

## Overview on Controlling the American Cockroaches (*Periplaneta americana*)

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### ABSTRACT

The project is based on the latest achievement of controlling the American cockroaches (*Periplaneta americana* L.). They are notorious pests, found everywhere and one of the largest common cockroach species. Today, many insecticides were used to control their different stages by different bioassays. Moreover, used insecticides can be conventional and non-conventional and both can be used against different stages of *Periplaneta americana*. A large number of studies have shown that controlling *Periplaneta americana* has complex resistance mechanisms and decreased the sensitivity of the insecticide. However, no effective insecticide and bioassay have yet been developed. This article reviews current knowledge of using a different insecticide against different stages of *Periplaneta americana*.

### 1. *P.americana* classification

American cockroach belongs to Kingdom: Animalia, Phylum: Arthropoda, Class: Insecta, order: Dictyoptera, Suborder: Blattodea, Family: Blattidae, Genus: Periplaneta, Species: *P.americana* [1]. *P.americana* is the largest of the common peridomestic [2]. This cockroach is readily found in commercial and large buildings such as restaurants, grocery stores, bakeries and anywhere food is prepared and stored. They can produce enormously [3]. Mass migrations of *P.americana* are common [4].

*P.americana* make their ways to houses from drainages pipes via the plumbing, and from trees and shrubs located alongside buildings or with branches overhanging roofs. During the day, the *P.americana*, which response negatively to light, rests in harborages close to water pipes, sinks, baths, and toilets where the microclimate is suitable for survival [5]. They feed on a variety of foods, with a preference for starchy and sugary material, also on book bindings, sizing, inner linings of shoe soles and dead insects. They have remained on their legs and bodies and may spread germs and contaminate food. Cockroaches also give off an offensive odor that may ruin food or may persist on dishes or other items that roaches walk across [6].

### 2. Association of cockroaches with human pathogens

Numerous pathogenic microbes are adhering with cockroaches, including viruses, bacteria, fungi, protozoa and helminthes. These organisms have often been isolated from field-collected cockroaches [7]. *P. americana* has filthy habits with an ability to spoil food, transfer pathogens and cause allergic reactions and psychological distress [8]. The distribution of bacteria, fungi and parasites in cockroaches could differ from one location to the other based on both environmental and sanitary conditions which could be used to assess the likely infectious diseases that pose a great risk as we consider the capacity of cockroaches in spreading diseases in a complementary manner [9]. More than 100 bacterial species have been isolated from domestic cockroaches [10], some could be potential mechanical transmitters of pathogenic

bacteria [11]. More than 40 pathogenic and nonpathogenic bacterial species have been isolated from cockroaches. About 70 Gram-positive species and 37 Gram-negative bacterial species were isolated from the surface and fecal pellets. These including: *Actinomyces randingae*, *Alcaligenes faecalis*, *Arthrobacter cumminnsii*, *Aureus bacterium* spp., *Bacillus* spp., *Brevibacterium* spp., *Burkholderia vietnamiensis*, *Buttiauxella* sp., *Citrobacter* sp., *Corynebacterium* spp., *Enterobacter* spp., *Erwinia* sp., *Escherichia coli*, *Hafnia* sp., *Kigali* sp., *Klebsiella* spp., *Kluyvera* sp., *Kauri rosea*, *Leuconostoc* sp., *Micro bacterium* spp., *Micrococcus* sp., *Proteus* spp., *Providencia ruttier*, *Pseudomonas* spp., *Rhodococcus australis*, *Rhodococcus rhodochrous*, *Salmonella typhimurium*, *Serratia* spp., *Shigella* sp., *Spingobacterium thalpopphilum*, *Staphylococcus* spp., *Stenotrophomonas macrophillia*, *Streptococcus* sp., *Tsukamurella inchonensis*, *Vibrio metschnikovii*, *Xanthomonas* spp., *Entamoeba histolytica*, *Escherichia coli*, *Klebsiella pneumoniae*, *Mycobacterium leprae*, *Shigella dysenteriae*, *Salmonella* spp., *Serratia* spp. and *Staphylococcus aureus* [12].

Many parasites were isolated from cockroaches such as cysts of *Entamoeba histolytica*, oocysts of *Cryptosporidium parvum*, *Cyclospora cayetanensis* and *Iso spora belli*, cysts of *Balantidium coli*, ova of *Ascaris lumbricoides*, *Anchylostoma deodunale*, *Enterobius vermicularis*, ovae *Trichuris trichura* and larvae of *Strongyloides stercoralis*. In addition, several bacteria were isolated from cockroaches such as *Escherichia coli*, *Klebsiella pneumoniae*, *Proteus vulgaris*, *Proteus mirabilis*, *Citrobacter freundii*, *Enterobacter cloacae*, *Salmonella* sp, *Pseudomonas aeruginosa*, *Serratia marcescens*, *Staphylococcus aureus*, *Streptococcus faecalis*, *Streptococcus epidermidis*, *Aeromonas* sp, *Candida* sp, *Rhizopus* sp, *Aspergillus* sp and *Mucor* [13].

Fungal infections have been associated with both the external body parts and feces of cockroaches including *Candida* spp., *Rhodotrula* spp., *Aspergillus* spp., *Fusarium* spp., *Penicillium* spp. and *Geotrichum* spp. that appeared on external surfaces of cockroaches. Another medically important

mold, *Alternaria* spp., *Cladosporium* spp., *Trichoderma* spp., *Mucor* spp. and *Chrysosporium* spp. were rarely isolated from a few cockroaches, *C. glabrata* and *C. albicans* were the highest species isolated from cockroaches. *C. parapsilosis* and *C. guilliermondii* were found on the external surfaces in a few cockroaches. Also, three species of *Aspergillus* were identified. *A.niger* was the most species that was isolated from cockroaches. *A. fumigatus* and *A. flavus* were found on the external surface in a few ones. A total of six samples were found to carry two species of *Aspergillus* on their external surfaces [14].

Helminthes have also been reported in cockroaches collected from different areas [15], is widely implicated as reservoir hosts of medically important parasites [16]. Pathogenic helminthes included *Strongyloides stercoralis*, *Ascaris lumbricoides*, *Trichuris trichiura* and *Taenia* spp. [17]. The cockroaches are also implicated in the spread of at least some pathogens like hepatitis [18].

Protozoa types that were identified from cockroaches included *Cyclospora* spp., *Endolimax nana*, *Blastocystis hominis*, *Isospora belli*, *Entamoeba histolytica*, *Cryptosporidium* spp., *Chilomastix mesnilli*, *Entamoeba coli*, *Balantidium coli* and *Iodamoeba butschlii* [17].

### 3. Economic and medical importance of cockroaches

Since World War 2, many studies have been done to investigate the transmission of infectious agents from cockroaches to humans [19]. Cockroaches play an important role in transmitting different diseases and they have been recognized as mechanical vectors of pathogens that can infect humans or animals [20]. Several studies have shown that cockroaches can carry disease-causing microorganisms [21]. Cockroaches may disseminate these microorganisms in many ways, predominantly by depositing them along with their excrement on human food [22]. Some of the bacterial isolates are known to be pathogenic (*Salmonella*, *Shigella*, *Bacillus cereus*) while others are either opportunistic pathogens (*Pseudomonas*, *Klebsiella*, *Vibrio*) or play roles in food spoilage (*Pseudomonas*, *Enterobacter*, *Escherichia*, *Erwinia*). Species belonging to these groups of bacteria have also been confirmed to be cockroach-borne previously [23].

Some parasites have been found in external surface or internal parts of the body of cockroaches and some studies have shown that exposure to cockroach antigens may play an important role in asthma-related health problems [24, 25]. Six genera of parasites were identified including *Ascaris*, *Trichuris*, *Capillaria*, *Toxocara*, *Hook Worm* and *Eimeria* were more recorded on the external surface of cockroaches than on the internal surface. The same tendency was obtained between sexes with female cockroaches having a higher transport rate. Cockroaches caught in toilets carried more parasites as compared to those from kitchens and houses. Almost all encountered parasites were recognized as responsible of zoonosis and they can be consequently released in nature by hosts and easily disseminated by cockroaches as mechanical vectors [20].

A cockroach can also producer's allergic reactions in sensitive people. Allergy is also known as hypersensitivity. It occurs because the immune system sometimes recognizes harmless antigens as harmful and then overreacts to them [8]. Allergy is one of the most widespread and common chronic concerns. In the worst situations, it may put people's lives at risk. *B. germanica* carry multiple allergens, some of which are specific to *B. germanica*, while others are cross reactive with allergens from other cockroach species. Frequent contact with cockroaches will lead to a higher rate of allergy. Higher contact rate with cockroaches is often associated with low socioeconomic status. Efforts to reduce exposure to cockroach allergens should be included in the management of cockroach-allergic asthma. A combination of IPM methods, chemical controls, and respiratory protection may achieve this purpose. In addition to asthma, other allergic reactions attributed to contact with cockroach body parts, secretions, dry feces, and exuviae include coughing and skin rash [26].

### 4. *P. americana* life cycle

Cockroaches undergo an incomplete metamorphosis that consists of three stages: egg, nymph (immature) and adult stages. *P.americana* was identified according to their morphological characteristics using standard taxonomic keys [27]. Identification keys are provided for male, female and nymphal stages for *P.americana*. Following are some illustration photographs with brief comments that help fast identification and make it an interested reader.

The adults grow to a length of approximately 35-50mm and a height of 7mm. They possess a reddish-brown color, except the margin of the pronotum shield which is yellowish. The body is typically oval in shape and flattened. Adult male and female have wings and the hind wings are delicate, used for flight and attached to the metathorax. The wings of the male cockroach extend 4-6 mm over the tip of the abdomen [28].

The body of the cockroach has three sections; the head, thorax, and abdomen. The head has mouthparts for chewing, antennae that are long and segmented and one pair of large compound eyes. The thorax is divided into three segments, prothorax, mesothorax and metathorax and each segment has a pair of legs [29]. Both have a pair of cerci, finger-like appendages, at the tips of their abdomens, which are jointed and slender and are possessed by both male and female cockroaches. The cerci are used to detect air movement in the cockroach's surroundings. Male cockroaches have an additional set of appendages called styli on their abdomens. The styli are located between the cerci of the male and absent in the female but are smaller and more delicate and are the easiest way to distinguish male from female cockroaches [30].

The female produces multiple sex pheromones, these may include chemicals such as hexanoic-acid, phenol, periplanone A and B and many others. These appealing chemicals draw in males for mating. The transfer of sperm takes place through the use of membranous sacs of sperm (spermatophores). The female then forms an egg sac (ootheca) once the process of fertilization is completed [5]. The female glues or drops the ootheca within 4 days of forming. A female produces 15 to

90 oothecae in her lifetime and each ootheca contains 14 to 16 eggs. Average development time from egg to adult is 600 days and they can live up to 786 days depending upon temperature and humidity. The nymphal stage begins when the egg hatches and ends with the emergence of the adult. The number of *P.americana* molts varies from six to fourteen. The first instar is white immediately after hatching then becomes a grayish brown [5, 2]. After molting, subsequent instars of the cockroach nymphs are white and then turn radish brown. Wings are not present in the nymphal stages and wing pads become noticeable in the third or fourth instar. The nymphal stage varies in length from 160 to 971 days [31].

The oothecae or egg cases are laid in capsules that are dark brown, symmetrically shaped, and about 5/16-inch long. The female drops her egg capsule in a suitable location near a food source or in a protected area [5]. Each capsule average 14 to 16 eggs. Usually, one capsule is produced each week and is often glued to a hidden surface with secretions from the female's mouth. Each female produces from 15 to 90 egg capsules. The length of the egg stage varies from 29 to 58 days at room temperature [31, 32].

## 5. Management measures and resistance

While cockroach infestations can have adverse health effects on humans, the measures used to control the infestation may also result in additional health risks. Treatment of infestations may inappropriately include insecticidal spraying of baseboards resulting in unnecessary pesticide exposure. Cockroaches are nocturnal and prefer to inhabit small cracks and crevices of structures. Inappropriate and unnecessary applications of insecticides often result in insecticide resistance [33]. Resistance to organophosphates and carbamates was first documented in the 1950s and 1960s and cockroaches, mainly *B.germanica* have demonstrated some form of resistance to most insecticide classes, used against them since [34] because cockroaches have developed resistance to several insecticide classes, many pest management professionals utilize a chemical rotation system to manage the resistance. In this system, chemicals are rotated by class and in addition, suitable mixtures of chemicals are used [34]. Cockroaches have yet to develop resistance to insect growth regulators and some of the traditional cockroach controls including the slow acting inorganic insecticides such as boric acid and diatomaceous earth. Cockroaches are, however, resistant to many of the plant-derived botanical insecticides such as pyrethrum and the synthetic pyrethroids [35]. Cockroaches are also demonstrating resistance to fipronil [36]. Fipronil was introduced as a cockroach bait in 1999, so the resistance is likely a cross-resistance in cockroach strains resistant to cyclodienes which have a similar mode of action [36].

Since the 1980s, targeted applications of pesticides in a bait formulation have been used to reduce pesticide application and combat pesticide resistance. Bait formulations to manage cockroaches is a preferred form of pest control because the bait is placed in enclosed stations or targeted in crack and crevice areas minimizing exposure. Since most bait formulations are not aerosolized, the adverse health effects associated with spray applications of pesticide are also

reduced. Abamectin, fipronil, imidacloprid, hydramethylnon, and sulfluramid are each available in cockroach bait formulations [37]. Since baiting has become the predominant form of cockroach control, the phenomenon of behavioral aversion to the bait formulation has been documented [38]. This resistance is different from the metabolic resistance where the insect detoxifies the chemical. The resistance lies in the behavior of the cockroach that reduces its exposure to a toxic substance. The cockroach is averse to feeding on the bait matrix, usually containing glucose, thus the toxicant is not or is sparingly ingested, resulting in low to no mortality [35].

## 6. Susceptibility to insecticides to different stages of cockroaches

### 1- Non-conventional insecticides

#### 1.1 Commercial bacteria

Entomopathogens have been suggested as controlling agents of insect pests for over a century, and belong to species of fungi, viruses, bacteria, and protozoa. Insect pest control refers to the regulation or management of a species defined as a pest. Many studies have been done against different insects. [39], said that about 15 biopesticide products are registered or pending registration for commercial use on various crops. Products based on *Bt* subsp. *kurstaki* are most widely sold for lepidopteran pest control, followed by *Bt* subsp. *israelensis* against dipteran pests in vector control programs. [40], identified 100 bacteria and he found that only a few were used commercially in pest management system including, *Bacillus popilliae*, *B. sphaericus*, *B. thuringiensis*, *Clostridium bifermentans*, *Pseudomonas alcaligenes*, *Pseudomonas aureofaciens*, *Saccharopolyspora spinosa*, *Serratia entomophila* and *Streptomyces avermitilis* were considered to be the major stock holders, and two bacterial candidates; spore-forming soil bacterium *B. thuringiensis* and non-spore-forming *S. entomophila* gain more popularity as a pest control agents. [41], mentioned that biological pesticides pose less threat to the environment and to human health. The most commonly used biological pesticides are living organisms, which are pathogenic for the pest of interest. These include bioinsecticides *Bt*. the potential benefits to agriculture and public health programmers through the use of biological pesticides are considerable. The development of commercial bacterial insecticides in the middle of the century that became the first successful and widely used microbial control agents. Most of these products were based on *Bt*, a bacterium that kills insects through the use of insecticidal proteins that subsequently became known as Cry proteins. While most of these products were only effective against lepidopteran pests [42]. [43], discovered that the commercial *Bt* products are powders containing a mixture of dried spores and toxin crystals. They are applied to leaves or other environments where the insect larvae feed. The toxin genes have also been genetically engineered into several crop plants. The method of use, mode of action, and host range of this biological control agent may differ within other *Bacillus* insecticidal species. [44], mentioned that the use of microbial insecticides is growing at a rapid pace of 10-25% per year compared with chemical insecticides at 1-2% per year. *Bt* Berliner is primarily responsible for this growth. Scientists [45], observed that in most countries of the world, products are available for control of caterpillars (var. *kurstaki*, *entomocidus*, *galleriae* and

*aizawai*), mosquito and blackfly larvae (var. *israelensis*) and beetle larvae (var. *tenebrionis*). Actively growing cells lack the crystalline inclusions and thus are not toxic to insects. The *Bt* preparations remain stable without any disintegration over years even in the presence of UV sun rays. As the insect feeds on the foliage, the crystals also are eaten up. These are hydrolyzed in the insect's midgut to produce an active endotoxin. The active toxin binds to receptor sites on gut epithelial cells and creates an imbalance in the ionic make-up of the cell. This is seen by the swelling and bursting of the cells due to osmotic shock. Subsequent symptoms are paralysis of the insect's mouthparts and gut. So obviously the feeding process is inhibited.

## 1.2 Botanicals

In the search for an eco-friendly pesticide, researchers have considered pesticides of biological origin, and the replacement of chemical pesticides with biological pesticides as a generally accepted one [46]. Plant-derived products have received increased attention and more than two thousand plant species are already known to have insecticidal properties (Sukumar *et al.*, 1991). Botanical derivatives have drawn attention as potential insect control agents and as a source of new pesticides for the insecticide industry in the last three decades [46]. Essential oils are an excellent alternative to traditional insecticides because of their low toxicity to wildlife [47]. Since they have low persistence, essential oils could be toxic to non-target insects initially; however, after a few days, insects that come in contact with the treated environment would not be affected as they would be with traditional insecticides [47]. [48], mentioned that the use of plant compounds (essential oils, flavonoids, alkaloids, glycosides, esters and fatty acids) were having anti-insect effects and their importance as an alternative to the chemical compounds used in the elimination of insects in different ways, namely repellents, feeding deterrents/antifeedants, toxicants, growth retardants, chemosterilants and attractants and they recommend using botanical insecticides as an integrated insect management program which can greatly reduce the use of synthetic insecticides. [49], evaluated five essential oils including, *Eucalyptus* sp (Eucalyptus oil), *Mentha Piperita* (Mint oil), *Achillea millefolium* (Yarrow oil), *Origanum vulgare* (Oregano oil) and *Rosmarinus officinalis* (Rosemary oil) against the 3<sup>rd</sup> and 4<sup>th</sup> instar nymphs using three bioassay methods; continuous contact toxicity, fumigant toxicity and repellent activity. The study showed that mortality rates by the lowest concentration (2.5%) of rosemary, oregano, yarrow, eucalyptus and mint oils were 100%, 62.2%, 45 %, 36.2% and 5.2% at 24 h. after exposure respectively. Rosemary oil was determined as the most toxic oil because of the 100 % mortality rate at the concentration range of 2.5% to 30%. The lowest fumigation effect using 50 µl/L air was recorded from mint oil with 97.2 % mortality after 24 h., while the other oils caused 100% mortality. The most repell activity was related to oregano oil which showed 96.5–99.1% repellency in the concentration range of 2.5–30% with a residual effect lasting at least a week after treatment. [50], studied the insecticidal activity of extracted *Agarista salicifolia* (gaggassa) plant leaves against cockroach and results suggested that extracts plant leaves showed the highest insecticidal effects on a cockroach. Considering the side effect of chemical insecticides on human

health, it is suggested that the use of organic insecticides should be encouraged to ameliorate health problems since it is eco-friendly in nature. [51], evaluated the efficiency of various plant powders of Neem, Tulsi, Adathoda, Turmeric, lantana etc., owing to its insecticidal properties. Studies were carried out on the repellency of the plant powders of six botanicals on *P. americana*. The tested plants include *Azadirachta indica*, *Curcuma longa*, *Lantana camara*, *Vitex negundo*, *Adhatoda vasica*, *Ocimum tenuiflorum*. Repellency of insect was monitored and recorded on 1, 6 and 24 h., duration and by statistically calculating mean, excess proportion index (EPI) and percentage of repellency. All the experimented six plants showed maximum repellency and high EPI value in the highest dose. [52], conducted that surface contact toxicity of clove (*Syzygium aromaticum*) and rosemary (*Rosmarinus officinalis*) oils were investigated against *P.americana*, in the laboratory. Both clove and rosemary oils showed variable mortality percentages according to concentration, exposure time and stage of the insect. Clove oil exhibited stronger toxic effects than rosemary oil. First instar nymphs were more sensitive than the fourth instars followed by adults. Clove oil induced highly significant contact toxic effects against *P. americana* nymphs and adults after 4, 24 and 48 h. exposure. First and fourth instar nymphs were more sensitive to clove oil (LC<sub>50</sub> values of 0.0001 and 0.0077 µl/cm<sup>2</sup>, respectively) than rosemary oil (LC<sub>50</sub> values of 1.92 and 2.25 µl/cm<sup>2</sup>) after 24 h, respectively. Regarding adults, the effect of both oils was very weak after 48 h. of exposure. Adults of *P. americana* were the least sensitive to clove and rosemary oils, recording LC<sub>50</sub> values 1.5375 and 6.09 µl/cm<sup>2</sup>, respectively. In continuous exposure tests, LT<sub>50</sub> values correlated negatively with concentrations. Clove oil had lower LT<sub>50</sub> values than rosemary oil. For clove oil the lowest LT<sub>50</sub> values ranged between 14.10 and 4.85 h. in case of the first instar at a low concentration level of 0.0005–0.0020 µl/cm<sup>2</sup> and 20.00 to 5.00 h for adults at a high concentration level of 2.0–3.0 µl/cm<sup>2</sup>. While the LT<sub>50</sub> was high for the fourth instar nymphs and ranged from 43.67 to 26.68 h. at moderate concentrations, 0.002–0.010 µl/cm<sup>2</sup>, respectively. For rosemary oil, the highest LT<sub>50</sub> values were 115.03-97.00 h. for adults followed by 32.76-8.86 h. for the fourth instar nymphs and 25.45-5.62 h. for first instars at the same concentrations level, 2–4 µl/cm<sup>2</sup>, respectively. [53], showed the toxicity and bioefficacy of an extract of *Cassia fistula*, *Datura alba* and commercial product neemarin (0.15%) was reported against adult *P. americana*. Lui *et al.*, 2011 discovered that eight essential oils of Chinese medicinal herbs were analyzed and among those *Cyperus rotundus*, *Eucalyptus robusta*, and *Ocimum basilicum* had strong repellent activity against *B. germanica*. [54], studied the toxicity of 12 essential oil components carvacrol, 1,8-cineole, trans-cinnamaldehyde, citronellic acid, eugenol, geraniol, S-(-)-limonene, (-)-linalool, (-)-menthone, (+)-α-pinene, (-)-β-pinene, and thymol to adult male, adult female, gravid female, large, medium, and small nymphs of *B.germanica*, was determined. Thymol was the most toxic essential oil component to adult males, gravid females and medium nymphs, with LD<sub>50</sub> values of 0.07, 0.12, and 0.06 mg per cockroach, respectively. Trans-Cinnamaldehyde was the most toxic essential oil component to adult females, large nymphs and small nymphs, with LD<sub>50</sub> values of 0.19, 0.12 and 0.04 mg per cockroach, respectively, (+)-α-Pinene was the least toxic essential oil

component to all stages of *B. germanica*. The most frequently occurring susceptibility ranking for the stages was small nymphs > medium nymphs > adult males > large nymphs > gravid females > adult females. Adult females were the least susceptible to the essential oils, so they will be the determining factor when considering a rate for field application. Toxicity was positively correlated with essential oil component density and boiling point. [55], showed that a study on seven commercial essential oils for repellency against cockroaches was done and he found that *Citrus hystix* exhibited complete repellency against *P. americana* and *B. germanica*. When *P. americana* was treated with *azadirachtin* (extracted from neem seeds) the activity of their midgut enzyme was reduced and their growth inhibited [56].

### 1.3 Isolated bacteria

[57], evaluated the toxicity of *Beauveria bassiana* and *Lecanicillium muscarium* against *B. germanica* and the results indicated that both fungi species were toxic against *B. germanica* and *B. bassiana* was significantly 4.8fold more toxic than *L. muscarium* against *B. germanica* using submersion method. [58], mentioned that a small number of entomopathogenic bacteria have been commercially developed for control of insect pests. These include several *Bt* sub-species, *Lysinibacillus sphaericus*, *Paenibacillus* spp. and *Serratia entomophila*. *Bt* sub-species *kurstaki* is the most widely used for control of pest insects of crops and forests and *Bt* sub-species *israelensis* and *L. sphaericus* are the primary pathogens used for control of medically important pests. *Bt* toxins are a selective and negative environmental impact is very limited. Of the several commercially produced, *Bt* has more than 50% of market share. [59], have evaluated the efficacy of *Metarhizium anisopliae* in combination with sublethal doses of some insecticides against *P. americana*. They concluded that combined use of insecticides and fungus enhanced the lethal effect of *M. anisopliae*. [60], suggested that application of a powdery formulation of *M. anisopliae* to provide a contaminated surface to control *B. germanica* may be more effective than using bait. [61], studied that the insect pathogens particularly bacteria and entomopathogenic fungi such as *Beauveria bassiana* have a long history in biological control of various pests. [62], mentioned that four genera of fungi including *Metarhizium*, *Paecilomyces*, *Verticillium* and *Aspergillus* have been reported as potential agents for biological control of cockroaches. [63], investigated that toxins of *Bt* var. *israelensis* were used to control cockroaches. [64], reported that species of bacteria could be an effective agent in controlling these cockroaches and also reported that isolated of *Bt* was shown to induce cockroach mortality.

### 1.4 Natural products

[65], investigated the effect of boric acid on a cockroach in terms of oxidative stress. Different anti-oxidants: catalase (CAT), glutathione peroxidase (GPx), super-oxide dismutase (SOD) as well as lipid peroxidation (LPO) levels, were estimated upon boric acid treatment to the cockroach, using standard methods. In addition, acetyl-choline esterase activity was also measured in boric acid treated cockroach. Values obtained were compared with untreated control cockroaches and t-test was applied to analyze the statistical significance of results. Our results revealed that boric acid treated *P.*

*americana* showed significantly increased SOD activity as well as LPO levels, significantly decreased CAT, GPx, and GSH compared to controls ( $p < 0.05$ ) was obtained, suggesting increased oxidative stress over boric acid treatment. Boric acid exposure also resulted in a decrease in AchE activities. [66], found that various formulations of the inorganic insecticides boric acid have been used to control cockroaches and other insects since the middle of the 19<sup>th</sup> century. [67], found that boric acid provokes an inhibition of the oogenesis, with a reduction of the oocyte number at day 2 only for the lower dose and at days 2 and 4 for the higher dose. A reduction of the volume of basal oocytes was observed for all the tested doses. [68], showed that boric acid reduced the number of oocytes per paired ovaries and the size of basal oocytes. Furthermore, the compound was examined on ovarian contents of proteins, lipids and carbohydrates. Results from biochemical analyses revealed a significant reduction of ovarian constituents with the two tested doses. Finally, the quantity of boric acid really incorporated into the body was determined for the two tested doses (LC<sub>50</sub> and LC<sub>90</sub>) during the first six days of the adult life. The amounts of residues incorporated into the body increased as a function the doses and the period of treatment. The mode of action of boric acid against insects is unknown, although destruction of the digestive tract wall and penetration of the exoskeleton have been reported, also, has been the subject of many research and several modes of action have been proposed such as abrasion of the cuticle, the neurotoxic action or disruption of the midgut [69]. [70], evaluated the effectiveness of borate solutions as baits against *B. germanica*. Several borate-sugar combinations were evaluated in choice and no-choice assays in the laboratory y were recorded for 15 d and expressed as LT<sub>90</sub> and the results showed that boric acid was more effective than borax. 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 molar concentrations of 0.05-1.0, can provide rapid and effective kill of *B. germanica*. [71], mentioned that boric acid is an inorganic, low-toxicity, non-volatile mineral with insecticidal, fungicidal and herbicidal properties. It has long been embraced as a safer alternative to highly volatile, synthetic chemical pesticides. Boric acid and its sodium salts, all boron-related compounds, generally refer to seven active ingredients, including boric acid, borax, sodium tetraborate pentahydrate (borax pentahydrate), sodium tetraborate (anhydrous borax), disodium octaborate tetrahydrate, disodium octaborate (anhydrous) and sodium metaborate [72]. Boric acid acts as a "stomach poison" for cockroaches and is most commonly used in a bait formulation containing a feeding attractant or as a dry powder. The powder can be injected into cracks and crevices, where it forms a fine layer of dust. Insects travel through the powder, which adheres to their legs. When the insects groom themselves, they ingest the poison, which causes death due to starvation and dehydration 3-10 days later and also abrade the exoskeletons of insects [73]. [33], reported that ingested boric acid destroyed the cellular lining of the foregut of *B. germanica*. This effect appears to be sufficient to bring about the death of the insects, perhaps ultimately by starvation. It has also been established that, in preening themselves following exposure to boric acid power, cockroaches ingest a significant amount of this material. Thus, the gut appears to be a major route of entry of

boric acid into the insect's body. While it had an observable effect on the foregut, boric acid was also present in the blood of the American cockroach, *P.americana*, 5 min after ingestion [74].

### 1.5 Insect growth regulators

[29], described that the Insect Growth Regulators (IGRs) for cockroach control are generally not available for homeowner purchase but are professional-use-only products. These compounds do not kill cockroaches. Instead, they disrupt the normal development of immature cockroaches making them functionally sterile as adults. The cockroach population then dies of attrition. Because of the slow-acting nature of IGRs, they are frequently used in combination with baits for faster control. While IGRs are certainly capable of controlling *P.americana* populations, they are not commonly used for peridomestic cockroach control because the cockroaches are not breeding indoors. However, to treat incipient populations in steam tunnels or boiler rooms. A new approach to insect pest control is the use of substances that adversely affect insect growth and development. These substances are classified as IGRs owing to their effects on certain physiological regulatory processes essential to the normal development of insects or their progeny and they are quite selective in their mode of action and potentially act only on target species [75]. Insect growth regulator (IGR) lufenuron was tested against populations of the Oriental cockroach *B. orientalis* and the *B. germanica* that had been established in simulated domestic environments. The treated populations of *B. germanica* declined rapidly three to four months after the start of bait or spray treatment and were completely eradicated after 12 months. As well as disrupting the molting process, lufenuron affected the reproduction of *B. germanica* by preventing the hatch of the oothecae. In *B. germanica*, it appeared probable that lufenuron was transferred from female cockroaches to the oothecae while they were being carried. By contrast with *B. germanica*, the treated populations of *B. orientalis* did not show any substantial decline compared with the control, even after 18 months exposure to lufenuron bait or spray treatments. Moreover, neither molting nor reproduction in the populations of *B. orientalis* appeared to be affected by either of the lufenuron treatments. Subsequently, laboratory investigations with surface deposits of either technical or formulated lufenuron, applied at dose rates up to 50 mg/m<sup>-2</sup>, failed to demonstrate any significant effects on the development or reproduction of *B. orientalis*. Laboratory tests with first- instar nymphs of both species revealed substantial differences in sensitivity to the molt-disrupting effects of the compound. These differences extended to the adult insects, where reproduction was markedly affected in *B. germanica*, but apparently unaffected in *B. orientalis*. Thus, both bait and spray formulations of lufenuron have been shown to provide rapid and effective control of *B. germanica* populations in simulated domestic environments. However, the same treatments were much less effective against similar populations of the *B. orientalis* [76]. Pyriproxyfen, a pyridyl ether compound, which shows high JHM activity against insects, was evaluated for activities against *B. germanica*. Topical application of pyriproxyfen to last instar female nymphs induced higher inhibition of emergence than that by hydroxyflufenorex. Last instar nymphs were the most sensitive to

pyriproxyfen. A high correlation was observed between the degree of inhibition of emergence of females and the inhibition of reproduction. Topical application or voluntary contact with pyriproxyfen caused the death of younger instar nymphs and supernumerary nymphs. Under laboratory conditions, a population of the *B. germanica* consisting of various nymphal stages and adults was exposed to harborages treated with pyriproxyfen at a rate of 3.8mg/m<sup>2</sup>. The growth of the experimental population was suppressed, and the insects died off in less than a year [77]. Four treatment of insect growth regulator hydroxyflufenorex were evaluated against *B. germanica*, in low-income, multifamily, public housing apartments. Results showed that all treatments significantly reduced cockroach populations. An initial application of a 1.2% hydroxyflufenorex total release fogger with a 1.0% propetamphos spray, followed by reapplication of the hydroxyflufenorex at 3 months, was superior. Population reduction attained by this treatment extended control at least 6 months longer than two applications of a 1.0% propetamphos spray [38].

### 1.6 Fermented

Spinosad is naturally derived from the fermentation of the actinomycete *Saccharopolyspora spinosa*, comprising two macrocyclic lactones: spinosyn A and spinosyn D [78]. Interestingly, spinosad has a new mode of action, primarily targeting binding sites on the nicotinic acetylcholine receptors (nAChRs), and in addition, it has secondary effects on gamma-aminobutyric acid (GABA) neurotransmission [79]. [80], founded that the fermented spinetoram residues are not sufficiently toxic to kill older flies quickly enough to reduce oviposition more than spinosad. Taken together, these conclusions imply that spinosad and spinetoram are equal for controlling *R. indifferens* infestations. Work comparing spinosad with spinetoram against a wide range of insect taxa has recently been published [81]. [82], investigated the effects of two insecticides, spinosad and indoxacarb, against adults of *B. germanica* and he founded that AChE and GSH were reduced, while LDH and SGT were increased. Spinetoram affects nicotinic acetylcholine receptors and  $\gamma$ -aminobutyric acid receptors on postsynaptic membranes in insect nervous systems, causing abnormal neural transmission and death [83]. [84], reported that spinosad act both by contact and ingestion, and it has a strong insecticidal activity, particularly against Lepidoptera and Diptera, beside it shows low levels of mammalian toxicity and relatively low hazards to non-target insects and aquatic invertebrates. [85], reported that a non-lethal dose of spinosad causes adult male and female German cockroach, *Blattella germanica*, to exhibit altered responses to their aggregation pheromone as well as to have a changed cuticular hydrocarbon profile. [86], studied the range of effects of spinosad to beneficial predatory and parasitic arthropods. [87], demonstrated that spinosad was highly toxic to worker honeybees under worst case laboratory conditions and that the oral route of exposure provided greater risk. Spinosyn A had no direct neuromuscular depressant effect and at very high concentrations actually enhanced neuromuscular transmission [79].

## 2- Conventional insecticides

### 2.1 Organophosphates

Organophosphates (OPs) are a class of insecticides, several of which are highly toxic. Until the 21<sup>st</sup> century, they were among the most widely used insecticides available and all can potentially cause acute and subacute toxicity. Organophosphates are used in agriculture, homes, gardens and veterinary practices; however, in the past decade, several notable OPs have been discontinued for use, including parathion, which is no longer registered for any use, and chlorpyrifos, which is no longer registered for home use. All share a common mechanism of cholinesterase inhibition and can cause similar symptoms, although there are some differences within the class. Since they share this mechanism, exposure to the same organophosphate by multiple routes or to multiple organophosphates by multiple routes may lead to serious additive toxicity. The heavy use of synthetic insecticides has resulted in the selection of resistant cockroach populations [88]. [89], estimated the susceptibility values for field- collected and laboratory strains of *B. germanica*, to three synthetic organophosphate insecticides were assessed by topical application. [90], examined that the residual effect of deltamethrin on *P. americana* using five different deltamethrin concentrations 0.8%, 0.4%, 0.2%, 0.1% and 0.05% (v/v) in three replications and the results showed that the toxic effect (LC<sub>50</sub>) of deltamethrin residue against *P. americana* reached a concentration of 0.2% in 24h. [91], discover that two organophosphate insecticides (Chlorpyrifos and Diazinon) significantly reduced cockroaches for only one week. [67], found that organophosphates have been used widely to control

cockroach which has developed resistance to these compounds. [92], studied the sensitivity level of *B. germanica* to deltamethrin, pirimiphos methyl and propoxur insecticides and mixtures of insecticides also examined the effect of temperature on the sensitivity level of *B. germanica* to insecticides. *B. germanica* was resistant to deltamethrin, tolerant to propoxur and susceptible to pirimiphos methyl.

### 2.2 Pyrethroids

[89], estimated the susceptibility values for field- collected and laboratory strains of *B. germanica* to five synthetic pyrethroid insecticides were assessed by topical application. [67], found that pyrethroids have been used widely to control cockroach which has developed resistance to these compounds. [91], studied that a product combining two pyrethroids (Tetramethrin and Alfacypermetrin) and piperonyl butoxide also gave excellent results with cockroach control for one month. [93], mentioned that the mortality of three pyrethroid insecticides (cypermethrin, Lambda-cyhalothrin, and Deltamethrin) rates of cockroaches were lower than 91%. An investigation on the efficacy of synthetic pyrethroids (0.02% deltamethrin+0.13% allethrin) and propoxur aerosol in the control of *B. germanica* showed that 89.36-87.8 and 77.95-59.74% reductions were achieved with propoxur and synthetic pyrethroid treatment respectively by first-week post-treatment [94]. Results of another study on *B. germanica* used commercial insecticides showed 100% mortality after 1h contact with propoxur 0.32%, permethrin 0.32%, bendiocarb 0.24% and pirimiphos methyl 0.16% [95].

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