to un-infested homes and businesses. Additionally, German cockroaches can infest apartments or offices connected by a common wall by moving
from the infested apartment through wall voids or across conjoining plumbing systems to
the new space (Owens and Bennett 1982).

Pest Status

German cockroaches commonly carry potentially pathogenic bacteria such as
*Klebsiella, Enterobacter, Serralia,* and *Streptococcus* (Elgderi et al. 2005; Kitae et al.
1995). No direct transmission of disease to humans has been demonstrated; however,
cockroaches have the potential of transmitting these pathogens via contamination of food
preparation surfaces and utensils (Kitae et al. 1995). New data has found that a great
number of pathogens isolated from wild strain cockroaches are multiple antibiotic
resistant (Elgderi et al. 2005).

Carrying pathogenic bacteria is not the German cockroach’s only method of
contaminating domiciles and causing harm to humans. Cockroaches have been linked to
human allergies since the mid 1940s (Kang 1990). In infested households, German
cockroach debris is second only to dust mites in the composition of “house dust” (Silva
1990). The greatest sensitivity to cockroach allergens occurs in children seven to twelve
years old (Garcia et al. 1993). As is the case with many allergens over time, cockroach
sensitivities can develop in those that previously had none and existing sensitivity can
increase (Steinberg et al. 1987, Kang 1990). Occasionally, the sensitivity becomes so
bad that shellfish can no longer be eaten, contact dermatitis occurs in the presence of
infestation, (Silva 1990) or asthmatic responses occur when cockroach allergens are
inhaled (Garcia et al. 1993). When human health risk is added to the psychological stress
and stigma caused by German cockroach infestation, it is no wonder German
cockroaches are considered a major pest worldwide.
Chemical Control of the German Cockroach

The oldest group of chemicals used in cockroach control is inorganic compounds such as boric acid and sodium fluoride. These were slow acting powders that worked both via contact and orally when ingested during grooming (Ebeling et al. 1974). While designed for a variety of insects, these dusts proved more effective on the larger cockroaches (*Periplaneta*) and offered no real control of the German cockroach (Reid et al. 1990).

The next group of insecticides used for German cockroach control was the chlorinated hydrocarbons such as DDT and chlordane. These compounds were very effective in both spray and dust form with long lasting residual effects. This class of chemical acted on the sodium channel causing repetitive firing. Physiological resistance to chlordane was first reported in 1951 and rapidly spread throughout the United States (Grayson 1964). Although chlorinated hydrocarbons have the differing modes of action, they all affected the nervous system. Worldwide resistance was documented to not just chlordane but many chlorinated hydrocarbons within 10 years of the first report (Grayson 1954, Matsumura 1975). Due to environmental issues, the Environmental Protection Agency (EPA) cancelled the use of chlorinated hydrocarbons in the late 1970s (Reid, et al. 1990).

In the early 1960s, first organophosphates and, shortly thereafter, carbamates began replacing chlorinated hydrocarbons (Siegfried et al. 1990, Cochran 1982). Examples of organophosphates are diaznon, chlorpyrifos, and malathion; while examples of carbamates are bendiocarb and propoxur. Both of these classes of chemical were used primarily in spray formulations, inhibited acetylcholinesterase, and were fairly toxic to vertebrates (Matsumura 1975). Just as with chlorinated hydrocarbons, German
cockroaches developed resistance to both these classes of chemical; however, the time it took for them to develop resistance was less than five years (Siegfried et al. 1990). For health issues, EPA no longer allows most of these chemicals to be used.

The pyrethroids became popular for cockroach control in the 1970s. Prior to this time, pyrethrin- a natural pesticide derived from chrysanthemums in the Family Compositae- had been used to augment inorganic pesticides. In the late 1950’s, pyrethroids- the synthetic analogue of pyrethrins- became commercially available; however these “Type I” pyrethroids were not photo stable and many cockroaches were able to metabolize the chemical and fully recover. It was the “Type II” pyrethroids that became popular in the 1970s. These were photo stable, used in spray formulation, and had excellent residual effects against cockroaches.

All pyrethroids acted on the sodium channel to interfere with the transmission of nerve impulses. As with all the other classes of chemical, German cockroaches developed resistance pyrethroids (Cochran 1994). It was found that cockroaches resistant to DDT also had inherent resistance, or cross-resistance, to many pyrethroids (Scott and Matsumura 1982). Pyrethroids are still used today; however, they are used as flushing agents to drive cockroaches out of their harborage (Fuchs 1988).

Throughout the late 19802 and 1990s, many new classes of chemical have come on the market for cockroach control. The safest are Insect growth regulators, more specifically, juvenile hormone analogs such as hydroprene and pyriproxifen. These chemicals mimic insect juvenile hormone, affecting the endocrine balance and causing developmental disturbances such as molting inhibition, morphogenetic abnormalities, longer developmental time, and reproduction suppression (King and Bennett 1989, Reid
1994). While juvenile hormone analogs have application in the field, they have their limitations. They have no ability to suppress a population quickly (Zemen, et al 1991, Koehler and Patterson 1991) and unless more than 80% of the population is strongly affected by the juvenile hormone analog, viable young can still be produced (Reid et al. 1994).

Today, insecticidal gel baits are the main method of German cockroach control in the United States (Wang et al. 2004). Gel baits contain many different chemical classes: Neonicotinoids such as imidicloprid and thiamethoxam, the avermectins such as abamectin, the aminidinohydrazones like hydromethylnon and sulfonomides such as sulfluramid, the phenyl pyrozoles such as fipronil, and the oxadiazines such as indoxacarb. With the exception of oxadiazines, which have only appeared commercially in the past year, the chemical classes became commercially available in the 1990s. One thing all gel baits have in common is that these newer active ingredients are highly toxic and take anywhere from hours to days to cause mortality (Scott 1991, Scott and Wen 1997, Koehler et al. 1991, Appel and Benson 1992). The benefit of slow acting active ingredients is that significant mortality occurs in cockroaches that did not directly ingest the gel bait. This secondary mortality occurs through three different pathways. The first is from trampling: When contaminated cockroaches return to the harborage, they defecate and orally secrete toxic metabolites. Secondary mortality occurs when other cockroaches travel through these contaminated secretions and unwittingly ingest them during grooming (Durier and Rivault 2000b, Kopanic and Schal 1997). The second pathway is mortality from coprophagy: Since first stage nymphs survive almost exclusively on the feces of older nymphs and adults, when feces are contaminated by
toxic metabolites, secondary mortality ensues (Kopanic and Schal 1999). The third pathway is from cannibalism: Even with plenty of food, German cockroaches typically consume dead or dying cockroach conspecifics. During cannibalism of contaminated cockroaches, toxic metabolites are ingested and secondary mortality occurs (Gahlhoff et al. 1999, Durier and Rivault 2000b).

Another benefit of the high toxicity of these new active ingredients regards physiologically resistance. When cockroaches consume gel bait, the active ingredient is toxic enough to deliver a lethal dose in one meal. Since physiological resistance develops when sub-lethal doses of an active ingredient are metabolized, the heightened toxicity of these new active ingredients should prevent resistance from occurring (Wang et al. 2004). Indeed, in the past ten years, gel baits have been the most common and effective control measure (Wang et al. 2004). Recently, there have been reports of German cockroach resistance to the active ingredient fipronil; however, this resistance is apparently due to a cross resistance from cyclodienes and not severe enough to date to compromise the efficacy of gel baits containing fipronil (Scott and Wen 1997, Holbrook et al. 2003).

Even with the effectiveness and high toxicity of gel baits and lack of significant physiological resistance, control failures have been reported. The first report occurred in the early 1990’s (Silverman and Bieman 1993). This isolated strain of German cockroach, T-164 strain, was found to be glucose averse. The active ingredients contained within the gel baits were still toxic to this strain; however, they refused to eat the gel bait because it contained glucose (Silverman and Bieman 1993, Silverman and Ross 1994). This feeding deterrence in T-164 strain was so pronounced, they refused to
ingest glucose even after a nine day starvation period (Silverman and Selbach 1998). Recently, greater numbers of control failures have been reported. In a few cases, the wild cockroaches were harvested and subsequently reared in laboratory settings. Preliminary studies show some similarity to T-164 strain; specifically, they are still susceptible to the active ingredients contained within gel baits but they refuse to consume the bait. Unlike the T-164 strain, these strains are not glucose averse. While the mechanism causing this bait aversion is currently unknown, it is obviously behavioral in nature. Behavioral aversion is defined as evolved behaviors that allow an insect to survive in an otherwise lethal environment and often involves stimulus-dependent mechanisms such as repellency, irritation (Sparks et al. 1989), or in this case, feeding deterrence. In the past, behavioral resistance was glossed over and considered far less important than physiological resistance (Sparks et al. 1989, Ross 1997). Today, more research is being done on behaviorally averse strains of German cockroach to try to find a way to overcome this resistance and again effectively manage German cockroach populations in the field.
Introduction

The German cockroach, *Blattella germanica* L., is and has been a very important urban pest worldwide (Cornwell 1968, Abd-Elghafar et al. 1990). As such, it has a long and varied history of control. Early methods of control utilized insecticidal spray formulations that began with the chlorinated hydrocarbons, progressed to organophosphates, carbamates, and then pyrethroids. All suffered the same fate: after about 5 years of intensive use, German cockroaches developed physiological resistance to the chemicals (Cornwell 1976).

In the late 1970’s through the 1980’s, strategies involving the use of insect growth regulators and biological control agents in the form of fungal pathogens were employed. Nothing provided adequate measures of control until toxic baits containing new classes of chemical compounds came on the market. While these classes all had differing modes of action, one thing they all had in common was that they were toxic enough, when ingested orally, to deliver a lethal dose of active ingredient in one meal (Wang et al. 2004). For ingestion to occur, the bait had to be palatable enough to compete with other food sources. It was believed this combination of palatability and toxicity would make development of physiological resistance less likely (Wang et al. 2004).

In the early 1990’s, there were reports of control failures in the field. By 1993, Silverman and Bieman determined that these failures were not due to physiological
resistance but due to behavioral resistance. They isolated the first bait averse strain of German cockroach. In this case, the aversion was to glucose contained within the bait matrix. Since then, other strains exhibiting glucose aversion have been isolated (Silverman and Ross 1994). In addition, many strains have been isolated that are not simply glucose averse, but averse to one or more inert ingredients in the bait matrix (Silverman and Ross 1994, Ross 1997a, Wang et al. 2004). Silverman and Ross (1994) discovered a surprising level of genetic variability in the strains they studied and Wang et al. found significantly different levels of consumption and mortality in the two strains they studied. Though there is variability among averse strains of cockroach, one thing remains the same: In all strains, decreased consumption of gel bait causes a decrease in mortality, possibly leading to control failure.

Daytona field strain was collected from Daytona, FL after reports of control failure using traditional baits. The purpose of this study was to determine if gel baits caused feeding deterrence in Daytona field strain, to determine the effect of consumption on mortality, and to determine if Daytona field strain is a bait averse strain of cockroach.

**Materials and Methods**

**Insects.** Orlando susceptible strain and Daytona field strain German cockroaches were obtained from laboratory colonies maintained at the urban entomology laboratory, University of Florida, Gainesville, FL. Rearing containers and harborages for Orlando susceptible strain cockroaches were as described by Koehler et al. (1994) with the exception that the harborages contained within the acrylic rack were looped cardboard sections (14 by 13 cm). Rat food (Purina Laboratory Rodent Chow, no. 5001, Ralston Purina, St. Louis, MO) and water was supplied *ad libitum.*
Rearing containers for Daytona field strain cockroaches were glass jars (7.57 liter, 22 cm diameter) greased on the inner rim with a petroleum jelly/mineral oil (2:3) mixture to prevent cockroach escape. Jars were covered with cotton cloth and secured with rubber bands. Dog food (Purina One Puppy Growth and Development, Nestlé Purina PetCare Company, St. Louis, MO) and water was supplied ad libitum.

Environmental conditions for both rearing rooms were 26°C and 55% relative humidity RH, with a photoperiod of 12:12 (L:D) h.

Insectide baits. The following gel bait products were tested: Maxforce® (2.15% Hydramethylnon, Bayer Environmental Science, Montvale, NJ), Avert® (0.05% Avermectin, Whitmire Microgen Research Laboratories, Inc, St. Louis, MO), DPX-MP062-411a (0.6% Indoxacarb, Dupont Crop Protection, Newark, DE), Advion Cockroach® (0.6% Indoxacarb, Dupont Crop Protection, Newark, DE), Maxforce® FC (0.01% Fipronil, Bayer Environmental Science, Montvale, NJ), Maxforce® FC Select (0.01% Fipronil, Bayer Environmental Science, Montvale, NJ). Gel bait (140 to 150 mg) was deposited from a syringe onto a piece of low nitrogen weighing paper (57 by 57 mm; Fisherbrand, Fisher Scientific Company, USA).

Preference and consumption assay. Cockroaches were anesthetized with CO₂ for 2 min and sorted through stacked 2.36 mm (No. 8, Fisher Scientific Company, Pittsburgh, PA) and 2.00 mm (No. 10, Fisher Scientific Company, Pittsburgh, PA) standard sieves. Cockroaches retained by the 2.00 mm sieve were placed in a greased glass holding jar (3.79 liter, 17.5 cm diameter) containing harborage, dog food and water. Ninety percent of retained cockroaches were 2nd stage nymphs weighing 190.24 ± 4.53 (Orlando susceptible strain cockroach) and 216.44 ± 3.06 (Daytona field strain cockroach). To
recover from the effects of CO₂, cockroaches were held for 48 to 72 h before placement into foraging arenas.

After the holding period, 50 cockroaches were aspirated and placed into a greased foraging arena containing water and harborage. Foraging arenas were clear plastic sweater boxes (26.5 by 9.5 by 19 cm, Pioneer Plastics, Dixon, KY). Water was provided by a plastic vial (33 by 16 mm diameter) with a cotton stopper. Due to the ability of nymphs to enter inside the corrugations of cardboard, an index card (76.5 by 28.5 mm) folded in half lengthwise and secured with a staple was used for harborage. This process was repeated until there were seven arenas per strain.

Cockroaches were starved for 24 h. At the end of the starvation period, two pre-weighed deposits of gel bait and two pre-weighed pieces of dog food were added to each arena on a piece of weighing paper. One of the gel bait placements and one of the dog food placements were used as moisture loss standards. Both moisture loss standards were placed inside individual soufflé cups (29.57 ml; Solo cup company, Urbana, IL.) and cups were covered with organdy and secured with a rubber band to prevent cockroach entry. After 24 h, both food sources and both moisture loss standards were reweighed and food sources were returned to the arena. Mortality was recorded 4 d after gel bait placement. Experimental set up was a randomized complete block design of six treatments and one control. Experiment was a randomized complete block design with six gel baits and an untreated dog food control replicated eight times per strain using a total of 5,600 cockroaches.

**Data analysis.** Gel bait consumption was calculated using the following formula:

\[
Consumption = A - [A \times (B - D / B) - C]
\]
where; A = Pre-consumption weight of exposed bait or food, B = Pre-consumption weight of comparable moisture loss standard, C = Post-consumption weight of exposed bait or food, and D = Post-consumption weight of comparable moisture loss standard. Consumption of gel bait product for each strain and each treatment was analyzed via Student’s $t$-test ($P$, 0.005; [SAS Institute, 2001]). Amount of active ingredient consumed was calculated by multiplying the percent active ingredient in gel baits by the amount of gel bait consumed. Mortality data was corrected using Abbott’s correction (Abbott, 1925) and percentages were arcsine-root transformed before analysis. Both active ingredient per cockroach body weight and mortality were analyzed by Analysis of Variance and means separated by SNK ($P$, 0.005; [SAS Institute, 2001]).

Results

Within a few minutes of introducing food sources to the arenas, nymphs fed on either dog food or gel bait. Orlando normal strain had no significant preference for dog food control or dog food choice, indicating no location bias within the arena (Table 3-1). There was no active ingredient in the control; therefore, no mortality occurred. All control cockroaches survived until the end of the experiment. Consumption of Maxforce gel bait was not significantly different than dog food consumption. Mean amount of active ingredient consumed was 1009.5 ng per mg cockroach body weight and resulting mortality was 58%. Consumption of Avert gel bait was not significantly different from dog food consumption. Mean amount of active ingredient consumed was 22.3 ng per mg cockroach body weight and resulting mortality was 66%. Consumption of DPX-MP062-411a gel bait was not significantly different from dog food consumption. Mean amount of active ingredient consumed was 271.9 ng per mg cockroach body weight and resulting mortality was 87%. Consumption of Advion gel bait was not significantly different from
dog food consumption. Mean amount of active ingredient consumed was 314.2 ng per mg cockroach body weight and resulting mortality was 88%. Consumption of Maxforce FC gel bait was not significantly different from dog food consumption. Mean amount of active ingredient consumed was 4.2 ng per mg cockroach body weight and resulting mortality was 81%. Consumption of Maxforce FC Select gel bait was not significantly different from dog food consumption. Mean amount of active ingredient consumed was 4.6 ng per mg cockroach body weight and resulting mortality was 92%.

Amount of active ingredient consumed per cockroach body weight significantly differed among products. Orlando normal strain cockroaches consumed significantly more active ingredient from Maxforce gel bait than all other products. The order of preference based on consumption of active ingredient was Maxforce > Advion = DPX-MP062-411a = Avert = Maxforce FC = Maxforce FC Select. Resulting mortality significantly differed among products. Highest mortalities occurred with Advion Cockroach, Dupont Formula 411a, Maxforce FC, and Maxforce FC Select. Order of mortality was Advion Cockroach = Dupont Formula 411a = Maxforce FC = Maxforce FC Select > Avert = Maxforce > Control.

Daytona field strain had no significant preference for dog food control or dog food choice, indicating no location bias (Table 3-2). There was no active ingredient in the control; therefore, resulting mortality did not occur. All control cockroaches survived until the end of the experiment. Consumption of Maxforce gel bait was significantly less than dog food consumption yielding a ratio of 1:5.2 (Maxforce:dog food), indicating feeding deterrence to Maxforce gel bait. Mean amount of active ingredient consumed was 326.2 ng per mg cockroach body weight and resulting mortality was 9%.
Consumption of Avert gel bait was significantly less than dog food consumption yielding a ratio of 1:9.4 (Avert:dog food), indicating feeding deterrence to Avert gel bait. Mean amount of active ingredient consumed was 3.1 ng per mg cockroach body weight and resulting mortality was 20%. Consumption of PX-MP062 411a gel bait was not significantly different than dog food consumption. Mean amount of active ingredient consumed was 212.3 ng per mg cockroach body weight and resulting mortality was 49%. Consumption of Advion Cockroach gel bait was significantly greater than dog food consumption yielding a ratio of 1.8:1 (Advion: dog food), indicating preference for Advion gel bait. Mean amount of active ingredient consumed was 450.3 ng per mg cockroach body weight and resulting mortality was 79%. Consumption of Maxforce FC gel bait was significantly less than dog food consumption yielding a ratio of 1:4.6 (Maxforce FC:dog food), indicating feeding deterrence to Maxforce FC gel bait. Mean amount of active ingredient consumed was 2.5 ng per mg cockroach body weight and resulting mortality was 15%. Consumption of Maxforce FC Select gel bait was significantly greater than dog food consumption 5.3:1 (Maxforce FC Select:dog food), indicating preference for Maxforce FC Select gel bait. Mean amount of active ingredient consumed was 5.9 ng per mg cockroach body weight and resulting mortality was 82%.

Amount of active ingredient consumed per cockroach body weight significantly differed among products. Daytona field strain cockroaches consumed significantly more active ingredient from Advion gel bait than all other products. The order of preference based on consumption was Advion > DPX-MP062-411a = Maxforce > Avert = Maxforce FC = Maxforce FC Select. Resultant mortality significantly differed among products. Highest mortalities occurred with Advion gel bait and Maxforce FC Select gel bait while
lowest mortality occurred with Maxforce FC gel bait. Order of mortality was Advion = Maxforce FC Select > DPX-MP062-411a > Maxforce > Avert = Maxforce FC > Control).

Discussion

Orlando susceptible strain cockroaches have never shown feeding deterrence to any commercial gel bait formulation. When Orlando susceptible strain cockroaches were simultaneously given a choice of six gel baits, all baits were consumed equally (Silverman and Liang 1999). A significant consumption difference between gel baits would indicate feeding preference or feeding deterrence. In my study, preference or feeding deterrence was determined by comparison of consumptions between gel bait and dog food. Similar to Silverman and Liang’s study, Orlando susceptible strain cockroaches also exhibited no feeding deterrence to six gel bait formulations, including two formulations that have not been commonly used.

A factor to take into account when performing a choice study is bait placement because location can affect consumption. German cockroaches locate food by random searching, so the more available and easily accessible the bait, the more likely it is to be ingested (Rust and Reierson 1981). In my study, when Orlando susceptible strain was given a choice between two pieces of dog food that had been placed equidistant from the harborage, both food sources were consumed equally, indicating no location bias in the experimental arena.

Gel baits containing hydramethylnon have been a common treatment for susceptible strain cockroaches, do not cause feeding deterrence, and cause mortality through time. Adult male insecticide susceptible German cockroaches exposed for 3 d to Maxforce gel bait (2.15% hydramethylnon), readily consumed the gel bait and exhibited
no feeding deterrence; LT$_{50}$ value for the uncontaminated gel bait was 4.1 d (Appel 2004). Scott (1991) determined LT$_{50}$ was 76 h for adult male CSMA susceptible strain cockroaches fed bait containing 1.56% hydramethylnon; Koehler and Patterson (1991a) determined LT$_{50}$ was 4.5 d for adult male Orlando susceptible cockroaches fed bait containing 1.0% hydramethylnon. My study also showed no feeding deterrence to Maxforce (2.15 % hydramethylnon) in Orlando susceptible strain cockroaches and the resultant 4 d mortality, was 58%; which was similar to the mortalities reported above.

When dealing with an averse strain of cockroach, it is not the active ingredient that causes feeding deterrence but the gel bait matrix. Adult male T-164 glucose averse strain cockroaches, given a choice between dog food and 2.0% hydramethylnon gel bait with glucose and without glucose, exhibited feeding deterrence to the gel bait with glucose and not to the gel bait without glucose (Silverman and Liang 1999). Gel bait without glucose caused 14 d mortality of approximately 90%. Similarly, adult male Dorie and Cincy bait averse strains of cockroach, given a choice between rat chow and Maxforce gel bait (2.15% hydramethylnon), exhibited feeding deterrence to the gel bait, resulting in only 10.0% and 33.3% 4 d mortality rates respectively (Wang et. al. 2004). My study showed Daytona field strain exhibited feeding deterrence to Maxforce gel bait, consuming 5 times less bait than food. Resulting 4 d mortality was 16%, which was similar to that of Dorie strain bait-averse cockroach.

Gel baits containing abamectin have also been a common treatment for susceptible strain cockroaches. Koehler et al. (1991b) determined that abamectin caused feeding deterrence at concentrations above 0.500%. The concentration of abamectin in commonly used gel bait is much lower than this; therefore, the gel baits containing
abamectin do not cause feeding deterrence and cause cockroach mortality through time.
Adult male insecticide susceptible German cockroaches exposed for 3 d to uncontaminated Avert gel bait (0.05% abamectin) readily consumed the gel bait and exhibited no feeding deterrence; LT$_{50}$ for the Avert gel bait was 1.05 d (Appel 2004). Mixed sex and stage Orlando susceptible cockroaches fed gel bait containing 0.05% abamectin readily consumed the gel bait exhibited no feeding deterrence; LT$_{50}$ values were 1.6 d for nymphs and 1.7 d for adult males (Koehler et al. 1991b). Mixed sex and stage Navy 3 susceptible cockroaches in a choice test between gel bait containing 0.01% abamectin and dog food readily consumed the gel bait and exhibited no feeding deterrence; 14 d mortality rates were approximately 90% for adult males and 95% for small (<9 d old) nymphs (Ross 1993). Because Avert gel bait was consumed as readily as dog food by Orlando susceptible strain cockroach, my study also showed no feeding deterrence to Avert (0.05 % abamectin); however, my approximate LT$_{50}$ for 2.15% hydramethylnon would be about 1 d more than the value reported by Koehler and Patterson.

Again, averse strains of cockroach exhibit feeding deterrence to the gel bait, not the active ingredient. Adult male Dorie and Cincy bait averse strains of cockroach, given a choice between rat chow and Avert gel bait did not readily consume the gel bait and exhibited feeding deterrence, resulting in 4 d mortality rates of 69.3% and 0.0% respectively (Wang et al. 2004). In my study, Daytona field strain consumed more than 10 times less Avert gel bait than food, exhibiting feeding deterrence. Resulting 4 d mortality was 20%, which was similar to the mortality of Cincy bait-averse strain cockroach.
Fipronil is a fast acting chemical that is used in gel baits for treatment of susceptible strain cockroaches. These gel baits do not cause feeding deterrence and cause cockroach mortality through time. Adult male insecticide susceptible German cockroaches exposed for 3 d to uncontaminated Maxforce FC gel bait (0.01% fipronil) readily consumed the gel bait and exhibited no feeding deterrence; LT$_{50}$ for the uncontaminated gel bait was 2.1 d (Appel 2004). Adult male Orlando susceptible strain cockroaches, given a choice between dog food, 0.03% fipronil gel bait with glucose and 0.03% fipronil gel bait without glucose, readily consumed both gel baits and resultant 14 d mortality was approximately 60% with an LT$_{50}$ of 4.5 d (Silverman and Liang 1999). Adult male JWAX susceptible strain cockroaches, given a choice between rat chow and Maxforce FC (0.01% fipronil), readily consumed gel bait and had resultant 4 d mortality of 100% (Wang et al. 2004). In my study, Orlando susceptible strain consumed Maxforce FC and Maxforce FC Select (0.01% fipronil) gel baits as readily as dog food. Resultant mortality was 85% for Maxforce FC and 92% for Maxforce FC Select, which was similar to the susceptible strain used in Appel’s study and JWAX strain used in Wang et al.’s study.

For averse strains of cockroach, it is the gel bait that causes feeding deterrence. Adult male T-164 glucose averse strain cockroaches, given a choice between dog food, 0.03% fipronil gel bait with glucose and 0.03% fipronil gel bait without glucose, readily consumed the gel bait without glucose and exhibited feeding deterrence to the gel bait with glucose; Resulting 14 d mortality for the bait with glucose was approximately 55% and the 14 d mortality for the bait without glucose was approximately 90% (Silverman and Liang 1999). When adult male Dorie and Cincy bait averse strains of cockroach
were given a choice between Maxforce FC (0.01% fipronil) and rat chow, Dorie bait averse strain cockroach readily consumed the gel bait whereas Cincy strain exhibited feeding deterrence to the gel bait; resulting 4 d mortalities were 100.0% and 16.7% respectively (Wang, et. al. 2004). In my study, Daytona field strain consumed 21.5 times less Maxforce FC (0.01% fipronil) than dog food and mortality rates were 15%, which was similar to Cincy bait averse strain cockroach; However, Daytona field strain consumed 19 times more Maxforce FC Select gel bait (0.01% fipronil) than dog food. Resulting 4 d mortality was 82%, which was similar to the 92% 4 d mortality of Orlando susceptible cockroach.

Indoxacarb is a new chemical, class oxadiazine, which is biologically activated within the insect midgut. It has not been shown to cause feeding deterrence and has been shown to cause cockroach mortality through time (Appel 2003). Adult male American Cyanamid susceptible strain German cockroaches had an LT₅₀ value of .068 d to .025% indoxacarb gel bait (Appel, 2003). In my study, Orlando susceptible strain cockroaches readily consumed both DPX-MP062-411a (0.6% indoxacarb) and Advion gel bait. Resulting mortality for both gel baits was 87%.

Because of the newness of indoxacarb, there are no published studies with bait averse cockroaches. In my study, Daytona field strain readily consumed DPX-MP062-411a and consumed two times more Advion than dog food. Resulting mortalities were 49% for DPX-MP062-411a, which was less than Orlando susceptible strain cockroaches and 79% for Advion, which is similar to Orlando susceptible strain cockroaches.

Orlando susceptible strain exhibited no feeding deterrence or preference to any food source. One would expect gel bait to be preferred in order for it to be effective,
especially in the field. It must be noted that this study had no location bias, whereas bait placement in the field has location bias. Additionally, Since Orlando susceptible strain cockroaches have been reared in the laboratory since 1947 (Koehler, et. al. 1994), it is possible they have lost the ability to discriminate between food sources. Even with the lack of preference, Orlando susceptible strain consumed enough gel bait to cause significant mortality for all products tested. Whereas only the gel baits specially formulated for bait averse cockroaches (Advion Cockroach Gel and Maxforce FC Select) had mortality rates above 50% at 4 d for Daytona field strain cockroach, indicating that Daytona field strain is, in fact, a bait-averse strain of cockroach.

Discovery of a bait-averse strain of cockroach in Florida, so far from the strains found around Ohio, indicates that bait aversion is a more widespread phenomenon than once believed. This study determined consumption of gel bait was positively correlated with mortality in German cockroaches. The bait-averse strains in both this study and that of Wang et al. (2004) demonstrated that three bait-averse strains find reformulated baits palatable; thus, feeding deterrence can be overcome by reformulating bait matrices. It is unknown if bait averse strains of German cockroach also have physiological resistance; therefore, simply reformulating gel bait matrices may not be enough for control in the future.
Table 3-1. Mortality (4 d) and consumption of gel bait, dog food, and AI for 50 Orlando susceptible strain German cockroaches 24 h after gel bait placement.

<table>
<thead>
<tr>
<th>Product</th>
<th>Consumption (mg)</th>
<th>Student’s t-test</th>
<th>ng AI consumed per mg body weight</th>
<th>% Mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gel Bait*</td>
<td>Dog food</td>
<td>df</td>
<td>t value</td>
</tr>
<tr>
<td>Control</td>
<td>9.34 ± 4.37</td>
<td>9.27 ± 3.31</td>
<td>14</td>
<td>0.03</td>
</tr>
<tr>
<td>Maxforce</td>
<td>10.16 ± 4.92</td>
<td>9.81 ± 2.07</td>
<td>14</td>
<td>0.19</td>
</tr>
<tr>
<td>Avert</td>
<td>9.63 ± 2.12</td>
<td>11.13 ± 3.51</td>
<td>14</td>
<td>-1.03</td>
</tr>
<tr>
<td>DPX-MP062 411A</td>
<td>9.81 ± 3.97</td>
<td>6.85 ± 3.27</td>
<td>14</td>
<td>1.24</td>
</tr>
<tr>
<td>Advion Cockroach</td>
<td>11.34 ± 3.82</td>
<td>8.68 ± 4.73</td>
<td>14</td>
<td>1.63</td>
</tr>
<tr>
<td>Maxforce FC</td>
<td>9.14 ± 3.63</td>
<td>13.46 ± 8.56</td>
<td>14</td>
<td>-1.31</td>
</tr>
<tr>
<td>Maxforce FC Select</td>
<td>9.92 ± 3.75</td>
<td>5.56 ± 5.10</td>
<td>14</td>
<td>1.95</td>
</tr>
</tbody>
</table>

*aControl was a piece of dog food.
Student’s t-test (P > 0.005, [SAS Institute, 2001]).
Means in a column followed by the same letter are not significantly different (P > 0.05; Student-Newman-Keuls sequential range test [SAS Institute, 2001]).
Table 3-2. Mortality (4 d) and consumption of gel bait, dog food, and AI for 50 Daytona field strain German cockroaches 24 h after gel bait placement.

<table>
<thead>
<tr>
<th>Product</th>
<th>Consumption (mg)</th>
<th>Student’s t-test</th>
<th>ng AI consumed per mg body weight*</th>
<th>% Mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gel Bait</td>
<td>Dog food</td>
<td>df</td>
<td>t value</td>
</tr>
<tr>
<td>Control</td>
<td>9.04 ± 5.31</td>
<td>9.60 ± 5.66</td>
<td>14</td>
<td>-0.20</td>
</tr>
<tr>
<td>Maxforce</td>
<td>3.28 ± 2.09</td>
<td>17.06 ± 3.70</td>
<td>14</td>
<td>-9.17</td>
</tr>
<tr>
<td>Avert</td>
<td>1.34 ± 1.70</td>
<td>12.56 ± 4.89</td>
<td>8.66</td>
<td>-6.14</td>
</tr>
<tr>
<td>DPX-MP062 411A</td>
<td>7.66 ± 2.85</td>
<td>10.60 ± 4.88</td>
<td>14</td>
<td>-1.47</td>
</tr>
<tr>
<td>Advion Cockroach</td>
<td>6.24 ± 6.34</td>
<td>3.51 ± 2.65</td>
<td>9.38</td>
<td>5.24</td>
</tr>
<tr>
<td>Maxforce FC</td>
<td>2.91 ± 1.68</td>
<td>13.51 ± 4.95</td>
<td>8.6</td>
<td>-5.74</td>
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<tr>
<td>Maxforce FC Select</td>
<td>12.86 ± 8.59</td>
<td>2.44 ± 1.53</td>
<td>7.44</td>
<td>3.38</td>
</tr>
</tbody>
</table>

*aControl was a piece of dog food.

Student’s t-test (P > 0.005, [SAS Institute, 2001]).

Means in a column followed by the same letter are not significantly different (P > 0.05; Student-Newman-Keuls sequential range test [SAS Institute, 2001]).
CHAPTER 4
ORAL TOXICITY OF INDOXACARB AND SECONDARY MORTALITY FROM NECROPHAGY IN A SUSCEPTIBLE STRAIN AND A FIELD STRAIN OF GERMAN COCKROACH, *Blattella germanica* (L)

Introduction

The German cockroach, *Blattella germanica* L., has been an important pest of all urban dwellings worldwide (Cornwell 1968, Abd-Elghafar et al. 1990). Over the years, attempts at control have largely shifted from applying residuals and sprays to placement of toxic baits (Reierson 1995). This was due in part to heightened consumer awareness regarding pesticides and a general trend to reduce pesticide application (Kopanic and Schal 1997).

Unlike sprays, baits are either contained in a protective unit or are placed in areas close to the harborages and foraging areas. This highly specialized application process has the advantage of targeting the pest species while simultaneously allowing for use of less chemical (Kopanic and Schal 1997). There are many active ingredients currently employed in baits used for German cockroach control, but bait is only effective if it is palatable and the active ingredient is not a feeding deterrent (Appel 1990). Current active ingredients are toxic enough to deliver a lethal dose in one meal (Wang et al. 2004). However, they act slowly enough to allow time for the cockroach to return to the harborage after feeding. Since German cockroaches are gregarious and not social, it was once thought this was of no consequence. However, secondary transmission in the German cockroach has been well documented and proved to be an important factor in control. Kopanic and Schal (1999) showed significant mortality in first and second stage
nymphs due to the ingestion of contaminated feces. Gahlhoff et al. (1999) showed significant mortality of adult and nymphal cockroaches due to consumption of contaminated conspecifics.

There is a new class of chemical available in toxic baits, oxadiazines. Indoxacarb, the only current oxadiazine, is bioactivated (Wing 1999). The purpose of this study was to determine if indoxacarb was a feeding deterrent, determine the oral toxicity of indoxacarb, and evaluate secondary mortality from necrophagy in a susceptible strain and a field strain of German cockroach.

Materials and Methods

Insects. Orlando susceptible strain and Daytona field strain German cockroaches were obtained from laboratory colonies maintained at the urban entomology laboratory, University of Florida, Gainesville, FL. Rearing containers and harborages for Orlando susceptible strain cockroaches were as described by Koehler et al. (1994) with the exception that the harborages contained within the acrylic rack were looped cardboard sections (14 by 13 cm). Rat food (Purina Laboratory Rodent Chow, no. 5001, Ralston Purina, St. Louis, MO) and water was supplied ad libitum.

Rearing containers for Daytona field cockroaches were glass jars (7.57 liter, 22 cm diameter) greased on the inner rim with a petroleum jelly/ mineral oil (2:3) mixture to prevent cockroach escape. Jars were covered with cotton cloth and secured with rubber bands. Dog food (Purina One Puppy Growth and Development, Nestlé Purina PetCare Company, St. Louis, MO) and water was supplied ad libitum. Environmental conditions for both rearing rooms were 26°C and 55% relative humidity RH, with a photoperiod of 12:12 (L:D) h.
Oral toxicity assay. Adult male cockroaches were pulled without CO₂ and placed into a greased plastic holding container (0.946 liter, 140 by 113 mm diameter) containing harborage and water. Cockroaches were starved for 24 h.

During the starvation period, one breadcrumb was placed in the bottom of a cell culture cluster well (COSTAR® Model number 3524, Corning Incorporated, Corning, NY). The breadcrumb was treated with 1 µl of chemical solution. Solutions were derived from Termidor (9.1 % fipronil, Bayer Environmental Science, Montvale, NJ), diluted in water and technical grade indoxacarb (56.2%, Dupont Crop Protection, Newark, DE), diluted in acetone. Each chemical had its own set of culture clusters. The solution treated breadcrumb was allowed to dry for at least 4 hrs. The breadcrumb was then treated with 1 µl of 10% sucrose solution and allowed to dry.

At the end of the starvation period, individual cockroaches were removed from the holding container and placed into soufflé cups (59.147 ml, Polar size “G”, Polar Plastique, St-Laurent, QUE) containing treated breadcrumbs and moistened cotton balls (~5 mm diameter). Cup lids were immediately secured to prevent cockroach escape. Cockroach weights were recorded per treatment and concentration. Cups were set aside for 24 h to allow cockroaches time to feed.

At the end of the feeding period, cockroaches that had consumed the entire breadcrumb, were released into a greased sweater box (26.5 by 9.5 by 19 cm, Pioneer Plastics, Dixon, KY). Each sweater box contained a plastic tube (33 by 16 mm diameter) of water with a cotton plug, and cardboard sections (14 by 13cm) folded in half lengthwise secured with a staple for harborage. There were separate arenas for each treatment concentration.
Mortality was counted 4 d after end of feeding period. All moribund cockroaches (defined as an inability to walk) were considered dead.

**Necrophagy assay.** Twenty adult male cockroaches were pulled without CO₂ and placed into a foraging arena, which was a greased clear plastic sweater box (26.5 by 9.5 by 19 cm, Pioneer Plastics, Dixon, KY). Each arena contained a plastic tube (33 by 16 mm diameter) of water with a cotton plug, and cardboard sections (14 by 13cm) folded in half lengthwise secured with a staple for harborage. This process was repeated until there were three arenas per strain. Cockroaches were starved for 24 hours.

At the end of the starvation period, cockroaches were fed thawed 2⁰-3⁰ stage nymphal German cockroaches that had previously ingested Formula 411a gel-bait (0.6% Indoxacarb, Dupont Crop Protection, Newark, DE) or Maxforce® FC gel-bait (0.05% Fipronil, Bayer Environmental Science, Montvale, NJ). Upon death, nymphs were frozen to preserve freshness. Control nymphs were gathered from the rearing containers and frozen. Initially, each arena received ten appropriately treated nymphs. Thereafter, each arena received seven nymphs daily for four days.

Number of nymphs cannibalized was recorded per day and uneaten nymphs were removed from arena. Moribund cockroaches unable to walk were considered dead. Evaluation was ended on day 5.

Experiment was a randomized complete block design with six replicates per strain per treatment for a total of 240 cockroaches.

**Statistical analyses.** Percent consumption of breadcrumbs was analyzed using Analysis of variance and Student’s t-test (P<0.05; SAS Institute 2001). Lethal dose values were determined using probit analysis (SAS Institute 2001). Necrophagy and
resultant mortality were analyzed via Analysis of variance and means separated with Student Newman Keuls (P<0.05; SAS Institute 2001).

**Results**

**Oral toxicity assay.** After 24 h in a soufflé cup with only a treated breadcrumb as a food source, Orlando susceptible strain cockroaches ate 96% of all treated and untreated breadcrumbs whereas Daytona field strain ate 85% of untreated and fipronil treated breadcrumbs and 93% of indoxacarb treated breadcrumbs. Feeding deterrence in Orlando susceptible strain cockroaches was not caused by increasing the concentration of fipronil or from increasing the concentration of indoxacarb (Fig 4-1). Feeding deterrence in Daytona field strain cockroaches was not caused by increasing the concentration of fipronil or from increasing the concentration of indoxacarb (Fig. 4-2).

Cockroaches that consumed the breadcrumb were included in an oral toxicity assay. Orlando susceptible strain cockroaches had LD$_{50}$ values of 0.072 ng per mg body weight and LD$_{90}$ values of 0.108 ng per mg body weight for fipronil and LD$_{50}$ values of 1.312 ng per mg body weight and LD$_{90}$ values of 4.104 ng per mg body weight for indoxacarb (Table 3-2). Daytona field strain cockroaches had LD$_{50}$ values of 0.656 ng per mg body weight and LD$_{90}$ values of 4.063 ng per mg body weight for fipronil and LD$_{50}$ values of 4.653 ng per mg body weight and LD$_{90}$ values of 18.045 ng per mg body weight for indoxacarb. Resistance ratios at the LD$_{50}$ level/ LD$_{90}$ level for Daytona field strain were 9.4/ 36.9 for fipronil and 3.5/ 4.4 for indoxacarb.

**Necrophagy assay.** Upon placing treated nymphs into the arena, both strains of cockroach investigated the bodies, but no immediate consumption was observed. When given a choice, Orlando susceptible strain cockroaches consumed a constant amount of control nymphs (df=4, $F=2.07$, $P=0.1152$), ranging from 1.1 to 2.4 nymphs per day
(Table 4-2), for a total 5 d consumption of 8.9 nymphs. Orlando susceptible strain cockroaches consumed 1.2 fipronil treated nymphs on day one of the choice experiment and consumption decreased significantly during days two through five, ranging from 0.1 to 0.4 nymphs per day for a total 5 d consumption of 2.1 nymphs. Orlando susceptible strain cockroaches consumed a constant amount of indoxacarb treated nymphs (df=4, $F=1.97$, $P=0.1299$) in the choice test, ranging from 0.2 to 1.2 nymphs per day, for a total 5 d consumption of 2.8 nymphs. When no choice was provided, Orlando susceptible strain cockroaches consumed a constant amount of control nymphs (df=4, $F=0.82$, $P=0.5235$), ranging from 4.8 to 6.3 nymphs per day, for a total 5 d consumption of 29.4 nymphs. Orlando susceptible strain cockroaches consumed a constant amount of fipronil treated nymphs (df=4, $F=0.66$, $P=0.6225$) in the no choice test, ranging from 3.3 to 4.8 nymphs per day, for a total 5 d consumption of 19.1 nymphs. Orlando susceptible strain cockroaches consumed a constant amount of indoxacarb treated nymphs (df=4, $F=1.58$, $P=0.2095$) in the no choice test, ranging from 2.8 to 5.0 nymphs per day, for a total 5 d consumption of 19.3 nymphs.

When given a choice, Daytona field strain consumed a constant amount of control nymphs (df=4, $F=0.77$, $P=0.5530$), ranging from 0.4 to 1.2 nymphs per day (Table 4-3), for a total 5 d consumption of 4.1 nymphs. Daytona field strain consumed a constant amount of fipronil treated nymphs (df=4, $F=0.31$, $P=0.8653$) in the choice test, ranging from 0.3 to 0.6 nymphs per day, for a total 5 d consumption of 1.8 nymphs. Daytona field strain also consumed a constant amount of indoxacarb treated nymphs (df=4, $F=1.22$, $P=0.3273$) in the choice test, ranging from 0.3 to 0.8 nymphs per day, for a total 5 d consumption of 2.2 nymphs. When no choice was provided, Daytona field strain
consumed a constant amount of control nymphs ($df=4$, $F=2.11$, $P=0.1096$), ranging from 1.5 to 4.3 nymphs per day for a total 5 d consumption of 13.9 nymphs. Daytona field strain consumed a constant amount of fipronil treated nymphs ($df=4$, $F=0.25$, $P=0.9044$) in the no choice test, ranging from 1.3 to 1.9 nymphs per day, for a total 5 d consumption of 8.5 nymphs. Daytona field strain also consumed a constant amount of indoxacarb treated nymphs ($df=4$, $F=2.10$, $P=0.1107$) in the no choice test, ranging from 1.0 to 2.7 nymphs per day, for a total 5 d consumption of 8.0 nymphs.

Low mortality of 1.3% occurred in Orlando susceptible strain cockroach at 5 d with choice control and there was no significant increase in mortality from 1 d ($df=4$, $F=1.19$, $P=0.3393$) (Table 4-4). Mortality of 6.0% occurred in Orlando susceptible strain cockroach at 5 d with choice fipronil and there was no significant increase in mortality from 1 d ($df=4$, $F=2.41$, $P=0.0760$). Mortality of 8.7% occurred in Orlando susceptible strain cockroach at 5 d with choice indoxacarb and there was significant increase in mortality from day one. Orlando susceptible strain cockroach had mortality of 6.0% by day five with no choice control and no significant increase in mortality from 1 d ($F=1.82$, $DF=4$, $P<0.05$). Mortality of 47.3% occurred in Orlando susceptible strain cockroach at 5 d with no choice fipronil and there was significant increase in mortality from 1d.

Mortality of 36.7% occurred in Orlando susceptible strain cockroach at 5 d with no choice indoxacarb and there was significant increase in mortality from day one.

For Orlando susceptible strain cockroach, mortality increased linearly for control, fipronil, and indoxacarb in both choice and no choice experiments (Fig 4-3). Highest slopes, indicating highest mortality rates, were no choice fipronil and no choice indoxacarb. Lowest slope, indicating least amount of mortality, was choice control. All
slopes were negative, indicating a delay in mortality, however, the largest delay, occurred with no choice indoxacarb. Intercepts indicate a delay of approximately 1 d after start of the experiment for all treatments with the exception of no choice indoxacarb, which had a delay of almost 1.5 d.

Low mortality of 2.0% occurred in Daytona field strain cockroach at 5 d with choice control and there was no significant increase in mortality from 1 d (df=4, $F=0.49$, $P=0.7413$) (Table 4-5). Mortality of 8.0% occurred in Daytona field strain cockroach at 5 d with choice fipronil and there was no significant increase in mortality from 1 d (df=4, $F=1.76$, $P=0.1684$). Mortality of 9.3% occurred in Daytona field strain cockroach at 5 d with choice indoxacarb and there was significant increase in mortality from 1 d. Mortality of 20.8% occurred in Daytona field strain cockroach at 5 d with no choice control and there was significant increase in mortality from day one. Mortality of 31.6% occurred in Daytona field strain cockroach at 5 d with no choice fipronil and there was significant increase in mortality from 1 d. Mortality of 26.0% occurred in Daytona field strain cockroach at 5 d with no choice indoxacarb and there was significant increase in mortality from 1 d.

For Daytona field strain cockroach, mortality increased linearly for control, indoxacarb, and fipronil in both choice and no choice experiments (Fig 4-4). Highest slope was no choice fipronil, followed by no choice indoxacarb and no choice control. Lowest slope was choice control. All slopes were negative; however, the largest delay, occurred with no choice indoxacarb and no choice control. Intercepts indicate a delay of approximately 1 d after start of the experiment for choice control, choice fipronil, and no choice fipronil. A delay of 1.25 to 1.5 d occurred with both no choice and choice
Discussion

Oral toxicity assay. Insecticidal concentration can reduce palatability of a toxic bait base. When Orlando susceptible strain German cockroaches were included in a lethal time test with concentrations of abamectin ranging from 0.0025% to 0.1000%, \( \text{LT}_{50} \) values failed to significantly decrease above concentrations of 0.0500% (Koehler et al. 1991). It was determined this was due to feeding deterrence caused by abamectin in concentrations above 0.0500%. In my oral toxicity study, bait consumption did not significantly decrease as fipronil concentrations increased 2 fold for Orlando susceptible strain cockroach and 13 fold for Daytona field strain cockroaches. Additionally, bait consumption did not significantly decrease as indoxacarb concentrations increased 10 fold for Orlando susceptible strain cockroach and 6 fold for Daytona field strain cockroaches. This indicates neither fipronil nor indoxacarb are feeding deterrents.

\( \text{LD}_{50} \) values are usually obtained by topical application of insecticides. Topical \( \text{LD}_{50} \) value for fipronil was 0.096 ng per mg body weight for Orlando susceptible strain cockroach (Valles et al. 1997). The same study also injected fipronil directly and determined the injected \( \text{LD}_{50} \) value was 0.081 ng per mg body weight. My study, which required ingestion of fipronil, determined \( \text{LD}_{50} \) value for fipronil was 0.07 ng per mg body weight for Orlando susceptible strain cockroach. Overlapping confidence intervals between Valles’ study and my study indicate \( \text{LD}_{50} \) value for ingested fipronil is equal to the \( \text{LD}_{50} \) value of injected fipronil.

When Dorie and Cincy bait-averse strain cockroaches were compared to JWAX susceptible strain cockroach for topically applied fipronil, resistance ratios at the \( \text{LD}_{50} \) /
LD$_{90}$ level were 8.7x / 44.9x for Cincy bait-averse strain cockroach and 9.3x / 52.7x for Dorie bait-averse strain cockroach (Wang 2004). Although my study determined Daytona field strain cockroach exhibited a resistance ratio at the LD$_{50}$ level very similar to Dorie bait-averse strain cockroach, it must be noted that Orlando susceptible strain cockroach was used for comparison. There is inherent variability in strains of German cockroach.

When Orlando susceptible strain cockroach and JWAX susceptible strain cockroach were compared to each other in a lethal time test using five carbamates, susceptible strain cockroach exhibited 1.2 to 2 fold tolerance to four of the carbamates, indicating that overall, Orlando susceptible strain cockroach is slightly more tolerant of insecticides (Koehler and Patterson 1986). This was true in my study; upon comparison of LD$_{50}$ and LD$_{90}$ levels of Orlando susceptible strain cockroach obtained in my study and values obtained for JWAX susceptible strain cockroach in Wang et al’s study, Orlando susceptible strain cockroach exhibited 2.3 fold and 2.6 fold tolerance to fipronil respectively. Therefore, even though resistance ratios for Daytona field strain cockroach were similar to Dorie bait-averse strain cockroach, when comparison strains are taken into account and direct comparison is made, Daytona field strain cockroach is 2.4x more resistant to fipronil than Dorie bait-averse strain cockroach. Additionally, Daytona field strain cockroach exhibited a low level of resistance (RR$_{50}$ = 3.5) to indoxacarb when compared to Orlando susceptible strain cockroaches.

When comparing resistance ratios, it is important to note differences of comparison susceptible strains used. It is also important to note method of application for lethal dose assays since it appears ingested lethal doses are significantly different from topically applied. Even with the lower ingested LD$_{50}$ value for fipronil and compared to a tolerant
susceptible strain, Daytona field strain cockroach had resistance ratios, especially at the LD$_{90}$ level that could possibly interfere with control in the field.

**Necrophagy assay.** German cockroaches are known to consume conspecifics, a process known as cannibalism. More specifically, when the cannibalized cockroaches are dead, it is known as necrophagy. When twenty adult male Orlando susceptible strain cockroaches were given a no choice test wherein the only food source was freshly dead nymphs, necrophagy was relatively low on the first day and steadily increased (Gahlhoff et al. 1999). Conversely, necrophagy in my study remained constant over the 5 d period for both Orlando susceptible strain cockroach and Daytona field strain cockroach, with the exception of choice fipronil in Orlando susceptible strain cockroach, which decreased. Although my experimental design was different from Gahlhoff et al.’s (1999) in that I fed fewer nymphs over the course of only 5 d, used two different strains, and offered a choice in addition to no choice, our results were similar because in both cases, necrophagy occurred.

German cockroaches can go several days before starving to death. In Gahlhoff et al.’s (1999) study, control mortality was approximately 2% on day five and increased to 10% on day seven, indicating starvation. In my no choice study, control mortality was not significant at 5 d in Orlando susceptible strain cockroach; however, significant control mortality occurred at 4 d in Daytona field strain cockroach. Because adult male field cockroaches increase foraging distance, time spent foraging, and movement velocity under the influence of starvation (Barcay and Bennett 1991), it is likely Daytona field strain cockroaches starved themselves while foraging for more nutritious food while Orlando susceptible strain did not.
Fipronil is a fast acting insecticide known to cause secondary mortality (Buczkowski et al. 2001, Durier and Rivault 2000b, Gahlhoff 1999). In Gahlhoff et al.’s (1999) study on cannibalization, mortality from fipronil was approximately 30% on day two and increased to 100% by day five. Similarly, in my no choice study, mortality caused by ingestion of fipronil treated nymphs increased linearly over time. Linear increase probably occurred due to constant necrophagy. Additionally, significant secondary mortality from fipronil occurred in both Orlando susceptible strain cockroach and Daytona field strain cockroach at 3 d. No significant mortality occurred from fipronil treated nymphs in the choice test for either Orlando susceptible strain cockroach or Daytona field strain cockroach.

Indoxacarb is a chemical that requires bioactivation to become effective (Wing et al. 1998). Using adult male American Cyanamid strain cockroaches, Appel (2003) determined the LT_{50} value of 0.25% indoxacarb was 0.68 days. In my study, only secondary mortality was recorded, and similar to the findings of Appel (2003), mortality from ingestion of indoxacarb treated nymphs was delayed. Significant secondary mortality from indoxacarb treated nymphs occurred in the no choice study at 3 d for Orlando susceptible strain cockroach and 4 d for Daytona field strain cockroach. Significant secondary mortality from indoxacarb treated nymphs occurred in the choice study at 4 d for Orlando susceptible strain cockroach and 5 d for Daytona field strain cockroach.

Secondary mortality from ingestion of indoxacarb treated nymphs was delayed and significant in both choice and no choice experiments for both Orlando susceptible strain cockroach and Daytona field strain cockroach; however, in the no choice test, for
Orlando susceptible strain, significant secondary mortality occurred on the same day as significant secondary mortality from ingestion of fipronil treated nymphs. This is perhaps due to the presence of already bioactivated indoxacarb metabolite in the midgut and fat bodies of the cannibalized nymphs. Significant secondary mortality occurred in no choice tests for fipronil for both Orlando susceptible strain cockroach and Daytona field strain cockroach. Significant secondary mortality in choice experiments only occurred for indoxacarb in both Orlando susceptible strain cockroach and Daytona field strain cockroach.

Necrophagy causes significant secondary mortality in laboratory settings (Gahlhoff, et al. 1999). My study has shown that, while necrophagy occurs both in the presence or absence of food, availability of food is important to significant secondary mortality. If another food source is readily available, German cockroaches engage less in necrophagy. In the absence of convenient food in a laboratory setting or a field setting, necrophagy could play a significant role in secondary mortality.
Figure 4-1. Proportion fipronil and indoxacarb treated breadcrumbs eaten by Orlando susceptible strain cockroaches after a 24 h starvation period.
Figure 4-2. Proportion fipronil and indoxacarb treated breadcrumbs eaten by Daytona susceptible strain cockroaches after a 24 h starvation period.
**Table 4-1.** Susceptibility of Orlando susceptibility and Daytona field strains of German cockroach to two ingested insecticides.

<table>
<thead>
<tr>
<th>Insecticide</th>
<th>Strain</th>
<th>n</th>
<th>Slope ± SE</th>
<th>Lethal dose (ng/mg)&lt;sup&gt;a&lt;/sup&gt;</th>
<th>RR&lt;sub&gt;50&lt;/sub&gt;&lt;sup&gt;b&lt;/sup&gt;</th>
<th>RR&lt;sub&gt;90&lt;/sub&gt;&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Model fit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>LD&lt;sub&gt;50&lt;/sub&gt; (95% FL)</td>
<td>LD&lt;sub&gt;90&lt;/sub&gt; (95% FL)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fipronil</td>
<td>Orlando</td>
<td>300</td>
<td>7.220 ± 0.954</td>
<td>0.072 (0.068-0.076)</td>
<td>0.108 (0.971-0.128)</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Daytona</td>
<td>300</td>
<td>1.618 ± 0.201</td>
<td>0.656 (0.535-0.822)</td>
<td>4.063 (2.634-8.071)</td>
<td>9.4</td>
<td>36.9</td>
</tr>
<tr>
<td>Indoxacarb</td>
<td>Orlando</td>
<td>370</td>
<td>2.588 ± 0.310</td>
<td>1.312 (1.128-1.488)</td>
<td>4.104 (3.329-5.634)</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Daytona</td>
<td>354</td>
<td>2.177 ± 0.301</td>
<td>4.653 (3.833-5.410)</td>
<td>18.045 (13.836-27.925)</td>
<td>3.5</td>
<td>4.4</td>
</tr>
</tbody>
</table>

<sup>a</sup> Dose (nanograms of insecticide per mg of insect) calculated based on body weights. Average body weights (mean ± SE) per strain (n = 982) were Orlando, 47.29 ± 0.28 and Daytona, 50.93 ± 0.27 mg.

<sup>b</sup> Resistance ratio based on LD50/ LD 90 values compared with Orlando strain.
Table 4-2. Daily consumption of insecticide treated nymphs by Orlando susceptible strain German cockroaches.

<table>
<thead>
<tr>
<th>Day</th>
<th>Control</th>
<th>Choice</th>
<th>Indoxacarb</th>
<th>Choice</th>
<th>Indoxacarb</th>
<th>Choice</th>
<th>Indoxacarb</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fipronil</td>
<td>Control</td>
<td></td>
<td>Fipronil</td>
<td>Control</td>
<td>Fipronil</td>
<td>Control</td>
</tr>
<tr>
<td>1</td>
<td>2.42 ± 0.33</td>
<td>1.17 ± 0.46a</td>
<td>0.83 ± 0.17</td>
<td>6.17 ± 0.79</td>
<td>4.75 ± 0.94</td>
<td>5.00 ± 1.28</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1.08 ± 0.27</td>
<td>0.42 ± 0.24b</td>
<td>0.42 ± 0.20</td>
<td>4.83 ± 0.88</td>
<td>3.50 ± 0.39</td>
<td>3.58 ± 0.57</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2.17 ± 0.33</td>
<td>0.08 ± 0.08b</td>
<td>0.17 ± 0.11</td>
<td>6.00 ± 0.56</td>
<td>3.92 ± 0.69</td>
<td>4.50 ± 0.65</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1.58 ± 0.44</td>
<td>0.17 ± 0.17b</td>
<td>0.25 ± 0.11</td>
<td>6.17 ± 0.40</td>
<td>3.33 ± 0.49</td>
<td>3.50 ± 0.26</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.67 ± 0.42</td>
<td>0.25 ± 0.11b</td>
<td>1.17 ± 0.60</td>
<td>6.25 ± 0.51</td>
<td>3.58 ± 0.80</td>
<td>2.67 ± 0.44</td>
<td></td>
</tr>
</tbody>
</table>

Means in a column followed by the same letter are not significantly different (P > 0.05; Student-Newman-Keuls sequential range test [SAS Institute, 2001]).
Table 4-3. Daily consumption of insecticide treated nymphs by Daytona field strain German cockroaches.

<table>
<thead>
<tr>
<th>Day</th>
<th>Control</th>
<th>Fipronil</th>
<th>Indoxacarb</th>
<th>Control</th>
<th>Fipronil</th>
<th>Indoxacarb</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.92 ± 0.35</td>
<td>0.58 ± 0.37</td>
<td>0.83 ± 0.28</td>
<td>2.17 ± 0.48</td>
<td>1.83 ± 0.40</td>
<td>1.58 ± 0.27</td>
</tr>
<tr>
<td>2</td>
<td>1.00 ± 0.41</td>
<td>0.33 ± 0.17</td>
<td>0.42 ± 0.20</td>
<td>1.50 ± 0.52</td>
<td>1.25 ± 0.60</td>
<td>1.08 ± 0.58</td>
</tr>
<tr>
<td>3</td>
<td>0.58 ± 0.33</td>
<td>0.33 ± 0.25</td>
<td>0.25 ± 0.11</td>
<td>2.58 ± 0.55</td>
<td>1.92 ± 0.61</td>
<td>1.67 ± 0.56</td>
</tr>
<tr>
<td>4</td>
<td>0.42 ± 0.20</td>
<td>0.17 ± 0.17</td>
<td>0.25 ± 0.17</td>
<td>3.42 ± 1.02</td>
<td>1.75 ± 0.59</td>
<td>2.67 ± 0.49</td>
</tr>
<tr>
<td>5</td>
<td>1.17 ± 0.42</td>
<td>0.42 ± 0.33</td>
<td>0.42 ± 0.27</td>
<td>4.25 ± 0.95</td>
<td>1.75 ± 0.31</td>
<td>1.00 ± 0.29</td>
</tr>
</tbody>
</table>
Table 4-4. Cumulative daily mortality from ingestion of insecticide treated nymphs in Orlando susceptible strain German cockroaches.

<table>
<thead>
<tr>
<th>Day</th>
<th>Choice</th>
<th>No Choice</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Fipronil</td>
</tr>
<tr>
<td>1</td>
<td>0.00 ± 0.00</td>
<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>2</td>
<td>0.00 ± 0.00</td>
<td>2.67 ± 0.84</td>
</tr>
<tr>
<td>3</td>
<td>0.37 ± 0.67</td>
<td>4.67 ± 1.61</td>
</tr>
<tr>
<td>4</td>
<td>1.33 ± 0.84</td>
<td>5.33 ± 1.98</td>
</tr>
<tr>
<td>5</td>
<td>1.33 ± 0.84</td>
<td>6.00 ± 2.25</td>
</tr>
</tbody>
</table>

Means in a column followed by the same letter are not significantly different (P > 0.05; Student-Newman-Keuls sequential range test [SAS Institute, 2001]).
Table 4-5. Cumulative daily mortality from ingestion of insecticide treated nymphs in Daytona field strain German cockroaches.

<table>
<thead>
<tr>
<th>Day</th>
<th>Choice Control</th>
<th>Fipronil</th>
<th>Indoxacarb</th>
<th>No Choice Control</th>
<th>Fipronil</th>
<th>Indoxacarb</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.00 ± 0.00</td>
<td>1.33 ± 0.84</td>
<td>0.00 ± 0.00a</td>
<td>0.67 ± 0.67a</td>
<td>2.03 ± 0.91a</td>
<td>1.33 ± 0.84a</td>
</tr>
<tr>
<td>2</td>
<td>0.67 ± 0.67</td>
<td>2.67 ± 1.33</td>
<td>0.00 ± 0.00a</td>
<td>0.67 ± 0.67a</td>
<td>8.08 ± 1.83ab</td>
<td>4.00 ± 1.79a</td>
</tr>
<tr>
<td>3</td>
<td>1.33 ± 1.33</td>
<td>6.00 ± 3.06</td>
<td>3.33 ± 1.23a</td>
<td>3.39 ± 0.68a</td>
<td>13.50 ± 3.63b</td>
<td>8.67 ± 3.33ab</td>
</tr>
<tr>
<td>4</td>
<td>1.33 ± 1.33</td>
<td>8.00 ± 2.73</td>
<td>7.33 ± 1.91b</td>
<td>12.84 ± 1.22b</td>
<td>22.83 ± 2.88c</td>
<td>18.00 ± 5.54bc</td>
</tr>
<tr>
<td>5</td>
<td>2.00 ± 1.37</td>
<td>8.00 ± 2.73</td>
<td>9.33 ± 1.33b</td>
<td>20.84 ± 2.71c</td>
<td>31.61 ± 2.99d</td>
<td>26.00 ± 3.83c</td>
</tr>
</tbody>
</table>

Means in a column followed by the same letter are not significantly different (P > 0.05; Student-Newman-Keuls sequential range test [SAS Institute, 2001]).
Figure 4-3. Percent mortality of Orlando susceptible strain cockroaches from ingestion of insecticide treated nymphs.
Figure 4-4. Percent mortality of Daytona field strain cockroaches from ingestion of insecticide treated nymphs.
German cockroaches are major pests of households and structures. The common method of control is the use of gel bait. Recently, reports of control failure were reported. In two cases, the cause of control failure was attributed to behavioral aversion, a fairly new phenomenon in German cockroaches. It is unknown if the feeding deterrence exhibited by bait averse strains of German cockroach can be overcome by reformulating the gel bait matrix. It is also unknown if bait averse strains of German cockroach also have physiological resistance. For these studies, a field strain of cockroach was collected from Daytona, FL in an area that reported control failure using gel bait. This strain, Daytona field strain, was determined to be bait averse.

Chapter 3 evaluated feeding deterrence to six different commercially available gel bait formulations and concluded that consumption was positively correlated with mortality. Daytona field strain cockroach exhibited feeding deterrence to four of the six gel baits. Two gel baits did not cause feeding deterrence and therefore, had the highest levels of mortality; indicating feeding deterrence can be overcome by reformulating bait matrices.

Chapter 4 evaluated the oral toxicity of indoxacarb and fipronil to both Orlando susceptible strain cockroach and Daytona field strain cockroach. At the LD90 level, Daytona field strain cockroach exhibited low levels of physiological resistance to indoxacarb and high levels of resistance to fipronil. Chapter 4 also evaluated the ability of fipronil and indoxacarb to cause secondary mortality from necrophagy. Necrophagy
occurred in both strains in the presence and absence of food choice. Significant secondary mortality from ingestion of fipronil treated nymphs only occurred in the no choice test for both strains. Significant secondary mortality from ingestion of indoxacarb treated nymphs occurred in both choice and no choice tests for both strains; however, mortality occurred significantly faster in the no choice test for both strains.

Overall, control failures in the field can be attributed to the combination of behavioral and physiological resistance. Changing gel bait formulations and ingredients can overcome these failures. Because the availability of food significantly affects secondary mortality, control measures will be more effective if sanitation is practiced along with application of gel baits.

Our bait averse field strain was collected in Florida whereas the only other isolated strains of bait averse cockroach were from Ohio. This indicates bait aversion is more widespread than once believed. While gel baits can be formulated so that bait averse cockroaches consume them, physiological resistance and insignificant secondary mortality from necrophagy can still affect control in the long term. This study has revealed that there is more to behaviorally averse cockroaches than decreased consumption of gel bait.
LIST OF REFERENCES


BIOGRAPHICAL SKETCH

Linda Anne NeHerne, daughter of Harry and Jessie Riley, was born in 1969. She graduated from Bayshore High School in Bradenton, FL, in 1987. She enlisted in the US Army in 1988 and performed her duties as a laboratory technician in Landstuhl, Germany. She graduated from the University of South Florida in 1996 with a bachelor’s in environmental science/ zoology. She joined the US Navy in 1998 and was commissioned in December of that year. During her time, she ran an office for the training of future military pilots in Pensacola, FL, and was a deck officer and a weapons officer onboard the USS Germantown stationed in Sasebo, Japan. Desiring to become a Medical Entomologist with the US Navy, she entered the University of Florida’s graduate program in August of 2003.