Chapter 10

Least Toxic Strategies for Managing German Cockroaches

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German cockroach resistance development, chronic infestations, and the health impact of insecticide applications have prompted increased interest in least toxic technologies and integrated pest management strategies (IPM) for managing German cockroaches to minimize insecticide use, increase long-term efficacy, and slow down insecticide resistance development. New research data on the relative efficacy of attractants, cockroach pheromones, sticky traps, inorganic insecticides, insect growth regulators, and IPM programs have assisted in the adoption of alternative cockroach management methods. Yet, challenges remain in voluntary adoption of IPM programs and least toxic technologies. Education and coordinated efforts among residents, management staff, pest management professionals, and policy makers will be needed for greater acceptance of least toxic strategies.

Introduction

Of the approximately 4,000 cockroach species in the world, the German cockroach, *Blattella germanica* L., is by far the most successful species. It is found in homes, restaurants, factories, hospitals, ships, and any other indoor environment with food, water, and a warm temperature. Cockroach infestations

are often closely related with sanitary conditions in a structure. German cockroaches can reproduce to huge numbers if the room is left untreated. As many as 3,657 cockroaches were trapped in 24 hours on 6 sticky traps placed in one occupied apartment in 2006 (Wang and Bennett, Purdue University, *unpublished data*). Estimated that only 3% of the cockroaches were trapped, the apartment had approximately 122,000 cockroaches!

German cockroaches have significant economic and medical impact. Cockroaches produce allergens and trigger asthma (*1*). In a national survey of 831 U.S. homes, 13% had > 2.0 U/g (units per gram of dust) cockroach allergen (Bla g 1, one of the allergens produced by cockroaches) in kitchen dust samples (*2*). German cockroaches contaminate food and other commodities. The cost for managing German cockroaches can become a significant burden over time, and pesticide use for cockroach management can be a serious health concern for young children.

There are a variety of consumer and professional products for managing German cockroaches, such as sprays, insect foggers, dusts, gel baits, bait stations, and sticky traps. These products vary in cost, formulation, toxicity, and effectiveness. The active ingredients in majority of the insecticide sprays and foggers sold for controlling cockroaches in the U.S. are synthetic pyrethroids. Common active ingredients are allethrin, cyfluthrin, cypermethrin, deltamethrin, lamda-cyhalothrin, permethrin, and resmethrin. Pyrethroids can pose both short and long-term health risks to humans (*3*). Children are at higher risk of pesticide poisoning due to their behavior and developmental stage (*4*). In addition to the pesticide active ingredient, adjuvants such as piperonyl butoxide, which is used to enhance the "knock-down" effect of pyrethroids, and inert ingredients, such as solvents, may cause health problems for sensitive individuals such as children, older adults, and people with chronic illnesses (*5*).

Unaware of the potential health or environmental effects of insecticides, consumers are often guided by price or advertisements in selecting a product. Based on a survey of cockroach control products sold in 106 New York City stores in 2002, insecticide sprays were the most commonly purchased item (*6*). Some residents sprayed daily and used multiple insecticides to kill cockroaches.

Pest management professionals often choose products based on the treatment cost. Periodic applications of gel baits or containerized bait stations containing organic insecticides are the main methods for cockroach management in inner cities by professionals in the U.S. (*7, 8*). Cockroach bait residues are commonly seen in multi-family apartments.

Frequent applications of insecticides not only may pose direct danger to humans, but also induce cockroach resistance and contaminate the environment. High levels of resistance to cockroach baits have been reported (*9-12*). Numerous pesticides have been detected in indoor air and settled dust in homes (*13*). These concerns have led to increased emphasis on alternative strategies and integrated pest management (IPM) for managing cockroach infestations. The objective of this chapter is to review the current status of non-chemical and low-impact chemical methods and IPM for managing German cockroaches.

Cultural Control

Cockroaches need food, water, and harborage to survive. Food residues, unwashed dishes, clutter, and pet food provide favorable conditions for cockroaches to survive and reproduce. Cockroach infestations are closely related to sanitary conditions in the environment and human activities. In an infested apartment, bedrooms usually do not have cockroaches or have the least cockroach numbers simply because there is a lack of food and water in bedrooms.

Cockroaches in a clean, uncluttered environment are much more easily eliminated than those in a dirty environment. Many reports cite the relationship between sanitary conditions and success in cockroach management programs (*14-16*). Reducing or eliminating unsanitary conditions is critical if we are to successfully manage German cockroaches with minimal use of insecticides. Simple practices such as cleaning floors and areas around kitchen appliances, prompt washing of dishes, removing food residues and garbage, and covering open food containers (including pet food) will help reduce cockroach infestations. Reducing clutter is equally important because clutter provides harborage for cockroaches and increases the difficulty in insecticide applications.

Environmental Modification

Cockroaches hide in narrow places. Sealing holes and cracks in the living environment reduces the number of potential hiding places, and improves control efficacy because dust or liquid chemicals are difficult to apply in these places. In multi-family dwellings, cockroaches can migrate between neighboring units through utility penetrations or through doors (*17*). Caulking these areas and adding door swipes will reduce the occurrence of new infestations.

Leaky pipes or faucets provide water sources for cockroaches. In an infested apartment, cockroaches usually concentrate in areas around the kitchen sink, refrigerator, or toilet where water is available (*18*). Prompt repair of malfunctioning faucets, pipes, etc., and cleaning up spills will reduce cockroach survival and reproductive potential.

Physical Control

Trapping

Traps are very useful tools for detecting cockroaches and many other crawling insects in the environment. The following animals were found in the monitoring traps placed in apartments: mice, ants, small flies, spiders, millipedes, and beetles (*18*).

Traps are also helpful for guiding pesticide applications thereby reducing pesticide use. In addition, sticky traps are useful for evaluating insecticide

efficacy against cockroaches (*19, 20*). Traps are convenient to use, non-toxic, and inexpensive. Hence, they are frequently used in cockroach management programs.

Trap Types

Two types of traps are used to monitor cockroaches: sticky traps and jar traps. Commercially available sticky traps have many different sizes and shapes. The traps have a thin glue surface to capture cockroaches that wander into the traps. Insect traps are designed to catch crawling insects and other arthropods. Mouse sticky traps can also catch cockroaches. However, mouse sticky trap designs do not have openings on the side or top, which are useful features for catching cockroaches.

Home-made jar traps are made of any type glass jar such as 0.943-liter wide mouth mason jars or 0.124-liter baby food jars (*21, 22*). Food needs to be placed in the jars to attract cockroaches. Bread wetted with beer is most effective in attracting cockroaches into jars. The inner surface of the jar is covered by a thin layer of vaseline and oil to prevent escape. Jar traps are cheaper than sticky traps and are re-usable. However, they are less convenient than sticky traps due to their size and the time needed for preparation.

Use of Traps

Proper placement of traps is very important to maximize trap efficacy. Traps should be placed in locations where cockroaches are likely to hide. In apartments, areas around the refrigerator, stove, kitchen sink, food pantry, and toilet are favored by cockroaches. Traps need to be placed against a wall or a vertical surface (*23*). Depending on the cockroach infestation levels, traps should be checked after one or more nights. In heavily infested areas, a large trap may become full after only one night.

Food and other attractive materials can be placed in the center of most any trap to increase the effectiveness. Wang and Bennett (*24*) studied the effect of five attractants on trap efficiency. All attractants significantly increased the number of cockroaches trapped in sticky traps compared with un-baited traps. Bread with beer was by far the most attractive bait, and increased the trap catches 34-fold over un-baited traps. The bait should be placed on an inverted small bottle cap or any other holding device to avoid wetting the glue surface of the sticky traps. The bait needs to be replaced every 1-2 days to maintain the attractiveness.

Effectiveness of Traps

In general, sticky traps are much more effective than jar traps in catching cockroaches (*24*). The effectiveness of sticky traps varies. Openings on the sides or top of the traps are a helpful feature enhancing the trap efficacy. A smooth

surface around the glue area also greatly increases the trap efficiency. Flat glue boards captured significantly more cockroaches than triangular traps in one study (*24*).

Cockroach susceptibility to trapping varies with trap type and cockroach size. Small nymphs are more likely to be trapped by sticky traps than large nymphs. In contrast, jar traps are biased toward large cockroach individuals (adults or large nymphs). Cockroach age structure measured by sticky traps is similar to field population structure, whereas, cockroaches collected from jar traps have a much lower percentage of nymphs than the populations in the natural environment (*24*). Small nymphs might be less likely to climb and/or fall into the jar traps than large nymphs and adults.

Moore and Granovsky (*25*) compared the susceptibility of five cockroach species to trapping. Among them, the Oriental cockroach (*Blatta orientalis* L.) was the easiest to catch and brownbanded cockroach (*Supella longipalpa* (F.)) was least susceptible. A study was conducted in simulated kitchens to compare the efficacy of trapping and baiting against the Oriental cockroach. Sixty Oriental cockroaches were released in each kitchen (5.6 m^2). Ten Trapper insect traps (Bell Laboratories, Inc., Madison, WI, U.S.A.) were placed in one kitchen. The other kitchen was treated with Advion (0.6% indoxacarb) and Maxforce FC Select (0.01% fipronil) cockroach gel baits. After 13 d, the number of Oriental cockroaches decreased by 95% and 100% in the trap and bait-treated kitchens, respectively (Wang and Bennett, Purdue University, *unpublished data*).

Role of Traps in Cockroach Management

German cockroach numbers caught in traps do not change significantly over time at most trap locations (*26*). This feature is useful for estimating population distributions and population changes after pesticide applications. Field studies in apartment buildings showed very consistent distribution patterns. Areas around refrigerators and stoves in the kitchens accounted for 60% of the trap catches (*18*).

Traps can remove a large number of cockroaches when they are placed in multiple locations. In a 29-week study, a median number of 40 traps were placed in 12 cockroach infested apartments; the median number of German cockroaches removed by trapping during the 29-week period was 439 (*27*). Despite the large number of cockroaches that can be removed by traps, traps are not recommended as the sole method for eliminating cockroaches because they are not effective in significantly reducing the cockroach population levels in the living environment (*28, 29*). The most efficient trap (Victor M-330, Woodstream, Lititz, PA, U.S.A.) only trapped an average of 3.7% of the cockroaches per day when ≈ 170 cockroaches were present in 1 × 1 m arenas (*24*).

Vacuuming

Vacuuming immediately removes many cockroaches in heavily infested environments, and removes cast skins, fecal materials, as well as dead cockroaches. These are the allergen sources that can exacerbate asthma. Thus, vacuuming provides additional benefits besides reducing cockroach numbers. Extensive trapping and vacuuming provided a similar level of control of German cockroaches as gel bait in a field trial (*20*). However, a disadvantage of vacuuming is that it takes a much longer time to reduce populations than applying insecticides. In addition, a vacuum with a HEPA filter needs to be used to avoid having allergens blown back into the air.

Electronic Devices

Various electronic devices are advertised for controlling pests. These products are claimed to repel insects and other pests through high frequency sound, electromagnetic waves, or negative ions. Gold (*15*) reviewed scientific studies on some electronic pest control devices and did not find any reports showing the effectiveness of the devices. To date, there are no scientific data proving the effectiveness of electronic devices against cockroaches.

Inorganic Materials

Inorganic materials are some of the oldest insecticides used for controlling cockroaches. They are widely used in managing ants, cockroaches, termites, stored product insects, and other crawling insects. The most common inorganic insecticides are boric acid and other borate materials, formulated as dust, gel bait, or granular bait. The main advantages of inorganic insecticides are long residual activity, low toxicity, no known resistance in cockroaches, and low cost. A comprehensive review of inorganic insecticides used in cockroach management is presented by Ebeling (*30*).

Boric Acid and Other Borate Materials

Boric acid (H_3BO_3), also called boracic acid or orthoboric acid, was first registered as an insecticide in 1948 by the U.S. Environmental Protection Agency for control of cockroaches, termites, fire ants, fleas, silverfish, and many other insects. Among the inorganic insecticides, boric acid is the most commonly used in German cockroach management. A less common borate material is disodium octaborate tetrahydrate.

The mode of action of boric acid against cockroaches is not completely clear. Generally, it acts as a stomach poison affecting the insects' metabolism, and the dry powder is abrasive to the insects' exoskeleton. Ebeling (*30*) suggested that both destruction of the digestive tract and penetration through the exoskeleton contribute to mortality. In a recent study, Habes et al. (*31*) revealed

that boric acid infected cockroaches showed destruction of epithelial cells, increased glutathione S-transferases, and lowered acetylcholine esterase activity. This is the first report indicating boric acid dust possesses neurotoxic functions. Symptoms of boric acid poisoning include erratic behavior, tremors and paralysis.

Boric acid is a slow-acting chemical. In choice assays, mortality plateaued after nine days of exposure to boric acid dust on vinyl panels at 1.5 mg/cm^2 (Wang and Bennett, Purdue University, *unpublished data*). Neurotoxin baits (such as fipronil, indoxacarb) can cause 100% mortality within 1-2 days. The slow-acting feature is a main limiting factor to the adoption of boric acid when speed of control is emphasized.

No significant resistance to boric acid in insects has been found. Although field cockroach strains are consistently less susceptible than the laboratory strains based on our experiments, they can be effectively controlled by boric acid dust. Thus, boric acid is still being widely used and effective against many crawling insects. Boric acid dust offers satisfactory control results in residences and commercial facilities at a very low material cost.

Boric acid is generally considered much safer to human and animals than organic insecticides because it has a relatively high LD_{50} (lethal dose to cause 50% mortality of the population) value and it does not volatilize. However, boric acid is used as undiluted or slightly diluted dust. Accidental ingestion, skin contact, and inhalation of boric acid dust can pose health risks to human or animals.

Dust Formulation

Among the various borate materials used for controlling cockroaches, dust is the primary formulation. In choice tests where cockroaches were provided with treated and untreated harborages, German cockroaches did not avoid boric acid treated harborage at its minimum effective rate (0.61 mg/cm^2 or 0.02 oz/ft^2) (Wang and Bennett, Purdue University, *unpublished data*). Significant repellency was found starting from 3.04 mg/cm^2. These results imply that in field applications, a thin layer of dust is more effective and economical than a thick layer of dust, which will repel cockroaches and reduce the efficacy.

In laboratory experiments evaluating the efficacy of boric acid dust applied to harborages, there was a clear concentration-mortality response at the rates below 1.5 mg/cm^2. Beginning from 1.5 mg/cm^2 concentration, boric acid dust caused > 96% control mortality to field strain cockroaches. In a similar experiment, Nibor-D (98% disodium octaborate tetrahydrate) dust (Nisus Corp., Rockford, TN, U.S.A.) applied at 1.5 mg/cm^2 induced 99% mortality at 7 d against the laboratory strain of the German cockroach. Its efficacy against two field strains was much lower, with only 61-70% mortality after 21 d exposure. The LT_{90} (time at which 90% of the population is killed) values against the laboratory strain and two field strains were 6, 27, and 28 days, respectively (*32*).

Field data documenting boric acid efficacy against German cockroaches is scarce. Ebeling et al. (*33*) reported in German cockroach infested apartments, thorough application of boric acid dust at the rate of 454 g per apartment

resulted in 99.7% and 100% trap catch reduction after 1 and 3 months, respectively. Moore (*34*) compared boric acid alone and boric acid plus silica dust treatments in apartments. Approximately 227 g dust was applied per apartment. Cockroach counts were reduced to < 4 after 3 months in all treatments. In livestock production systems, the efficacy of boric acid dust was comparable to organic residual insecticide for managing German cockroaches (*35*). High humidity or water in the environment does not affect the toxicity of boric acid dusts and silica gel (*36*). They remain effective after absorbing moisture from the air or wetted by water in the environment.

Boric acid dust involves higher labor cost than baits during application. In addition, boric acid dust cannot be applied into certain places or surfaces (e.g. corners of door frames, door hinges, window shades, metal surface). Thus, in heavily infested areas, additional tools need to be used to achieve satisfactory control.

Solid Bait Formulation

Boric acid baits are generally toxic but have moderate performance in field trials (*37, 38*). Dry or wet bait containing boric acid and disodium octaborate tetrahydrate is repellent to German cockroaches (*39*). This is the main reason that solid baits containing boric acid are not very effective in field studies. Despite the shortcomings, several boric acid gel baits and granular baits are available in the U.S. Two common cockroach baits are InTice roach bait (30% orthoboric acid) and Niban FG granular bait (5.0% orthoboric acid). They have the advantage of easy application, but are much more expensive (3-4 times) than dust formulations. There are no reported data on their effectiveness to field cockroach populations.

In laboratory experiments, LesCo granular bait (5% orthoboric acid; LesCo, Inc. Cleveland, Ohio, U.S.A.) caused 72% mortality to the laboratory German cockroach strain, whereas, only 5-13% mortality occurred among the three field strains (Wang and Bennett, Purdue University, *unpublished data*). In another laboratory test, the Niban-FG granular bait (5% orthoboric acid; Nisus Corp., Rockford, TN, U.S.A.), caused 100% and 65.9% mortality to the laboratory and field strains, respectively (Table I) (*40*).

Table I. Effectiveness of boric acid granular bait (Niban FG) against laboratory and field strains of the German cockroach

Cockroach strain	*LT_{50} (95% FL) (day)*	*LT_{90} (95% FL) (day)*	*Mean control mortality after 28 d*
Jwax (laboratory strain)	3.9 (3.4-4.7)	5.9 (5.1-7.4)	100%
Dorie (Field strain)	24.9 (23.0-27.6)	37.6 (33.7-43.7)	65.9%

In laboratory choice tests using small number of cockroaches (15-20 per box), boric acid gel bait caused near 100% mortality to field strains after 11-21 days of exposure. However, in large mixed-stage population studies (> 200 cockroaches per box), < 50% mortality occurred from boric acid gel bait treatment.

Compared with gel baits containing conventional organic insecticides, boric acid gel bait is much less palatable and effective (*41*). Laboratory assays showed boric acid gel bait was significantly less palatable than cockroach baits containing fipronil (Maxforce FC Select cockroach gel bait), indoxacarb (Advion cockroach gel bait), dinotefuran (Advance cockroach gel bait), and acetamiprid (Transport cockroach gel bait) (Wang and Bennett, Purdue University, *unpublished data*). Field cockroach populations often have multiple food sources and hence, elimination by boric acid gel bait will be very challenging.

Liquid Bait Formulation

Liquid boric acid baits are used for controlling urban ant pests such as Argentine ant, black carpenter ant, Florida carpenter ant, odorous house ant, red imported fire ant, and pharaoh ant (*42-46*). Strong et al. (*39*) showed water based liquid bait containing boric acid or disodium octaborate tetrahydrate was not repellent to German cockroaches. They cause mortality and alter cockroach behavior. However, no liquid boric acid baits are currently available for managing cockroach infestations.

Laboratory assays showed that boric acid was more effective than sodium tetraborate or disodium octaborate tetrahydrate at controlling cockroaches (*47*). Aqueous solutions containing mixtures of 0.5-2% boric acid and any of several inexpensive sugars, including fructose, glucose, maltose, and sucrose as a phagostimulant, at 0.05-1% molar concentrations were effective in controlling field German cockroach populations. A boric acid-based sugar water solution was tested for managing German cockroaches in swine farms (*48*). Bait consisting of 1 or 2% of boric acid and 0.5 M sucrose provided effective population reductions. Cockroach populations were reduced by > 90% within 1-2 months and the populations were maintained below threshold levels. Liquid boric acid bait has not been tested in other commercial facilities or residential structures, Challenges remain in developing a convenient delivery method.

Diatomaceous Earth

Diatomaceous earth (DE) is primarily used to manage stored grain pests (*49*). The mode of action of DE is generally accepted as a desiccation effect on insects. Similar to boric acid materials, DE has very low mammalian toxicity. Nevertheless, health risks of newly developed DE formulations are unclear.

DE deposits are repellent to German cockroaches. There are no reports of population elimination by DE application. This is probably due to the lack of effectiveness in high humidity environment and repellency.

Faulde et al. (*50*) reported the following factors are related to the effectiveness of DE: oil-carrying capacity, humidity, and origin of the DE. The oil-carrying capacity is positively correlated with DE's efficacy against German cockroaches. High humidity decreases the effectiveness of DE. DE formulations based on freshwater diatoms are more effective when compared with those including marine diatoms. Adding hydrophobic silanes can compensate the loss of toxicity at high humidity (> 80% relative humidity) and achieve complete eradication of test populations in simulated field conditions. Further studies on effectiveness and health risks of hydrophobic DE formulations are needed to manage German cockroaches.

Biopesticides

Biopesticides are certain types of pesticides derived from animals, plants, bacteria, and certain minerals. Biopesticides fall into three major classes: microbial pesticides (consist of a microorganism as active ingredient), plant incorporated protectants, and biochemical pesticides. Much of the research related to cockroach management has been on essential oils and fungal pathogens.

Essential Oils

Many essential oils and plant extracts have repellent activity against German cockroaches (*51-54*). They may be useful in protecting sensitive areas and equipment from cockroach infestations.

The volatile components of essential oils can be classified into four main groups: terpenes, benzene derivatives, hydrocarbons, and other miscellaneous compounds (*55*). Essential oils are used in fragrance and flavor industries for producing food flavorings, cosmetics, and detergents. Ngoh et al. (*56*) tested the insecticidal and repellent properties of nine volatile constituents of essential oils against the American cockroach, *Periplaneta americana* (L.). They found the benzene derivatives were more toxic and repellent than terpenes. The LC_{95} (concentration at which 95% of the population is killed) values of eugenol, methyl-eugenol, safrole, and isosafrole were between 0.33-0.46 (mg/cm^2). The KD_{50} (24 h) (concentration at which 50% of the population is knocked down) values were between 0.23-0.49 (mg/cm^2). Safrole was the most effective repellent among the nine tested compounds.

Fungi

Metarhizium anisopliae (Metschnikoff) Sorokin is a well known entomopathogen used for controlling hundreds of insect pests (*57*). Kaakeh et al. (*58*) reported > 90% mortality with *M. anisopliae* strain ESC-1 in controlling German cockroaches by contact method. The same strain induced 50-57% mortality by topical application at a concentration of 4.18×10^8 spores/ml (*59*).

M. anisopliae needs at least three weeks to induce 90% cockroach mortality, which is a serious drawback for its use as a control agent for German cockroaches.

One product, Bio-Path, was registered by the U.S. Environmental Protection Agency for cockroach control in 1993 (EcoScience Corporation, Worcester, MA, U.S.A.). Lack of field efficacy and slow control led to its discontinuation (*60*). Subsequent studies focused on combinations of *M. anisopliae* and chemicals to improve the field efficacy. Kaakeh et al. (*61*) found *M. anisopliae* and an imidacloprid bait had a synergistic effect against the German cockroach. Sublethal doses of chlorpyrifos and cyfluthrin and propetamphos enhanced the effect of *M. anisopliae* in laboratory experiments (*59*). However, in vitro studies indicated adverse effect of chlorpyrifos, propetamphos, and cyfluthrin on the growth and sporulation of *M. anisopliae* (*60*). Zurek et al. (*62*) demonstrated 12.5% boric acid dust or 0.1% (w/v) boric acid in drinking water had synergistic effect to *M. anisopliae*. Boric acid enhances the pathogenic activity of the fungus and not vice versa. The mechanism was suggested as physicochemical or immunologically based.

Ascomycetous fungi in the order Laboulbeniales are known as ectoparasites of millipedes, mites, and insects (*63, 64*). The order contains nearly 2,000 described species worldwide. Among these, about 25 species in the genus *Herpomyces* are parasites of cockroaches (*65, 66*). Infected German cockroaches have shortened and curled antennal flagella, uneven wings, darkened and flaccid cadavers, and putrefied odor. Symptoms develop after 20 days and death occurs within 30 days. There is no field data demonstrating Ascomycetous fungi as an effective biological control agent against German cockroach populations.

Pheromones

Cockroach fecal materials contain aggregation pheromones, which are attractive to German cockroaches (*67, 68*). Crude extract from feces and a mixture of six carboxylic acids are very effective attractants to German cockroaches in laboratory assays (*69*). Cockroach fecal extract can increase food consumption (*70*), efficacy of toxic baits (*71*), and trap catches (*72*). At least one glue trap product contains cockroach pheromones extracted from cockroach feces (Woodstream Corporation, Lititz, PA, U.S.A.). Laboratory studies showed aggregation pheromones can significantly increase trap efficacy (*73*).

Other Organic Non-neurotoxins

Steltenkemp (*74*) described N-monosubstituted neoalkanamides of 11 to 14 carbon atoms for repelling cockroaches, including American, German and Oriental cockroaches. This group of chemicals is also effective against mosquitoes (both *Anopheles* and *Aedes*), black flies and carpenter ants, and to

some extent against deer ticks. High levels of repellency to German and American cockroaches by alkyl and aryl neoalkanamides were reported (*75*). These compounds may be useful for repelling cockroaches and preventing cockroach infestations.

Insect Growth Regulators

Insect growth regulators (IGRs) are a group of compounds that disrupt the natural growth and development of insects. IGRs are selective to insect pests and have less effect on other animals than conventional insecticides. IGRs are a desirable alternative for managing German cockroaches because this insect has a relative short life cycle and high reproductive potential. Currently, only juvenile hormone mimics have been registered for control of the German cockroach. They cause sterility of adult cockroaches. Two commonly used IGRs are hydroprene and methoprene. Juvenoid IGRs applied alone provide relatively slow population control against German cockroach and are typically recommended for use with a companion conventional insecticide (*76*).

Another potential group of IGRs for cockroach management is the chitin synthesis inhibitors (CSIs). Flufenoxuron, lufenuron, and noviflumuron are some of the CSIs which have strong population effects against the German cockroach (*77-81*). These chemicals act much faster than juvenoids. CSIs cause mortality of nymphs during molting and adult sterility. Lufenuron sprays caused complete mortality of German cockroach populations after 12 months in simulated domestic environments (*78*). Flufenoxuron wettable powder formulation achieved > 80% population control in multifamily apartments within 8 wk of treatment (*77*). Noviflumuron gel bait caused 95.0% and 97.1% median trap count reduction after 8 and 20 weeks, respectively (Wang and Bennett, Purdue University, *unpublished data*). However, CSIs are not commercially available for cockroach management. The availability of a wide variety of other effective and fast-acting products might have contributed to the lack of interests in developing CSI-based cockroach control products.

Integrated Pest Management

Integrated pest management, or IPM, is a sustainable approach to managing pests by combining biological, cultural, physical, and chemical tools in a way that minimizes economic, health, and environmental risks (*definition from the National IPM Network*). The goal of urban IPM programs is to manage pests by the most economical means, and with the least possible hazard to people, property, and the environment. IPM has gained increased attention in rural and urban settings in recent years. Various residential IPM programs are proposed. In general, they include the following four groups of elements: periodic monitoring, education of property management staff and residents, non-chemical methods (cleaning, reducing clutter, reducing harborages and pest entry points, vacuuming, trapping), and selective use of chemical methods (boric acid, baits,

etc.). Interviews with residents and staff, visual inspection, and laying monitoring traps are used during periodic monitoring to understand the pest infestation levels and environmental conditions that contributing to the pest infestations. Staff and resident education includes topics such as cockroach prevention, proper housekeeping, modification of the environment, and record-keeping. Non-chemical methods are used to prevent infestations and eliminate the existing infestations. Heavy cockroach infestations often need chemical tools such as dust or bait to supplement the non-chemical tools. Robinson and Zungoli (*82*) discussed model cockroach IPM programs in various settings.

Kramer et al. (*83*) compared four treatment strategies in apartments. A combination of baiting, cleaning, and education resulted in more rapid reduction in cockroach numbers than baiting alone.

Brenner et al. (*84*) evaluated the effectiveness of an IPM program in East Harlem, New York City, NY. The IPM treatment included education of residents on housekeeping, repairs by a project handyman, fixing plumbing leaks, and providing cockroach bait stations and gel baits to residents. The control group did not receive these treatments. Sticky traps were laid to monitor cockroach infestations. The proportion of intervention households with cockroaches declined from 81 to 39% after six months. By contrast, the control households showed no reduction (from 78 to 81%).

Miller and Meek (*85*) compared the cost and efficacy IPM and insecticide sprays for managing cockroaches in low-income housing. The average cost of IPM was three times of the spray treatment. However, IPM caused 84% cockroach population reduction within four months. The population levels in the spray treatment remained steady for the first five months and increased afterwards during the summer.

Williams et al. (*86*) compared IPM with conventional calendar-based pest control in schools for 12 months. The IPM included initial vacuuming and monthly use of baits and IGR device. The two treatment strategies incurred similar total costs and the efficacy of both treatments was similar. IPM treatment indicated most of the conventional treatments were unnecessary.

Wang and Bennett (*87*) compared IPM and baiting alone for managing German cockroaches in low-income apartments. The IPM treatment included education, vacuuming, trapping, and placing gel baits. The baiting treatment only used gel bait. After 8 months, IPM and baiting resulted in 100 and 95% reduction in trap counts, respectively. The cumulative cost of IPM was $64.5 and $35 per apartment, respectively. IPM treatment resulted in significant improvement in sanitatary conditions of the apartments.

Although the above experimental IPM programs showed various advantages over the chemical-only method, voluntary IPM adoption is very limited. The initial high cost and the need for involvement of multiple parties in education, coordination, and record keeping make it less appealing to property management staff. When selecting a pest control contractor, property managers are compelled to select the lowest bid. Pest management companies often offer low-bids in order to obtain a contract, and the low-bid practice often does not provide effective pest infestation reduction and long-term control.

Conclusion

Sanitation, trapping, vacuuming, dusting, and insect growth regulators are effective tools for reducing/eliminating German cockroach infestations with no or minimum environmental contamination. A combination of several methods should be considered for effective control of cockroach infestations. Using IPM strategies will greatly reduce the insecticide use, improve long-term effectiveness, and reduce cockroach allergens levels.

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