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Plant-based repellents and insecticides for cockroach control: A comprehensive review

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Abstract

Cockroaches associated with human habitat, act as vectors and produce allergens. Synthetic insecticides are commonly used to control cockroaches, but they have a negative impact on human health and the environment. Moreover, cockroaches develop resistance to insecticides. On the other hand, plant-based insecticides are more eco-friendly and safer than chemical- based. The development of resistance in pests to plant-based insecticide products is slower due to the presence of various chemical compounds. In this review article, data has been compiled regarding the use of plant constituents (phytochemicals, essential oils) that control cockroaches, and can be used as an alternative to synthetic chemicals. They act in different ways namely repellent, insecticidal, and antifeedant. This review focuses on the efficacy of plant-based materials against two species of cockroaches (*Periplaneta americana* L., and *Blattella germanica* L.). Different methods were enlisted here which were used to assess the plants to control cockroaches. This article will be helpful for researchers to select suitable plant species, plant parts and methods to control cockroaches as well as other related species of insects. The phytochemicals present in plants should be isolated and can be used for manufacturing biopesticides.

Keywords: Cockroach, Essential oil, Insecticides, Phytochemicals, Repellent

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Introduction

Cockroaches are ubiquitous; out of 4600 species, 50 species of cockroaches are associated with human accommodations (Cochran and Organization, 1999). The most commonly reported species of cockroaches, *Blatta orientalis* (L.), *Blattella. germanica* (L.), *Blatta lateralis*, and *Periplaneta americana* (L.) have been associated with humans (Wahid ur Rehman et al., 2005; Ahmed et al., 2010; Wakil et al., 2012; Memona et al., 2017). Cockroaches have chewing mouthparts, flattened body, bent head, antennae, integuments, and cerci (Triplehorn & Johnson, 2005). They are considered pests because they spread germs and allergens that lead to various illnesses, including asthma, diarrhea, and other inflammatory bowel diseases (Ifeanyi & Olawumi, 2015; Do et al., 2016; Zahraei-Ramazani et al., 2018). They are known to be mechanical vectors of intestinal parasites of human, animal infections and also a source of human allergies. Cockroach antigen has been discovered to be the most common asthma-inducing allergen among children in cities (Arruda et al., 2001; Busse & Mitchell, 2007). Cockroaches spread filth and ruin fabrics, book bindings as well as food. They emit an obnoxious, lingering odor in places or foods with unpleasant secretions from both the mouths and gland openings on their bodies (Manzoor et al., 2012).

To address the adverse effects of cockroaches mentioned above, two methods—chemical and biological—are employed for their control. But the most commonly used method is the chemical method which includes the use of synthetic organic pesticides, which consist of aerosols, liquid sprays, baits, and total release foggers (Sittichok et al., 2013a). Although insecticides are effective in controlling pests, their continued use may have detrimental implications, such as interrupting the natural biological control system and develop resistance (Sittichok et al., 2013a). The chemical application in dwellings can be hazardous and can cause chronic effect due to contact toxicity and environmental pollution (Gahukar, 2017). The harmful effects, persistent nature, and environmental hazards of synthetic insecticides demand eco-friendly alternatives (Dhale, 2013). Continuous usage of insecticides for some decades has caused many socio-economic issues, prompting the idea of the integrated pest management (IPM) approach. IPM employs a variety of technologies; one of them is the usage of plant-based insecticides to control household insect pests(Dhale, 2013). Different studies were conducted to control cockroaches using plant extracts, essential oils, and plant-based products.

This review article contains information on plant-based materials that have insecticidal, antifeedant, and repellent effects on different species of cockroaches (Tables 2, 3, and 4). This article will be helpful to new researchers in selecting promising plants or methods in developing plant-based insecticides. This will also be helpful to the manufacturers in developing new materials and formulations to control cockroaches and other related insects.

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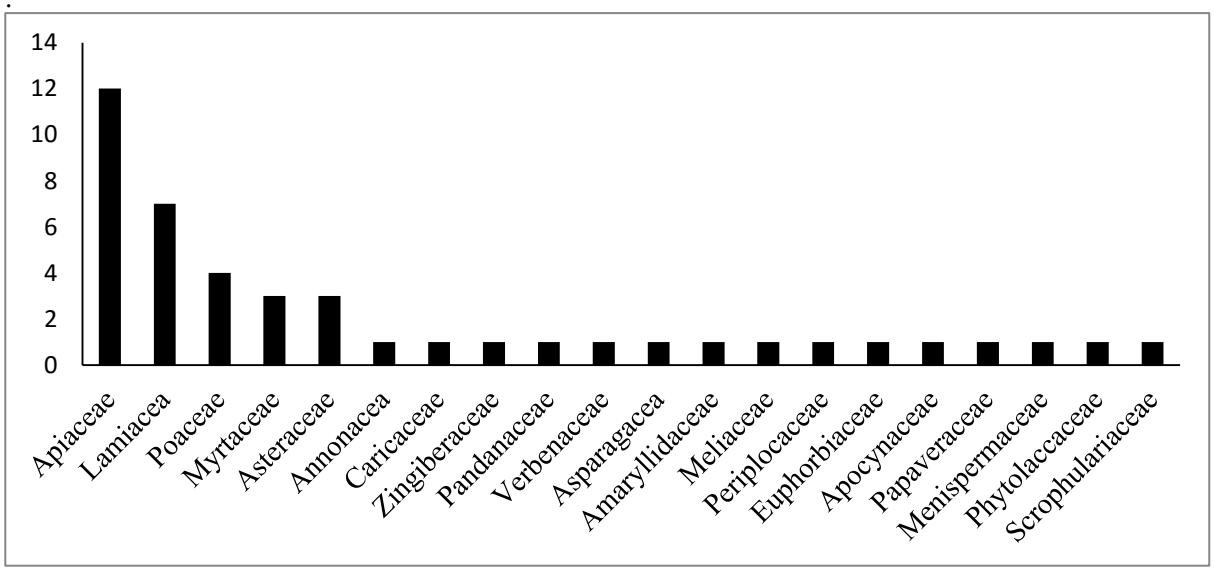

Fig. 1 The number of plant species belonging to families used for insecticidal or repellent activity against the control of cockroaches (publish data from 2001-2020)

Control using plants and plant-based products

The control of cockroaches through plants and plant-based products (essential oil) is cost-effective, eco-friendly, and safe (Isman, 2000; Koul et al., 2008; Regnault-Roger et al., 2012). Different plant parts such as leaf, stem, seed, flower, and rhizome extract have been investigated for their insecticidal activities against cockroaches (Aldo et al., 2021; Rahayu et al., 2020; Ukoroije and Bawo, 2019a). Most works were done on two cockroach species *Periplaneta americana* and *Blatella germanica* which were controlled through plants.

Phytochemicals

Phytochemicals possess a complex mixture of compounds, resulting in a notably slower development of pest resistance (Riat, 2018). They show different activities like insecticidal, antibacterial, and antifungal. They can compete well with the manufactured chemicals to control the target organism. Alkaloids, terpenes, polyphenols, and glycosides are all compounds found in plants. Plants are typically utilized because they are inexpensive and readily available (Rajasree et al., 2016). Different studies were conducted to check the nature and types of phytochemicals and their effects (Table 1).

Table 1 List of phytochemicals and their effects

Phytochemical	Effects	References
Tannins	astringent properties that hold the insect tissue together, preventing blood flow and causing insects death	(Organization, 1999)
Glycoside	poisonous and antifeedant	(Sosan et al., 2001)
Saponin	hemolysis of blood, poisoning, and eventual death of the insects	(CB Nya et al., 2016)
Alkaloids	potent insecticides, neurotoxins and cause death of the nymphs and adults	(Adeyemi, 2010; Eleazu et al., 2012)
Flavonoid	antioxidants, antifeedant, repellent, and having the capacity to modulate the feeding behavior of insects	(Jackai et al., 1992; Upadhayay& Vigyan, 2014)
Terpenoids	insect repellents and feeding inhibitor	(Dubey et al., 2000; Lale & Mustapha, 2000)
Phenols	insecticides and antifeedant	(Ukoroije & Bobmanuel, 2019b)

Effects of phytochemicals

Phytochemicals have a variety of pharmacological and physiological effects when ingested by insects. Plant bioactivity is influenced by chemical substances that may

prevent insects from feeding. Phytochemicals have various effects like repellent, insecticidal, toxicity, antifeedant, and larvicidal. Similarly, they have different mechanisms of action on cockroach tissues or organs such as initiating antiperistalsis wave in the alimentary canal, abrasive effect on the cuticle, interfering with the respiratory mechanism, inducing vomiting, effect on midgut epithelium, gastric caeca, malpighian tubules and cause death (Fig. 2).

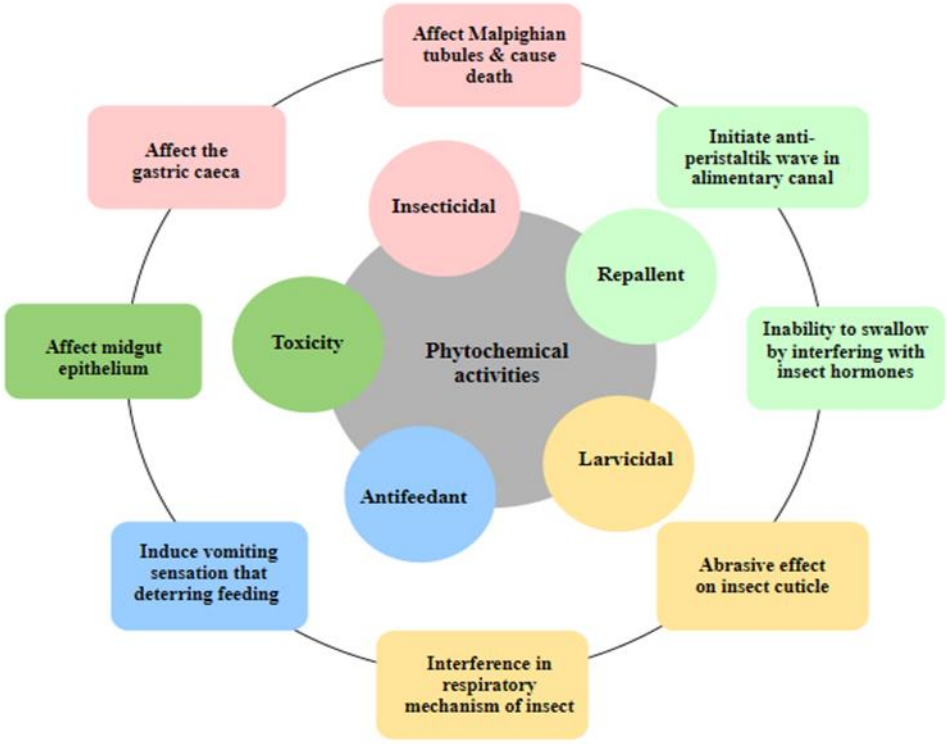

Fig. 2 Effects of Phytochemicals on cockroaches and their mechanistic actions

Insecticidal activity

Insecticide is any toxic substance that is used to kill insects. The presence of alkaloids, tannins, flavonoids, terpenoids, steroids, and cardiac glycosides in the plants show insecticidal activities of plants (Hassanali et al., 1990). The high flavonoid and polyphenolic contents present in plants indicated that plants have insecticidal effects. Compound Salannin, Nimbin, Meliantriol, and Nimbidin are reported as insecticides against several insects as well as cockroaches. When cockroaches ingest these compounds, they affect their metamorphosis by preventing their development and growth (Biswas et al., 2002; Musa et al., 2009; Anis et al., 2010). Acetone, an aqueous & Ethanolic extract of *Agarista salicifolia* showed the presence of polyphenols, alkaloids, cardiac glycosides, flavonoids, tannins, steroids, and terpenoids that exhibit the highest insecticidal effect against cockroaches (Hailemariam et al., 2015). The information on the plant from published articles (2001-2020) predicted that Families of plants with more species that are used as insecticides or pesticides to control cockroaches are Apiaceae and Lamiaceae shown in Fig. 1.

Antifeedant activity

Antifeedant is a natural substance that stops or inhibits feeding by a pest or an insect. These compounds are produced by plants and classified as secondary metabolites that do not play role in the metabolism of plants. They are considered toxic to insect species. Terpenoids have been reported in Azadirachta indica, Ocimum gratissimum, Dracaena arborea, and many other plants. Azadirachtin a compound present in A.indica (Neem) works as a repellant, preventing insect from feeding. Because of the deterrent ingredient's secondary hormonal or physiological effects, insects stop feeding after the initial taste (Orwa et al., 2009). Phenolic compounds flavonoids are the most important antioxidants in the diet. As a result, their molecules delayed and blocked radical-catalyzed oxidation-reduction reactions, preventing cockroaches from feeding (Jackai et al., 1992).It has been demonstrated that medial deterrent cell's response induces feeding inhibition directly that confirm the idea of a connection between sensory input and feeding inhibition (Adeyemi & Mohammed, 2014).

Repellent activity

O. gratissimum essential oil is said to have repellant bioactive components. The chemicals eugenol and sesquiterpenoids contained in the plant extract cause toxicity and a repellent effect (Kéïta et al., 2000). Citronella and eucalyptus oil which are extensively used in candles have maximum insect repellent activity (Leal, 2014). The plant species release a variety of volatiles, such

as different alcohols, terpenes, and aromatic chemicals camphor, linolool, geraniol, citral, methyl charicol, and lincalyacetale, which act as defensive mechanisms against pathogens. These substances have the potential to prevent insects or other pests from feeding, have direct toxic effects, or are involved in attracting predators and parasitoids in response to feeding damage (Vethanayagam & Rajendran, 2010; Adeyemi & Mohammed, 2014; Tura & Bezuneh, 2015). Terpenoids are tetranortriterpenoid compounds that serve as feeding inhibitors, insect repellents, as solvents to assist the passage of other toxins through membranes and the hormone ecdysone, limiting the growth of insects from the nymph stage to adult, and so influencing the metamorphosis process (Jackai et al., 1992; Lale & Mustapha, 2000; Rattan, 2010; Khater, 2012). Studies have revealed that Azadirachtin, a compound present in neem plants is a more efficient insect repellent than N, N-diethyl-meta-toluamide (DEET), and a carcinogen when used for longer time periods (Sarinho et al., 2004).

Toxicity

The extent to which a chemical compound or a mixture of chemicals can harm an organism is referred to as toxicity. Plants contain many toxic compounds which can cause harm to insects. Plants contain many toxic compounds such as enzyme papain, alkaloid, carpainin, pseudocarpaine, carpaine, choline, tannin, saponin, carposid glycosides, and vitamins E23 and C that are can be toxic for cockroaches (Rahayu et al., 2020).

Biological activities of essential oils

In plants, essential oils consist of a volatile compound as secondary metabolites. Oils are made up of a complex combination of sesquiterpenes, terpenes, phenols, monoterpenes, 1, 8-cineole, esters, oxides, ethers, alcohols, ketones, aromatic phenols, aldehydes, and other compounds. (Brooker and Kleinig, 2006; Isman, 2000). They have repellent, insecticidal, and fumigant action. Some of the essential oils are listed below in (Table 2).

***Cymbopogon citratus* oil**

Cymbopogon citratus oil (oil of lemongrass) has been reported as a natural repellent, having a fumigant and toxic effect. It is a powerful insect repellent. Plant extract and oil from this plant have been tested against Periplaneta americana (L.) and showed maximum toxic effect (i.e., 20-100%) between 2 to 24 h intervals, 70 to 100% fumigation, and repellency (100%) after 24 h time period. Lemongrass essential oil has the potential to be an alternative insecticide in controlling *Blatella germanica* through contact and repellency application. *P.americana* was completely repellent to *C. citratus* essential oil in ethyl alcohol (Gahukar, 2017; Manzoor et al., 2012; Sittichok et al., 2013a). *C. citratus* oil is a widely used medicinal herb with a wide range of applications. Citral the main aromatic ingredient of C. citratus oil has been found to have several uses, including antibacterial, anti-inflammatory, and sedative properties.

***Cymbopogon flexuosus* oil**

Cymbopogon flexuosus oil also shows effectiveness against the control of *Blatella germanica* (L.). Lemongrass essential oil possesses a significant level of repellency, even when used at low concentrations. Lemongrass essential oils contain different compounds i.e. citral, geraniol, and linalool, which have an unpleasant odor for cockroaches. The concentrations of lemongrass essential oil that were used are toxicity (3.15 g cm-2), Fumigation (1 g cm-3), and Repellency test (0.16 mg cm-2). In a Contact Toxicity Test (LT90<24 h), German cockroaches were found to be resistant to lemongrass essential oil. Essential oil (Lemongrass) was also found to repel German cockroaches at sub-lethal concentration, with repellency values of 100 percent reported for 48 hours of the trial (Rahayu & Mairawita, 2018).

***Eucalyptus citriodora* oil**

Oil of eucalyptus consists of sesquiterpenes, oxides, monoterpenes, esters, alcohols, ethers, aromatic phenols, ketones, and aldehydes. It has been observed that Eucalyptus oil is toxic to *P.americana*. The percentage mortality of cockroaches that have been observed by treating Eucalyptus oil is up to 80% For eucalyptus oil (E. citriodora) it has been reported that after 2, 4, 6, and 24 h LC50 values were 8.268, 10.392, 7.050 and 4.814 (Manzoor et al., 2012; Sittichok, et al., 2013b).

***Mentha arvensis* oil**

Mint oil has insecticidal activity. The insecticidal and repellent activity of mint oil was reported because of the presence of pulegone (0.86%) which is an important compound and is being used in comprehensive integrated pest management (IPM) programs against insects. After 2, 4, 6, and 24 h while applying M. arvensis oil, lethal concentration values were 8.122, 8.013, 6.004, and 4.640, respectively (Manzoor et al., 2012; Sittichok et al., 2013b).

***Syzygium aromaticum* L. oil**

Syzygium aromaticum L. oil showed maximum mortality of *P.americana*. After 4, 24, and 48 hours of exposure, clove oil had substantial contact toxic effects on *P.americana* nymphs and adults. 1st and fourth instar nymphs were more susceptible to clove oil after 24 hours. (LC50 values of 0.0001 & 0.0077 l/cm2, respectively) than adult cockroaches (Sharawi et al., 2013). This oil also has a repellent effect against *P.americana*. The repellency percentage of this oil against cockroaches was reported up to 90% (Sittichock et al.,2013a).

***Rosmarinus officinalis* L. oil**

Rosmarinus officinalis L. oil showed a toxic effect against *Periplaneta americana* (L.). This oil had significantly substantial contact toxic effects on P.americana nymphs after 4, 24, and 48 hours. After 24 hours, 1st and fourth instar nymphs were more killed while applying rosemary

oil (LC50 values of 1.92 and 2.25µl/cm2) than adults (Sharawi et al., 2013).

Cymbopogon nardus

Citronella grass oil has a repellent effect against *Periplaneta americana* (L.) & *Blatella germanica* (L.). The oil had a significant repellent effect against cockroaches i.e. 81% repellent effect (Sittichok, et al., 2013a). The cockroach can effectively be repelled by citronella grass essential oil, which has a repellency range of 65.72–100.00 percent after one hour and is remains effective after 24 hours. Essential oil of citronella grass has the potential to become a repellent to the Germans cockroaches (Jannatan et al., 2017).

Eucalyptus robusta

Eucalyptus robusta oil has a repellent effect against German cockroaches. This oil contains two important components i.e., 1, 8-cineole and α-pinene that showed the maximum repellent effect. At a concentration of 5ppm, these two components of *Eucalyptus robusta* oil showed a repellent effect after one hour of exposure (Liu et al., 2015).

***Nepeta cataria* L.**

Catnip oil has repellent activity against German cockroach. The essential oil contains two nepetalactone isomers, E, Z, and E-nepetalactone, which were evaluated for repellent efficacy against adult male German cockroaches. It has been observed that catnip oil has a repellent effect (Peterson et al., 2002).

***Cyperus rotundus* oil**

Cyperus rotundus oil also shows a repellent effect against German cockroaches (Liu et al., 2011) evaluated the effect of essential oil of eight Chinese medicinal herbs. Out of eight herbs, the oil of *Cyperus rotundus* has the strongest repellent effect. At 1 ppm concentration, this oil showed a greater repellent effect.

Effects of plants and plant-derived products on *Periplaneta americana*

The different plants and their parts were used in different studies to control Periplaneta americana which has different effects like insecticidal, toxic, and repellent.

Table 2 Essential oils and their effects on cockroaches

Name of oil (plant name)	Plant part used	Effects on cockroaches	References
Cymbopogen citrus oil	Leaves	Repellent, Fumigant, and toxic	(Manzoor et al., 2012; Sittichok, et al., 2013b)
Cymbopogon flexuosus oil	Whole Plant	Repellent, Toxic	(Rahayu & Mairawita, 2018)
Eucalyptus citriodora oil	Whole plant	Toxic	(Manzoor et al., 2012)
Mentha arvensis oil	Whole plant	Insecticidal	(Manzoor et al., 2012)
Syzygium aromaticum L. oil	Buds	Insecticidal, Repellent	(Sharawi et al., 2013; Sittichok et al., 2013a)
Rosmarinus officinalis L. oil	Leaves & Stem	Toxic	(Sharawi et al., 2013)
Cymbopogon nardus oil	Whole plant	Repellent	(Jannatan et al., 2017; Sharawi et al., 2013)
Eucalyptus robusta oil	Leaves	Repellent	(Liu et al., 2011)
Nepeta cataria L. oil	Aerial parts	Repellent	(Peterson et al., 2002)
Cyperus rotundus oil	Tubers	Repellent	(Liu et al., 2011)

Insecticidal effect

An insecticidal activity of (Mentha spicata L.) oil was reported against *Periplaneta americana* (L.). This oil consists of phenols, terpenes, and terpenoids (especially citronellal, citral, geraniol & eugenol) and has an insecticidal effect through contact & fumigant actions when applied to filter paper i.e., 250 g oil/g (Appel et al., 2001). The insecticidal activity of seed oil of Jatropha curcas was studied against nymph and adult cockroaches. A dose of 34, 54, 79, and 84 % v/v was tested against the cockroaches. The highest concentration (84 %v/v) revealed the greatest efficiency, by killing all cockroaches within the shortest period. Jatropha curcas oil phorbol esters possess a great insecticidal effect against nymph and adult cockroaches (Udebuani et al., 2015). Leaf extract of *Annona Squamosa* exerted insecticidal activity against *Periplaneta americana* (L.). Different concentrations of leaf extract that is 0.05ml (5%), 0.025 (20%) 0.5ml (25%), 1 ml (50%), 1.5ml (75%), and 2ml (100%) were applied. Leaves extract at 25, 50, 75, and 100% ascertained effective against controlling *Periplaneta americana*. The lethal concentration of leaf extracts *Annona squamosa* (LD50) were 61.302% against cockroach (Kesetyaningsih, 2012). It has been studied that *P. americana* can be controlled by leaf extract of *Chromolaena odorata*. A dose of 0.3- 1.0 ml of the leaf extract of *Chromolaena odorata* was applied on filter paper, a higher dose that is 1.0

ml/filter paper gave 73.26 percent mortality (Udebuani et al., 2015). The insecticidal activity of three plants was analyzed against *Periplaneta americana* (L.). They utilized these plants as a powder or extract forms through topical application of plant extract to assess contact toxicity and by contact toxicity by using filter paper. The result revealed that a considerable amount of mortality was observed in the decreasing order of *A. indica*, *O.gratissimum*, and *D. arborea*. Thus *Azadirachta indica* can be used as the best source to control *P.americana*. They reported that powder (10-50g) and extracts (10-50 g/ml) of the leaf of the *Dracaena arborea* cause mortality of cockroaches when applied through contact toxicity using filter paper and by topical application. All the treatments proved that the mortality of adults increased as extract concentration and exposure time increased (Ukoroije & Bobmanuel, 2019b).

An experiment was conducted to assess and contrast the bioefficacy of various botanicals *Argemone mexicana*, *Nerium oleander*, and *Parthenium hysterophorus* against *Periplaneta americana* (L.) with that of commercially available biopesticides Anosom®, Derisom®, Margosom®. It has been observed that these botanicals can be used as insecticides to control cockroaches. Antifeedency was determined by comparing pre-and post-treatment weights and calculating % starving. After 24 hours of treatment, Derisom showed 83.24 percent starvation, while *A. mexicana* showed the least percent starvation (51.84 percent) at the greatest doses (Khan & Qamar, 2015).

An experiment was conducted in which a dose (10,000 to 80,000 ppm) of essential oils of *Piper aduncum* was applied against adults and nymphs of *P. americana*. The essential oil of *P. aduncum* proved toxic effect against adult females and males, as well as nymphs of *P. americana* (Sulaiman & Othman, 2009). The toxicity of *Cymbopogen citratus*, *Eucalyptus citriodora*, and *Mentha arvensis* was tested against *Periplaneta americana* (L.). A dose (4-7%) of 1.5 ml of essential oils showed insecticidal activity through contact, fumigant, and repellent action. *Cymbopogen citratus* had the highest toxicity i.e., (20 to 100 percent) between 2 and 24 h intervals. *E. citriodora* showed percentage mortality (0 to 80%) between 2 to 24 h at the various dosage of oil (Manzoor et al., 2012). The toxicity of the essential oils of rosemary and clove was studied against the American cockroach. It gave higher mortality against nymphs than adults. The mortality percentages of clove and rosemary oils varied depending on the exposure time, concentration, and stage of the insect. Clove oil was found to be more hazardous than rosemary oil. Nymphs in their first instar were more delicate than nymphs in their fourth instar, which were followed by adults. After 4, 24, and 48 hours of exposure, clove oil caused highly substantial contact toxicity in *P. americana* nymphs and adults. Clove oil was more sensitive to first and fourth instar nymphs (LC50 values of 0.0001 & 0.0077 l/cm2, respectively) than rosemary oil (LC50 values 1.92 and 2.25 l/cm2, respectively). After 48 hours of exposure, both oils had a negligible effect on adults (Sittichok et al., 2013b).

The toxic effect of stem powder of *Parquetina nigrescens*, *Azadirachta indica*, and *Zanthoxylum zanthoxyloides* as well as flower buds' powder of *Eugenia cariophyllus* was studied against *Periplaneta americana* (L.). The plant materials (PM) were crushed and given to the American cockroaches in four different doses. 25(0.5 g) percent PM+75 percent biscuit, 50(1.0g) percent PM+50 percent biscuit, 75(1.5 g) percent PM +25 percent biscuit, and 100(2.0) percent PM+0 percent biscuit were the dosage rates used. Higher doses of these plants gave 100 percent mortality (Ogunleye, 2010).

Repellent effect

At 2ml/cm2 of filter paper essential oils from Thai local plants, including *Cymbopogon nardus* (citronella grass), *Cymbopogon citratus* (lemongrass), and *Syzygium aromaticum* (clove) were tested and observed a knock-down effect after an hour and complete mortality of *Periplaneta americana* (L.) after 24 hours. *C. citratus* oil was shown to be the most effective. The repellency of the Eos of *C. citratus* in ethyl alcohol was the highest (100 percent). The percentage repellency of all Eos in ethyl alcohol was greater (81-100 percent) against *P. americana* while all the essential oil in soybean oil exhibited (66-84%) repellency (Sittichok et al., 2013a). The repellent activity of mentha (*Mentha spicata* L.) oil was studied against *Periplaneta americana* (L.). This oil consists of terpenoids, phenols, and terpenes (especially, citronellal, citral, geraniol, and eugenol) and have repellent activity. Adults were repelled up to 98 percent by citrus (*Citrus reticulata* Blanco) oil containing limonene, but this was reduced to 86 percent when it was combined with soybean oil at 10% (Appel et al., 2001). The repellent activity of *Mentha arvensis*, *Cymbopogen citratus*, and *Eucalyptus citriodora* were tested against *Periplaneta americana* (L.). Cymbopogen citratus had the highest repellency value (100 percent) between 2 and 24 h intervals. Eucalyptus (*E. citriodora*) showed less repellency. The repellent effect of these plants in decreasing order was *C. citratus*, *M. arvensis*, and *E. citriodora* (Appel et al., 2001). Plant powder of *Azadirachta indica*, *Lantana camara*, *Curcuma longa*, *Ocimum tenuiflorum Adhatoda vasica*, and *Vitex negundo* combined with a biscuit showed repellent activity against *Periplaneta americana* (L.). Treatments included 25% plant material (PM) + 75% biscuit, 50% PM+ 50% biscuit, 75% PM+ 25% biscuit and 100% PM. A higher concentration of plant material gave higher mortality of insects. *Azadirachta indica* had the most repellency, while *Adathoda vasica* had the lowest. The order of repellency of these plants in decreasing order as *A. indica, C. longa, L. camara, V. negundo, O. tenuiflorum* & *A.vasica* (Rejitha et al., 2014).

Table 3 Effects of plant leaves to control *Periplaneta americana*

Plant (Scientific name)	Common name	Effects	Extract/Raw powder/Oil	Reference
Chromolaena odorata	Siamweed	Insecticidal	Distilled water extract	(Udebuani et al., 2015)
Annona squamosa	Custard apple	Insecticidal	Methanolic extract	(Kesetyaningsih, 2012)
Curcuma longa	Turmeric	Repellent	Oil	(Rejitha et al., 2014)
Lantana camara	Lantana	Repellent	Powder	(Rejitha et al., 2014)
Adathoda vasica	Malabar-nut leaf	Repellent	Powder	(Rejitha et al., 2014)
Azadirachta indica	Neem	Repellent	Powder	(Rejitha et al., 2014)
Vitex negundo	Chinese chaste tree	Repellent	Powder	(Rejitha et al., 2014)
Cymbopogon citratus	Lemon grass	Repellent	Essential oil	(Manzoor et al., 2012)
Ocimum tenuiflorum	Tulsi	Repellent	Powder	(Rejitha et al., 2014)
Dracaena arborea	Dracaena Tree	Insecticidal, larvicidal	Ethanolic extract	(Ukoroije & Bawo, 2019a)
Ocimum gratissimum	Basil	Insecticidal and Larvicidal	Ethanolic extract	(Ukoroije & Bobmanuel, 2019b)
Rosmarinus officinalis	Rosemary	Toxicity, Insecticidal	Essential oil	(Sharawi et al., 2013)
Mentha arvensis	Corn Mint	Repellent, Toxicity, Insecticidal Fumigant action	Essential oil	(Appel et al., 2001; Manzoor et al., 2012)
Eucalyptus citriodora	Lemon-scented gum	Toxic, Repellent, fumigant	Oil	(Manzoor et al., 2012)
Parthenium hysterophorus	Carrot grass	Antifeedant, Toxic	Ethanolic extract, powder	(Hailemariam et al., 2015; Khan & Qamar, 2015)
Nerium oleander	Indian oleander	Antifeedant, Toxic	Ethanolic extract	(Khan & Qamar, 2015)
Argemone mexicana	Prickly poppy	Antifeedant, Toxic	Ethanolic extract	(Khan & Qamar, 2015)
Tinospora rumphii L	Panyawan	Toxic.	Acetonic extract	(Pregoner et al., 2020)

Table 4 Effects of Plants parts (Stem, seed, and flower, whole plant) to control *Periplaneta americana*

Plants parts	Plants (Scientific Names)	Common name	Effects	Extract/Raw powder/Oil	Reference
Stem	Zanthoxylum zanthoxyloides	Prickly-ash plant	Toxic	Powder	(Ogunleye, 2010)
	Parquetina nigrescens	Periploca	Insecticidal, Repellent	Powder	(Ogunleye, 2010)
	Azadirachta indica	Neem	Insecticidal, Repellent	Powder	(Ogunleye, 2010)
	Rosmarinus officinalis	Rosemary	Toxicity, Insecticidal	Oil	(Sharawi et al., 2013a)
	Cymbopogon citratus	Lemongrass	Repellent	oil	(Sittichok et al., 2013a)
	Cymbopogon nardus	Citronella Grass	Repellent	oil	(Sittichok et al., 2013a)
Seed	Jatropha curcas	Barbados nut	Insecticidal	Oil	(Lateef et al., 2014)
	Parthenium hysterophorus	Carrot grass	Toxic	Powder	(Hailemariam et al., 2015)

Flower	Eugenia cariophyllus	Clove	Insecticidal	Powder	(Ogunleye, 2010)
	Syzygium aromaticum	Clove	Repellent	Oil	(Sharawi et al., 2013)
	Parthenium hysterophorus	Carrot grass	Toxic	Powder	(Hailemariam et al., 2015)
Whole plant	Piper aduncum	Spiked pepper	Toxic	Oil	(Sulaiman & Othman, 2009)

Effects of plants and plant-derived products on *Blatella germanica*

The different plants and their parts were used in different studies to control Blatella germanica which has different effects like insecticidal, toxic, and repellent.

Insecticidal effect

An insecticidal activity of EOs was studied (peppermint, geranium, palmarosa, rosemary, and lavender) loaded with polymeric nanoparticles to control German cockroaches. Oils were mixed with a polyethylene glycol 6000 matrix to make EO-loaded polymeric nanoparticles. Palmarosa, Peppermint, and essential oil-loaded polymeric nanoparticles boosted the lethal and sub-lethal effects of the essential oil against *Blatella germanica* (L.) (Yeguerman et al., 2020). It was investigated that mint oil showed insecticidal effect against German cockroaches. It showed a maximum toxic effect within 24 hours. The mortality rate of German cockroaches was 100 % after 24 h of exposure (Appel et al., 2001).

A study had been conducted to investigate how effectively *Blattella germanica* (L.) responded by the leaf extracts from *Buddleia polystachya*, *Vernonia amygdalina*, and *Phytolacca dodecandra*. Three distinct concentrations (15g/100ml, 10g/100ml, and 5g/100ml of water) of these botanical leaf extracts were made. Cockroach mortality was measured after 24, 48, and 72 hours of exposure. After 72 hours at 5g/100ml, after 48 hours at a concentration of 10g/100ml, and 15g/100ml after 24 hours *P. dodecandra* observed 100% (100%) of mortality, while after 48 hours at a concentration of 15g/100ml *B. polystachya* & *V. amygdalina* recorded 100% (100%) of mortality (Kassie, 2020).

The toxicity and repellency of 12 Eos components (carvacrol, (-)-linalool, transcinnamaldehyde, (-)-β-pinene citronellic acid, 1, 8-cineole geraniol, (-)-menthone, S-(-)-limonene, eugenol, thymol and (+)-α-pinene, were determined against German cockroaches. Thymol was the greatest lethal essential oil component to medium nymphs and adults. Trans-cinnamaldehyde showed the greatest toxicity against adult females and small and large nymphs. (+)-α-Pinene showed minimum toxic effect against all stages of the German cockroach. S-(-)-Limonene showed the minimal while (-)-Menthone showed the greatest effect against ootheca (Phillips, 2009).

The fumigant toxicity of some essential oils (*Oregano dubium* (L.), *Rosemarinus officinalis* (L.), *Thymus vulgaris* (L.), *Allium cepa* (L.), *Allium sativum* (L.), and selected monoterpenoid components (citronella eugenol, and carvacrol,) were studied against the adult German cockroach, *Blattella germanica* (L.). The insecticidal activity of allyl isothiocyanate (a component of horseradish) and the essential oil of *A. sativum* against adult *B. germanica* specimens were great, but none of the others showed any insecticidal activity (Tunaz et al., 2009). The essential oil was obtained from the seven plants (*Cymbopogon nardus* L., *Eucalyptus citriodora* Hook., *Cymbopogon citratus* (DC.) Stapf, Mill, *Ocimum basilicum* L. *Foeniculum valgare*, *Mentha piperita* L., *Zingiber officinalle* Rosc.) and ascertained their toxic effect against German cockroach. *M. piperita* oil showed higher toxicity against B. germanica. The toxicity level of these plants in decreasing order was *M. piperita* oil, *C. citratus* oil, *F. valgare* oil, *E. citriodora* oil, *Z. officinalle* oil, *O. basilicum* oil, and *C. nardus* oil (Sittichok et al., 2013b).

The contact toxicity of Eos of *Cymbopogon flexuosus* was studied against German cockroaches. Lemongrass essential oil having different concentrations (3.15 mg cm-2, 1 g cm^{-2}, and 0.16 mg cm^{-2}) was applied through Contact toxicity, fumigation toxicity, and repellency test respectively. This oil has the potential to kill German cockroaches (Rahayu et al., 2018). It has been evaluated the toxicity of *Colocacia esculanta* leaf extracts on adult males and females of *Blattella germanica* cockroaches was examined in laboratory settings. Bioassays revealed that ethanol and petroleum ether extracts were toxic to the insects examined, with mortality rates for adult males and females increasing as concentrations increased. Males were more sensitive to both extracts than females, and ethanol extract was more hazardous than petroleum ether extract, according to the LC50 values (Reda et al., 2017).

The toxicity profiles of some aromatic (β-thujaplicin, eugenol, carvacrol, and tropolone), aliphatic (cyclononanone, α-pinene, limonene, nerolidol) essential oil component had been studied against three strains (susceptible strain (S), and two multi-resistant strains – strains D and E) of the German cockroach. The four Eos were equally toxic against all strains as in decreasing order were carvacrol, eugenol, tropolone, limonene. The other four were more toxic against the S strain than the resistant strain (Oladipupo et al., 2020). The toxic activity of *Carica papaya* L. has been reported against German cockroaches. The ethanolic extract of papaya leaf had an LR50 of 2.97-4.72 mg cm^{-2} and an LR90 of 6.05-8.92 mg cm^{-2}, indicating that it was particularly effective in killing German cockroaches. Ethanolic extract from papaya leaf could be used to make a powerful natural insecticide to reduce the number of German cockroaches that have developed resistance to synthetic insecticides (Rahayu et al., 2020).

Repellent effect

It has been evaluated the repellent activity of seven compounds and fractions prepared from leaves of *P. amaryllifolius* against German cockroaches. 2-Acetyl-1-pyrroline, hexane-pandan extract, and the pandan essence were repellent (65-93 % repellency) at all concentrations that were tested (Li & Ho, 2003). The repellent activity of the essential oil of *Eucalyptus globulus*, *Rosmarinus officinalis* was evaluated against cockroaches. The mixed formulation of these essential oils gave 100% repellency against Blatella germanica. The result showed that a mixed formulation of this essential oil can be used to repel cockroaches (Zibaee & Khorram, 2015). (Wazifeshenas et al., 2015) studied the contact toxicity of essential oil of *Allium sativum* L. and *Citrus nobilis* var. deliciosa (Ten.) Swingle against adult German cockroaches. The toxicity of *A. sativum* oil was significantly higher than *C. nobilis* oil. Moreover, males were more vulnerable than females to *A.sativum* and *C. nobilis* oils (2.24 and 1.58 times, respectively). The essential oil of 12 Apiaceae plants has been studied against German cockroaches. These oils have a good effect as natural repellents against cockroaches. At 2.5 mg/cm2, carvacrol, R-(-)-carvone, and thymol were found to be >80% effective in repelling adult female & male German cockroaches. At 10 mg/cm-2 of S-(+)-carvone, terpinen-4-ol, (+)-dihydrocarvone, and male and female adult German cockroaches were repelled by >70% (Lee et al., 2017). The repellent activity of the essential oil of *Cymbopogon flexuosus* has been studied against German cockroaches. Lemongrass Eos having concentrations (0.16 mg cm-2) was applied through a repellency test. This oil has a 100% repellency value against cockroaches (Rahayu et al. 2018). The repellent activity of *Carica papaya* L. was reported against German cockroaches. The repellency value of ethanolic extract was between 88.89 -94.74% showing a higher repellency value (Rahayu et al., 2020) .

Table 5 Effects of different Plants parts (leaf, seed, bulb, whole plant) to control *Blatella germanica*

Plant part	Plant	Common name	Extract/Raw powder/Oil	Effects	Reference
Leaf	*Rosmarinus officinalis*	Rosemary	Essential oil	Toxicity, Insecticidal	(Sharawi et al., 2013b)
	Pandanus amaryllifolius Roxb.	Pandan	Hexane extract	Repellent	(Li & Ho, 2003)
	Phytolacca dodecandra	African soapberry	Distill water extract	Insecticidal	(Kassie, 2020)
	Buddleia polystachya	Butterfly bush	Distill water extract	Insecticidal	(Kassie, 2020)
	Vernonia amygdalina	Bitter leaf	Distill water	Insecticidal	(Kassie, 2020)
	Colocacia esculanta	Taro Plant	Ethanolic extract, Petroleum ether extract	Toxic	(Reda et al., 2017)
	Petroselinum sativum (Mill.) Fuss	Parsely	Oil	Repellent	(Lee et al., 2017)
	Carica papaya L.	*Papaya*	Ethanolic extract Oil	Repellent, toxic Insecticidal,	(Rahayu et al., 2020)
	Pogostemon cablin	Patchouli		Repellent	(Liu et al., 2015)
	Passiflora foetida L	Permot	Extract	Insecticidal	(Susilowati & Rumiati, 2021)
Seed	*Daucus carota L*	Carrot seed	oil	Repellent	(Lee et al., 2017)
	Apium graveolens (Mill.) Pers	Celery	oil	Repellent.	(Lee et al., 2017)
	Cuminum cyminum L.	Cumin	Oil	Repellent	(Lee et al., 2017)
	Coriandrum sativum L.	Coriander	oil	Repellent	(Lee et al., 2017)
Bulb	*Allium sativum*	Garlic	Oil	Fumigant action	(Tunaz et al., 2009)
Whole plant	*Ammi visnaga* Lam	Khella	Oil	Repellent	(Lee et al., 2017)
	Mentha piperita	Mint	Oil	Repellent, toxic	(Appel et al., 2001)

Methods to assess repellent and insecticidal activities

Several methods were reported to assess the insecticidal and repellent activity of plants.

Extraction of essential oil

The widest methods to extract essential oil are the Soxhlet extraction and steam distillation and Hydro distillation method.

Soxhlet extraction

The sample or plant material is first placed in a disposable thimble and then into the Soxhlet apparatus. The solvent is continuously extracted by refluxing it. After the extraction chamber is filled, the extract is transferred to the boiling flask. This operation is carried out again and again until the extraction is completed (Tura & Bezuneh, 2015; Azhari et al., 2017).

Steam distillation

It is done by passing dry steam through plant material, allowing the steam's volatile chemicals to evaporate, condense, and collect in receivers. For many years, steam distillation has been used to extract essential oils (Peterson et al., 2002; Sulaiman & Othman, 2009; Sharawi et al., 2013).

Hydro distillation method

It is a method to extract the bioactive component from plants. Plant materials are packed in a still compartment, then an appropriate amount of water is added, and the mixture is brought to a boil. Direct steam can also be injected directly into the plant sample. By cooling, the vapour mixture of water and oil gets condensed. The condensed mixture flows from the condenser to a separator, which separates the oil and bioactive chemicals from the water automatically (Fanta et al., 2013; Liu et al., 2015).

Repellent assay

These assays were determined by using Petri plates or boxes. A filter paper was placed on Petri plates and divided into two halves. One half was treated with plant material and the other half was treated as control. A certain number of cockroaches were released in the centre of the paper, after some intervals observation was made, and recorded the number of cockroaches on both halves and then calculate the percentage repellency. A bioassay procedure called linear track olfactometer has been also used to determine the repellent activity of plants. A classical olfactometer consists of different types of behavioural assay systems. A Y-tube olfactometer consists of a stem pipe branched into two-tube, one is treated as odor and the other is treated as control (Sakuma et al., 1985). In designing a linear tract olfactometer, a T-shaped wind olfactometer with a special wire pathway was designed. Test insects were introduced into it and then note their movement toward the control and treated chamber (Li & Ho, 2003).

Insecticidal assay

This assay can be determined by generally as contact toxicity, fumigant action, and antifeedant assay. Plant materials are either applied topically as a spray or applied on filter paper to assess the contact toxicity of the plant. A fumigant action was determined by randomly placing cockroaches in square glass jars having a cotton ball (1 cm diameter) that were treated with plant material. Plant material was inserted into the centre of each cotton ball and allows volatilization while preventing the cockroaches from contacting the residue (Appel et al., 2001). Each treatment varies in concentration & number of insects etc. Because the approaches used to analyze repellent and insecticidal assay in the literature vary, each author employs different settings, variables, and parameters when quantifying these actions.

Conclusion and recommendations

The use of plant-based products to control pests has been recommended by researchers. Phytochemicals act as insecticides, repellents, and larvicides. Pests also develop lower resistance against plant-based products because of the presence of different phytochemicals like flavonoids, alkaloids, terpenoids, tannins, phenols, etc. Although chemical pesticides give effective control to cockroaches but considering an assessment of marketed formulations and crude preparations that is harmful to humans as well as non-target organisms, preference should be given to products based on indigenous plant species that are abundantly available. The best treatment is a water extract from the plant that is cheap and also safer for other organisms. Currently, many scientists in industry and academia are attempting to extract beneficial chemicals from plants for use as natural pesticides. Plant-based products have been utilized as a personal protective strategy against insects in traditional pest management practices since the dawn of time. Plant-derived products should be used worldwide commercially as synthetic pesticides or insecticides that are being used worldwide. Consumers have recently become more interested in commercial products using plant-based components, which are widely considered "safe" in comparison to long-established synthetic insecticides. From this review, it has been concluded that the plant kingdom has extensive amounts of phytochemical substances that could be used in integrated pest management to control cockroaches as well as other insects. Plant extracts gave favorable results against cockroaches, but proper ready-to-made formulation should be available so that it can be easy to use. The main component of plants that are more effective in the control of cockroaches should be extracted and used against the control of this pest. Moreover, the collection of this information provided data to general people with a most

welcomed additional about plants to control this household pest.

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