Botanical insecticide as simple extractives for pest control

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Abstract: One of the most important global problems is protecting crops from insects. For the control of insects, synthetic chemicals are continuously used, and their toxicity endangers health of farm operators, animals and food consumers. The negative effects on human health led to a resurgence of interest in botanical insecticides due to their minimal costs and ecological side effects. In this, we review the use of plant compounds (essential oils, flavonoids, alkaloids, glycosides, esters and fatty acids) 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. Botanical insecticides affect only target insects, not destroy beneficial natural enemies and provide residue-free food and safe environment. We, therefore, recommend using botanical insecticides as an integrated insect management program which can greatly reduce the use of synthetic insecticides.

Keywords: natural products; insecticides; active constituents; crop protection; insect

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PUBLIC INTEREST STATEMENT

Provision of food has always been a challenge facing mankind. A major cornerstone in this challenge is the competition from insects. Insect pests inflict damage to humans, farm animals and crops. They are responsible for destroying one fifth of the world’s total crop production annually. Considerable losses of agricultural products add a serious burden to people’s daily life. There is an urgent need to move toward natural products as insecticides because it reduces negative impacts to human health and the environment, and we recommend the botanical insecticides to reduce the insect population and increase food production. Therefore, this study is useful for farmers, producers and exporters of crops and recommends the use of botanical insecticides as an alternative to chemicals or synthetic insecticides to eliminate insects and maintain crops and meet the risks of food shortages as well as the preservation of the environment and human and animal health.
1. Introduction
Insects are the most diverse species of animals living on earth and can be found in all habitats. Less than 0.5% of the total number of the known insect species are considered pests, and only a few of these can be a serious menace to people. Insects inflict damage to humans, farm animals and crops. Some insects can constitute a major threat to entire countries or a group of nations. One prominent example is the tsetse fly that puts about 100 million people and 60 million head of cattle at risk in sub-Saharan Africa due to the transmission of trypanosomiasis (ICIPE, 1997; Imms, 1964).

Provision of food has always been a challenge facing mankind. A major cornerstone in this challenge is the competition from insects. Herbivorous insects are said to be responsible for destroying one-fifth of the world’s total crop production annually. Particularly in the tropics and sub-tropics, where the climate provides a highly favorable environment for a wide range of insects. In the developing countries, the problem of competition from insects is further complicated with a rapid annual increase in the human population. Taking into consideration sudden problems caused by drought in places such as Africa, considerable losses of agricultural products add a serious burden to people’s daily life. The introduction of alien insects into new habitats due to the global increase of trade and transport causes another dilemma. Insects inflict their damage on stored products mainly by direct feeding. Some species feed on the endosperm causing loss of weight and quality, while other species feed on the germ, resulting in poor seed germination and less viability. Thus, due to damage done by insects, grains lose value for marketing, consumption or planting. In addition to direct consumption of the product, insect pests contaminate their feeding media through excretion, molting, dead bodies and their own existence in the product, which is not commercially desirable. Damage done by insects encourages infection with bacterial and fungal diseases through transmission of their spores (Malek & Parveen, 1989; Santos, Maia, & Cruz, 1990).

In this review, we will focus on biological control of insects in crop production using botanical products. We provide an overview of botanical insecticides from the chemical point of view and classify their effects on insects.

2. Types of botanical insecticides

2.1. Essential oils
Plant secondary natural products are natural chemicals extracted from plants and used as an excellent alternative to synthetic or chemical pesticides (Regnault-Roger & Philogène, 2008; Sithisut, Fields, & Chandrapathaya, 2011). In addition insecticide resistance to synthetic pesticides, which led to a significant losses of food arising from failure of chemicals in pest and annually caused economic losses of several billion dollars worldwide (Elzen & Hardee, 2003; Pereira, Sanoveerappanavar, & Murthy, 2006; Shelton, Zhao, & Roush, 2002). Furthermore, United States Food and Drug Administration (FDA) recognized botanical pesticides (essential oils) as safe than synthetic pesticides which caused increase in risk of ozone depletion, neurotoxic, carcinogenic, teratogenic and mutagenic effects in non-targets and cross- and multi-resistance in insects (Regnault-Roger, Vincent, & Arnason, 2012).

Essential oils extracted from aromatic plants have increased considerably as insecticides owing to their popularity with organic growers and environmentally conscious consumers. They have repellent, insecticidal, antifeedants, growth inhibitors, oviposition inhibitors, oviicides, and growth-reducing effects on a variety of insects (Don-Perdo, 1996; Elzen & Hardee, 2003; Koshier & Sedy, 2001; Lu, 1995; Pereira et al., 2006; Regnault-Roger et al., 2012; Shelton et al., 2002; Sithisut et al., 2011; Tripathi, Prajapati, Khanuja, & Kumar, 2003). Essential oils possess interesting larvicidal effects on Limantria dispar (Lepidoptera: Lymantridae, gypsy moth) larvae (Moretti, Sanna-Passino, Demontis, & Bazzoni, 2000), insecticidal activity, repellent properties against ants, cockroach, bedbugs, head lice and moth and toxic to termites. Mentha piperita oil repels ants, flies, lice, moths’ and is effective against Callosobruchus maculatus and Tribolium castanum (Kordali, Cakir, Mavi, Kilic, & Yildirim, 2005). Trachyspermum sp. oil has larvicidal against Aedes aegypti and southern house
mosquito, *Culex quinquefasciatus* (Tripathi et al., 2000). Nepetalactone, the active constituent in catnip (*Nepeta cataria*) essential oil is highly effective for repelling mosquitoes, bees and other flying insects. It repels mosquitoes more than DEET. It is particularly effective against *Ae. aegypti* mosquito, a vector for yellow fever virus. Oils of *Zingiber officinalis* rhizomes and *Piper cubeb* berries were exhibited insecticidal and antifeeding activities against *Triabolium castaneum* and *Sitophilus oryzae* (Chaubey, 2012a, 2012b). Tagetes species oil possesses as anti-insect activity on *Ceratitis capitata* and *Triatoma infestans* (López et al., 2011). *Melaleuca alternifolia* essential oil possesses the fumigant toxicity against *Sitophilus zeamais* (Min et al., 2016). Rosemary, oregano, yarrow, eucalyptus and mint oils used as the safe compounds for surface treating or fumigation in cockroach control. Oregano oil used as a potential repellent against *Supella longipalpa* (Sharififard, Safdari, Siahpoush, Hamid, & Kassi, 2016). Kanat, Haky, and Alma (2003) found that essential oils of many plants have insecticidal effects against the larvae of pine processionary moth, *Thaumetopoea pityocampa*. Also, *Laurus nobilis* essential oil was toxic activities against *Rhyzopertha dominica* and *T. castaneum* (Ben Jembo, Tersim, Toudert, & Khouja, 2012). *Lavandula hybrida*, *Rosmarinus officinalis*, and *Eucalyptus globulus* oils were insecticidal on *Anthocorynce obteuts* adults (Papachristos, Karamanol, Stamopoulos, & Menkissoglu-Spirodi, 2004). Moreover, essential oil of *Tagetes minuta* has toxicity against *Cochliomyia macellaria* (Diptera: Calliphoridae) and as acaricidal, repellent (Chaaban, de Souza, Martins, Bertoldi, & Molento, 2017). Eugenol which the principle compound of the essential oils from basil oil have a strong repellent effect on mosquitoes and linalool also in basil oil has toxic effect to the *Bruchid zabrotes* sub fasciatus and other storage pests (Chogo & Crank, 1981; Weaver, Dunkel, Ntezurubanza, Jackson, & Stock, 1991). Essential oil of *Zingiber zerumbet* has repellent against *Lasioderma serricorne* (Wu et al., 2017). *Juniperus procera* essential oil was exhibited significant repellent against the malarial vector *Anopheles arabiensis* (Karunamoorthi, Girmay, & Cantrell, 2008). Terpinen-4-ol, 1,8-cineol, verbamene and camphorin Eucalyptus oil were active against *Anopheles arabiensis* (Karunamoorthi, Girmay, & Cantrell, 2008; Fradin & Day, 2002; Isman & Machial, 2006). Lucia et al. (2007) reported that essential oil from *Eucalyptus globules* is toxic to *Ae. aegypti* larvae. Seyoum, Killeen, Kabiru, Knols, and Hassanali (2003) reported that burning of leaves of *Eucalyptus citriodora* used as protection against mosquitoes in Africa. Also, CDC (Center for Disease Control and Prevention, USA) recommended the use of lemon eucalyptus oil (with p-menthane-3,8-diol, PMD, as active ingredient) for protection against West Nile virus that causes neurological disease or even death and is spread by mosquitoes (CDC, 2005).

Toloza et al. (2006) concluded the fumigant toxicity/repellent activity of essential oil from *Eucalyptus cinearea*, *Eucalyptus viminalis*, and *Eucalyptus saligna*, against permethrin-resistant human head lice. The pesticidal and antifeeding activities of eucalyptus oils has been due to 1,8-cineole, citronellal, citronellyl acetate, p-cymene, eucamalol, limonene, linalool, α-pinene, Υ-terpinene, α-terpineol, alloocimene, and aromadendrene components (Batish, Singh, Setia, Kaur, & Kohli, 2006; Chimanga et al., 2002; Li, Madden, & Potts, 1996; Liu, Chen, Wang, Xie, & Xu, 2008; Watanabe et al., 1993). Eucalyptus oils rich in cineole have affective against varroa mite, *Varroa jacobsoni*-an important parasite of honey bee (Calderone & Spivak, 1995), *Tetranychus urticae*, *Phytoseiulus persimilis* and *Dermatophagoides pteronyssinus* (Choi, Lee, Park, & Ahn, 2004; El-Zemity, Watanabe et al., 1993). Eucalyptus essential oil was exhibited significant repellent against the malarial vector *Anopheles arabiensis* (Karunamoorthi, Girmay, & Cantrell, 2008). Terpinen-4-ol, 1,8-cineol, verbamene and camphorin Eucalyptus oil were active against *An. arabiensis* adults (Tholl, 2006), antifeedant against biting insects, insecticidal agents and prevent mosquito bite (Bakkali, Averbeck, Averbeck, & Idaomar, 2008; Batish, Singh, Kohli, & Kaur, 2008; Fradin & Day, 2002; Isman & Machial, 2006). Lucia et al. (2007) reported that essential oil from *Eucalyptus globules* is toxic to *Ae. aegypti* larvae. Seyoum, Killeen, Kabiru, Knols, and Hassanali (2003) reported that burning of leaves of *Eucalyptus citriodora* used as protection against mosquitoes in Africa. Also, CDC (Center for Disease Control and Prevention, USA) recommended the use of lemon eucalyptus oil (with p-menthane-3,8-diol, PMD, as active ingredient) for protection against West Nile virus that causes neurological disease or even death and is spread by mosquitoes (CDC, 2005).
2.2. Alkaloids

Alkaloids are the most important group of natural substances playing an important role in insecticidal (Balandrin, Klocke, Wurtele, & Bollinger, 1985; Rattan, 2010). Wachira et al. (2014) concluded that pyridine alkaloids extracted from *Ricinus communis* against the malaria vector *Anopheles gambiae*. Furacoumarin and quinoline alkaloids extracted from *Ruta chalepensis* leaves showed larvicidal and antifeedant activities against the larvae *Spodoptera littoralis* (Emam, Swelam, & Megally, 2009). Acheuk and Doumandji-Mitiche (2013) found that alkaloids extract of *Pergularia tomentosa* caused antifeeding and larvicidal effects. Lee (2000) concluded that piperonaline and piperidine alkaloids have mosquito larvicidal activity. Alkaloids from *Arachis hypogaea* extract have larvicidal activity against chikungunya and malarial vectors (Velu et al., 2015).

2.3. Flavonoids

Flavonoids could be useful in a pest-management strategy. Flavonoids play an important role in the protection of plants against plant feeding insects’ and herbivores (Acheuk & Doumandji-Mitiche, 2013). Both flavonoids and isoflavonoids protect the plant against insect pests by influencing their behavior, growth, and development (Simmonds, 2003; Simmonds & Stevenson, 2001). Rutin and quercetin-3-glucoside in *Pinus banksiana* inhibit the development and increase the mortality of *L. dispar* (Gould & Lister, 2006). Quercetin and rutin glycosides in peanuts caused increased mortality of the tobacco armyworm (*Spodoptera litura*). In rice, three flavone glucosides inhibit digestion in insects and function as deterrent agents in *Nilaparvata lugens* and herbivores (Acheuk & Doumandji-Mitiche, 2013). Diwan and Saxena (2010) found that flavinoid glycosides isolated from *Tephrosia purpuria* showed insecticidal property on *C. maculatus* grubs. Isoflavonoids and proanthocyanidins are other classes of flavonoids responsible for plant protection against insects. For example, naringenin procyanidin inhibits the development of *Aphis craccivora* and herbivores (Acheuk & Doumandji-Mitiche, 2013). Kumar, Bhadauria, and Mishra (2015) concluded that quercetin/azadirachtin insecticide can be a safe and efficient insecticide which improved the activity of *Euphaedra orientalis* and is non-toxic to it, and also is environmentally less harmful as it is easily biodegradable. Goławska, Sprawka, Łukasik, and Goławski (2014) found that two polyphenolic flavonoids (flavanone naringenin and flavonol quercetin) used as insecticides of the pea aphid, *Acyrthosiphon pisum* (Hemiptera: Aphididae). Santos et al. (2016) conclude that *Tagetes erecta* and *Tagetes patula* have phytotoxic compounds (flavonoids) that can promote and expand its use as a natural insecticide. Morimoto, Kumeda, and Komai (2000) showed that flavonoids can act as feeding deterrents. Flavonoids from *A. hypogaea* extract have larvicidal activity against chikungunya and malarial vectors (Velu et al., 2015).

Goławska and Łukasik (2012) showed the effects of isoflavone genistein and flavone luteolin on the feeding behavior of the pea aphid. Flavonoid glycosides in alfalfa affect feeding behavior of pea aphid (Goławska, Łukasik, Goralska, Kanust, & Janda, 2010; Goławska, Łukasik, Kapusta, & Janda, 2012). Goławska, Sprawka, Łukasik, and Goławski (2014) found that two polyphenolic flavonoids (flavanone naringenin and flavonol quercetin) used as insecticides of the pea aphid, *Acyrthosiphon pisum* (Hemiptera: Aphididae). Santos et al. (2016) conclude that *Tagetes erecta* and *Tagetes patula* have phytotoxic compounds (flavonoids) that can promote and expand its use as a natural insecticide. Goławska, Kapusta, Łukasik, and Wojcicka (2008) suggests that quercetin, kaempferol + RCO-, kaempferol, tricin, apigenin + RCO-, and apigenin are good for control of the insect pests.

2.4. Glycosides

Cyanogenic glucosides presented in plant species and considered to have an important role in plant defense against herbivores (Zagrobly et al., 2004). Al-Rajhy, Alahmed, Hussein, and Kheir (2003) concluded that the cardiac glycoside, digitoxin, from *Digitalis purpurea*, a cardiac glycosidal (cardenolide) extract from *Calotropis procera*, azadirachtin and neem oil from *Azadirachta indica* posses against larvae and adult stages of the camel tick, *Hyalomma dromedarii*. Also, Kubo and Kim (1989) found that flavan glycosides, *Viscutin-1, -2* and -3, which exhibit insect growth inhibitory activity against the cotton pest insect; *Pectinophora gossypiella*. However, iridoid glycosides posses as insect antifeeding on gypsy moths (*L. dispar*, Lymantriidae) and buckeeyes (*Junonia coenia*, Nymphalidae) (Bowers & Puttick, 1989). Also, cyanogenic glycosides are known as plant defense chemicals and found in cassava, bamboo, flax, and other plants. They are effective against stored-product insects as fumigants. Due to their insecticidal activity to insects, cyanohydrins can be used as an alternative...
fumigant and also as soil fumigants (Park & Coats, 2002). Dave and Lediwane (2012) found that anthraquinones isolated from Cassia species possess antimalarial and insecticidal activity. Glycosides from A. hypogaea extract have larvicidal activity against chikungunya and malarial vectors (Velu et al., 2015). Juvenogens have a potential application in insect pest control (Wimmer et al., 2007).

2.5. Esters and fatty acids

Allyl cinnamate caused rapid toxic effects in S. littoralis larvae at low concentrations potential for use in pest control (Giner, Avilla, Balcells, Caccia, & Smagghe, 2012). Schmidt, Tomasi, Pasqualini, and Ioriatti (2008) demonstrated that ethyl (E,Z)-2,4-decadienoate (pear ester) have insecticide activity against Cydia pomonella.

Fatty acids methyl esters were isolated from Solanum lycocarpum have larvicidal activity against the vector C. quinquefasciatus (Silva, Ribeiro Neto, Alves, & Li, 2015). Mullens, Reifenrath, and Butler (2009) showed that saturated fatty acids (particularly C8, C9 and C10) used as repellents or antifeedants against houseflies, horn flies and stable flies. Samuel, Oliver, Wood, Coetsee, and Brooke (2015) concluded that fatty acids mixture (C8910) has toxicity and repellence against insecticide susceptible and resistant strains of the major malaria vector Anopheles funestus. Yousef, EL-Lakwah, and EL Sayed (2013) reported that toxicity and reduction in larval body weight of linoleic acid against the larvae of S. littoralis.

3. Insecticide effects on insects

Botanical insecticides affect various insects in different ways depending on the physiological characteristics of the insect species as well as the type of the insecticidal plant. The components of various botanical insecticidal can be classified into six groups namely; repellents, feeding deterrents/antifeedants, toxicants, growth retardants, chemosterilants, and attractants (Rajashekar, Bakhavatsalam, & Shivanandappa, 2012).

3.1. Repellents

A botanical pesticide have a repellent property, where keeps away the insect pest, and protect the crops (Isman, 2006) with minimal impact on the ecosystem, as they drive away the insect pest from the treated materials by stimulating olfactory or other receptors (Talukder, 2006; Talukder, Islam, Hossain, Rahman, & Alam, 2004). Botanical pesticides are considered safe in pest control because they have low or none pesticide residue making them safe to the people, environment and ecosystem (Talukder et al., 2004). Ghavami, Poorrastgoo, Taghiloo, and Mohammadi (2017) found that essential oils of Ziziphora tenuiore, Myrtus communis, Achillea wilhelmsii and M. piperita have repellent activities against human fleas. Rahdari and Hamzeh (2017) demonstrated the efficacy of M. piperita, R. officinalis, and Coriandrum sativum oils for applying in organic food production due to repellent activity of essential oils on Tribolium confusum. Zhang et al. (2017) reported the repellent activities of six Zanthoxylum species including Z. armatum, Z. dimorphophyllyum, Z. dimorphophyllyum var. spinifolium, Z. pisezkiii, Z. stenophyllyum, and Z. dissitum essential oils against two storage pests including T. castaneum and L. serricorne adults and the essential oils of these six Zanthoxylum species essential oils possessed significant repellent activities against T. castaneum and L. serricorne adults. The different repellent activities on two insects might be attributed to the different anti-insect mechanism and different non persistent volatility of essential oil sample. Kimutai et al. (2017) demonstrated that the essential oils of Cymbopogon citratus and T. minuta on the sandfly, Phlebotomus duboscqi. However, the effectiveness of the repellents depends on multiple factors including the type of repellents (active ingredients), formulation, mode of application, environmental factors (temperature, humidity, and wind), the attractiveness of individual people to insects, loss due to removal by perspiration and abrasion, the sensitivity of the insects to repellents, and the biting density. In addition, Origanum onites essential oil had repellent activity against Amblyomma americanum (L.) and A. aegypti (L.). Carvacrol and thymol were strongly repellent to A. aegypti and A. americanum. Thus, carvacrol-rich O. onites essential oil, carvacrol, and possibly thymol appear to have potential for use to protect humans and domestic animals against mosquitoes and ticks.
Various natural fatty acids have insecticidal properties, some involving action on acetylcholinesterase and octopaminergic receptors (Perumalsamy, Jang, Kim, Kadarkarai, & Ahn, 2015). A saturated fatty acid mixture composed of octanoic acid (also called caprylic acid, nonaoic acid and decanoic acid (also called capric acid), collectively called “C8910 acids” (C8, C9, and C10 mixture), repelled horn flies. C8910 acids deterred horn flies from feeding by > 85% and the pest was also strongly repelled (Zhu, Brewer, Boxler, Friesen, & Taylor, 2015). Feeding deterrence caused by C8910 acids and > 50% antifeedancy was observed (Zhu et al., 2015). The naturally occurring oleic and linoleic acids, and methyl oleate synergized the repellency of DEET and the monoterpenoids cuminyl alcohol, cuminaldehyde, and α-phellandrene (Hieu, Choi, Kim, Wang, & Ahn, 2015; Showler, 2017).

3.2. Feeding deterrents/antifeedants
Botanical pesticides that inhibit feeding or disrupt insect feeding by rendering the treated materials unattractive or unpalatable (Rajashekar et al., 2012; Talukder, 2006). The insects remain on the treated material indefinitely and eventually starve to death. Liao et al. (2017) demonstrated that oil of *M. alternifolia* and their chemical constituents possessed obvious antifeedant activities against *Helicoverpa armigera* Hubner. The phytoconstituents found in the leaf extract of *Khaya senegalensis* include tannins, saponins, flavonoids, steroids, and alkaldoids may have been responsible for the mortality of *Dinoderus porcellus* (Loko et al., 2017). Chaudhary et al. (2017) and Ghoneim and Hamadah (2017) pointed that azadirachtin which is prominent constituent of neem established as a pivotal insecticidal ingredient. It acts as an antifeedant, repellent, and repugnant agent and induces sterility in insects by preventing oviposition and interrupting sperm production in males. The same result obtained by Abdullah et al. (2017) who found that, 1,8-cineol found in Galangal essential oil exhibited antifeedant activity, repellent activity, and toxicity effect toward the termites. Jose and Sujatha (2017) revealed that terpenoids, coumarin and phenols, present in the methanol extracts of *Gliciridium sepium* exhibited significant antifeedant activity. This indicated that the active compounds present in the plant inhibit the larval feeding behavior while others disrupt hormonal balance or make the food unpalatable. These active substances may directly act on the chemosensilla of the larvae resulting in feeding deterrence.

3.3. Toxicity
Some botanical pesticides are toxic cause death to stored product insects (Padin, Fuse, Urrutia, & DalBello, 2013). Rotenone is considered as a toxic compound since it is a mitochondrial poison which blocks the electron transport chain and prevents energy production (Hollingworth, Ahammadsahib, Gadelhak, & McLaughlin, 1994). As an insecticide, it is a stomach poison because it must be ingested to be effective (Isman, 2006). Essential oil of *Lavandula angustifolia* exhibited good fumigant and contact toxicity against granary weevil adults. In addition, a strong repellent activity is able to disrupt granary weevil orientation to an attractive host substrate (Germinara et al., 2017). Trivedi, Nayak, and Kumar (2017) demonstrated fumigant toxicity against the stored grain pest *Callosobruchus chinensis*. The essential oils of cinnamon, clove, rosemary, bergamot, and Japanese mint showed potential to be developed as possible natural fumigants or repellents for control of the pulse beetle. Lucia, Tolaza, Guzmán, Ortega, and Rubio (2017) found that the mortality of adults and eggs for head lice associated with the use of (geraniol, citronellol, 1,8-cineole, linalool, α-terpinol, nonyl alcohol, thymol, menthol, carvacrol, and eugenol) essential oils. Bouguerra, Djebbar, and Soltani (2017) showed that *Thymus vulgaris* essential oil exhibited significant antifeedant activity. This indicated that the active compounds present in the plant inhibit the larval feeding behavior while others disrupt hormonal balance or make the food unpalatable. These active substances may directly act on the chemosensilla of the larvae resulting in feeding deterrence.

Wu et al. (2017) observed the toxicity and repellent activities of the rhizomes of *Z. zerumbet* (L.) Smith (Zingiberaceae) essential oil contains the component α-caryophyllene against cigarette beetles (*L. serricorne*). Alkan, Gokce, and Kara (2017) indicate that *Heracleum platytaenium* and *Humulus lupulus* extracts have great potentials as insecticides in the management of larvae of *Leptinotarsa decemlineata*. Papanastasiou et al. (2017) showed the toxicity of limonene, linalool and α-pinene on adult Mediterranean fruit flies. Qari, Nilly, Abdel-Fattah, and Shehawy (2017) showed DNA damage
due to alterations in enzymatic system (acetylcholinesterase, acid phosphatase, alkaline phosphatase, lactate dehydrogenase and phenol oxidase), total protein and DNA concentration after treatment with essential oils of Citrus aurantium, Eruca sativa, Z. officinale and Origanum majorana against R. dominica. Park, Jeon, Lee, Chung, and Lee (2017) demonstrated that T. vulgaris oil had the highest insecticidal toxicity followed by R. graveolens, C. aurantium, L. petersonii, and A. millefolium oils. The insecticidal toxicity of T. vulgaris oil against P. shantungensis nymphs was about 1.3-fold more than that against P. shantungensis adults. Differences in the insecticidal toxicities of plant-derived oils may be explained on the basis of species-specific responses to plant species, phytochemicals, and the weight and size of P. shantungensis adults and nymphs.

3.4. Growth retardants and development inhibitors

Botanical pesticides showed deleterious effects on the growth and development of insects, reducing the weight of larva, pupa and adult stages and lengthening the development stages (Talukder, 2006). Plant derivatives also reduce the survival rates of larvae and pupae as well as adult emergence (Koul, Waliai, & Dhaliwal, 2008). It has been reported that both azadiracthin and neem seed oil increased aphid nymphal mortality significantly at 80 and 77%, respectively, and at the same time increasing development time of those surviving to adulthood (Kraiss & Cullen, 2008). Many botanical pesticides have been reported to have a pronounced effect on the developmental period, growth, and adult emergence (Shaalan, Canyon, Younes, Abdel-Wahab, & Mansour, 2005).

3.5. Sterility/reproduction inhibitors

Sterility can be induced by sterile insect technique (SIT) or a chemosterilant, a chemical compound that interferes with the reproductive potential of sexually reproducing organism (Morrison et al., 2010). Chemosterilants are used to control economically destructive or disease-causing pests (usually insects) by causing temporary or permanent sterility of one or both of the sexes or preventing maturation of the young to a sexually functional adult stage (Navarro-Llopis, Vacas, Sanchis, Primo, & Alfaro, 2011; Wilke et al., 2009). It has been reported that plant parts, oil, extracts, and powder mixed with grain reduced insect oviposition, egg hatchability, postembryonic, and progeny development (Asawalam & Adesiyan, 2001; Shaalan et al., 2005). Hexane extracts of Andrographis lineata, A. paniculata, and T. erecta showed 100% ovicidal activity against Anopheles subpictus (Elango et al., 2009). Some botanical insecticides are used as chemosterilants, for example, at the physiological level azadiracthin blocks the synthesis and release of molting hormones from the prothoracic gland, leading to incomplete ecdisis in immature insects and in adult insects it leads to sterility (Isman, 2006).

Garlic essential oil and its constituents, diallyl sulfide and diallyl disulfide have been highly toxic to S. zeamais and T. castaneum (Ho, Koh, Ma, Huang, & Sim, 1996; Huang, Lam, & Ho, 2000) at different developmental stages. Plata-Rueda et al. (2017) showed that Tenebrio molitor was more susceptible in the pupal stage followed by larvae and adults exposed to diallyl sulfide and diallyl disulfide. One possible explanation for the developmental stages difference is that efficacy may be affected by the penetration of the garlic compounds into the body and the ability of the insect to metabolize these compounds. When insects exposed to the garlic essential oil displayed altered locomotion activity, and muscle contractions and paralysis were observed. Paralysis and muscle contractions can be explained by the toxic effect in the nervous system. The toxicity of essential oils in insects indicates neurotoxic action with hyperactivity, hyperextension of the legs and abdomen and rapid knock-down effect or immobilization (Prowse, Galloway, & Foggo, 2006; Zhao et al., 2013). Acetylcholinesterase is an enzyme that has been shown to be inhibited by garlic compounds and can act only or in synergism as diallyl disulfide, diallyl trisulfide, and allicin (Bhatnagar-Thomas & Pal, 1974; Singh & Singh, 1996). Diallyl sulfide in garlic compounds have toxic effect in T. molitor and may cause inhibition by cross-linking with essential thiol compounds in enzyme structures, altering the functional shape of the protein and denaturation (Halliwell & Gutteridge, 1999). Also, diallyl disulfide as main volatile compound in garlic essential oil has repellent properties to S. zeamais and T. castaneum (Huang et al., 2000). Diallyl disulfide, and diallyl sulfide have high activities of behavioral deterrence against T. molitor, as evaluated by the behavioral responses of larvae and adults to
different odor sources and the number of insects repelled, indicating their potential to the pest control in stored products. As well as garlic essential oil compromised the respiration rate of T. molitor. Thus, low respiration rate is an indicator of physiological stress, and essential oils can compromise insect respiration by impairing muscle activity, leading to paralysis (Correa, Faroni, Haddi, Oliveira, & Pereira, 2015; de Araújo et al., 2017; Guedes, Oliveira, Guedes, Ribeiro, & Serrão, 2006).

Dehghani-Samani, Madreseh-Ghahfarokhi, Dehghani-Samani, and Pirali-Kheirabadi (2015) showed that essential oil of E. globulus had repellent activity against Dermanyssus gallinae due to the essential oil components such as 1, 8-cineole, citronellal, citronellyl acetate, p-cymene, eucamalol, limonene, linalool, α-pinene, g-terpinene, α-terpineol, alloocimene, and aromadendrene. Among the various components of eucalyptus oil, 1, 8-cineole is the most important one which is largely responsible for a variety of its pesticidal properties and insecticide effects. Jayakumar, Arivoli, Raveen, and Tennyson (2017) recorded the repellent activity of camphor, citronella, eucalyptus, lemon and wintergreen oil essential oils against stored product pests; the adult rice weevil S. oryzae Linnaeus 1763 (Coleoptera: Curculionidae) due to essential oils components repellent nor attractant activity. The protection of stored products and the phytochemical constituents from essential oils can work synergistically, improving their effectiveness.

Ho, Ma, Goh, and Sim (1995) concluding that adult mortality might be attributed to the contact toxicity or to the abrasive effect on the pest cuticle (Mathur, Shankar, & Ram, 1985), which might also interfere with the respiratory mechanism of insect (Agarwal, Lal, & Gupta, 1988; Kim, Roh, Kim, Lee, & Ahn, 2003; Schoonhoven, 1978). Fumigation studies showed that the essential oils had a “knock down effect” on the test insect. Essential oils act by inhibiting insect acetylcholinesterase (AChE) and thus, ultimately blocking the nerve functions. Also, Obeng-Ofori and Amitaye (2005) who observed signs of immobilization with flexed legs and clinging to the grain outstretched meta thoracic wings from the elytra and paralysis of the dead or dying insects. The enzyme AChE is also the target site of inhibition by organophosphates and carbamate insecticides (Matsumura, 1985). The observed rapid action of essential oils could be attributed to their property of acting in the vapor phase, hence gaining entry into the insect’s internal systems with ease through the spiracles; whereas, in topical application procedures, the insect is protected by its exoskeleton against external influences.

Essential oils possess acute contact and fumigant toxicity to insects (Abdelgaleil, Mohamed, Badawy, & EI-arami, 2009), repellent activity (Nerio, Olivero-Verbel, & Stashenko, 2009), antifeedant activity (Huang et al., 2000), as well as development and growth inhibitory activity (Wallwiitya, Kennedy, & Lowenberger, 2008). Repellent activity has been linked to the presence of essential oils that cause death of insects by inhibiting AChE activity in the nervous system (Houghton, Ren, & Howes, 2006). Essential oils being more useful as insect fumigants (Regnault-Roger & Hamraoui, 1993; Weaver et al., 1991) and have strong toxicity to insects due to high volatility and lipophilic properties can penetrate into insects rapidly and interfere in physiological functions (Lee et al., 2002; Negahban, Moharramipour, & Sefidkon, 2007). Due to their high volatility, they have fumigant and gaseous action on stored product insects. Carvacrol component has broad insecticidal and acaricidal activity against agricultural, stored product, medical pests and acts as a fumigant being highly toxic to adults of S. oryzae (Ahn, Lee, Lee, & Kim, 1998). Besides, menthol, methonene, limonene, β-pipene, α-pipene, pulegone, linalool and linalyl acetate exhibited fumigant toxicity in S. oryzae and inhibited AChE activity (Koul et al., 2008; Lee, Choi, Lee, & Park, 2001; Lee, Lee et al., 2001; Singh, Siddiqui, & Sharma, 1989). Caryophyllene, a volatile compound, was reported to be a strong fumigant and toxic to S. zeamais (Chu, Liu, Jiang, & Liu, 2010).

The insecticidal activity varies with plant-derived material, insect species, and exposure time. The presence of volatile compounds having strong odor would have blocked the tracheal respiration of the insects leading to their death. Similar observation was made by Liu and Ho (1999) against S. zeamais and T. castaneum. Brown (1951) however, pointed out that the amount of fumigant absorbed depends on whether the insect’s initial contact with the fumigant resulted in suppletion or
stimulation of the tracheal opening. Moreover, the ability of the insect to exclude vapor from its cuticle and prevent dehydration of body fluid plays a vital role in susceptibility or tolerance to fumigants of various life stages of insects particularly beetles and weevils infesting stored products (El-Nahal, Schmidt, & Risha, 1989). The toxic effect of essential oils, apart from the variability of phytochemical patterns, involves several other factors. The point of entry of the toxin is one of them where essential oils can be inhaled, ingested or skin absorbed by insects (Regnault-Roger, 1997).

The presence of volatile compounds is responsible for strong odor that could block the tracheal respiration of the insects leading to their death (Pugazhvandan, Ross, & Elumalai, 2012). The mode of action of oils was partially attributed to interference in normal respiration, resulting in suffocation (Schoonhoven, 1978). Most insects breathe through the trachea which usually leads to the opening of the spiracle.

These spiracles might have been blocked thereby leading to suffocation (Adedire, Obembe, Akinkurolere, & Oduleye, 2011; Ileke & Olotuah, 2012). Essential oils are presumed to interfere with basic metabolic, biochemical, physiological, and behavioral functions of insects (Mann & Kaufman, 2012). Essential oils block the spiracles, resulting in blockage of respiratory siphons (asphyxiation) and death (Kaufmann & Briegel, 2004; Rotimi, Chris, Olusola, Joshua, & Josiah, 2011). Further, Rattan (2010) reviewed the mechanism of action of essential oils on the body of insects and documented several physiological disruptions, such as inhibition of AChE, disruption of the molecular events of morphogenesis, and alteration in the behavior and memory of cholinergic system. Of these, the most important activity is the inhibition of AChE activity as it is a key enzyme responsible for terminating the nerve impulse transmission through synaptic pathway. Plant oils affect AChE and have an action on the nervous system (Mikhaiel, 2011). Recent research has demonstrated the interference of Monoterpenes with AChE activity in insects (Chaubey, 2012a, 2012b). Essential oils are lipophilic in nature and can be inhaled or ingested. The rapid action against insect pests is indicative of a neurotoxic mode of action and interference with the neuromodulator octopamine (Enan, 2005) or GABA-gated chloride channels (Priestley, Burgess, & Williamson, 2006).

Several essential oil components act on the octopaminergic system of insects. Octopamine is a neurotransmitter, neurohormone, and circulating neurohormone-neuromodulator, and its disruption results in total breakdown of the nervous system (Holllingworth, Johnstone, & Wright, 1984). Thus, the octopaminergic system of insects represents a target for insect control. Low molecular weight terpenoids are too lipophilic to be soluble in the hemolymph after crossing the cuticle, and the proposed route of entry is tracheae (Veal, 1996) and may also bind to target sites on receptors that modulate nervous activity (Holllingworth et al., 1984) and interrupt normal neurotransmission leading to paralysis and death.

3.6. Attractants
Botanicals chemicals that cause insects to make oriented movements toward their source are called insect attractants. They influence both gustatory (taste) and olfactory (smell) receptor or sensilla. Iso-thiocyanates from seeds of Cruciferae, sugar and molasses and terpenes from bark in with pheromones are natural attractants for various insects of Cruciferae and bark beetles. In onion propylmercapton from Umbelliferae and phenylacetaldehyde from flowers of Araujia serisofera are attracted carrot fly (Psila rosae) and Lepidoptera, respectively. Insect attractants can be used in three ways for the control of insects. In sampling or monitoring insect populations to assess the extent of infestation and decides the measure of control to be adapted in lusting insect to insecticide-coated traps or poison baits and in distracting insects from normal mating, aggregation feeding or oviposition. They do not kill the insects therefore, do not disturb ecosystem. They can be used to misguide the insects to wrong oviposition sites whereby their number will go down by starvation or by producing unfertilized eggs. They cannot be relied as sole control measure used only in integrated control program (Arora, Singh, & Dhawan, 2012).
4. Conclusion
Botanical insecticides are natural chemicals extracted from plants with insecticidal properties and used as an excellent alternative to synthetic or chemical pesticides for crop protection to avoid negative or side effects of synthetic insecticides. Botanical pesticides (essential oils, flavonoids, alkaloids, glycosides, esters and fatty acids) have various chemical properties and modes of action and affect on insects in different ways namely: repellents, feeding deterrents/antifeedants, toxicants, growth retardants, chemosterilants, and attractants. So it is preferable to use the botanical insecticides instead of synthetic insecticide and these botanical insecticides are recognized by organic crop producers in industrialized countries. So, we recommended using botanical insecticidal and being promoted and research is being conducted to find new sources of botanical insecticides.

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References
Abdelgalel, S., Mohamed, M., Badawy, M., & El-arami, S. (2009). Fumigant and contact toxicities of monoterpenes to Sitophilus oryzae (L.) and Tribolium castaneum (Herbst) and their inhibitory effects on acetylcholinesterase activity. Journal of Chemical Ecology, 35, 518–525. https://doi.org/10.1007/s10886-009-9635-3
Abdullah, F., Subramanian, P., Ibrahim, H., Abdul Malek, S. N., Lee, G. S., & Hong, S. L. (2017). Chemical composition, antifeedant, repellent, and toxicity activities of the rhizomes of galangal, Alpinia galanga Against Asian Subterranean Termites, Coptotermes gestroi and Coptotermes curvignathus (Isoptera: Rhinotermitidae). Journal of Insect Science, 15(7), 2015.
Acheuk, F., & Doumandj-Mitiche, B. (2013). Insecticidal activity of alkaloids extract of Pergularia tomentosa (Asclepiadoaceae) against fifth instar larval of Locusta migratoria cinerascens (Fabricius 1781) (Orthoptera: Acrididae). International Journal of Science and Advanced Technology, 3(6), 8–13.
Adedire, C. O., Obembe, O. M., Akinkuolure, R. O., & Oduleye, S. O. (2013). Response of Callosobruchus maculatus Fabricius (Coleoptera: Chrysomelidae: Bruchinae) to extracts of cashew kernels. Journal of Plant Diseases Protection, 118(2), 75–79. https://doi.org/10.1017/SF03356385
Agnawal, A., Lol, S., & Gupta, K. C. (1988). Natural products as protectants of pulse betles. Bulletin of Grain Technology, 26, 154–164.

Ahn, Y. J., Lee, S. B., Lee, H. S., & Kim, G. H. (1998). Insecticidal and acaricidal activity of carvacrol and b-thujaplicine derived from Thujaopsis dolabrata var. hondai sawdust. Journal of Chemical Ecology, 24, 1–90.
Aljabr, A. M., Hussain, A., Rizwan-ul-Haq, M., & Al-Ayedh, H. (2017). Toxicity of plant secondary metabolites modulating detoxification genes expression for natural red palm weevil pesticide development. Molecules, 22, 169. https://doi.org/10.3390/molecules2210169
Alkan, M., Gokce, A., & Kara, K. (2017). Contact toxicity of six plant extracts to different larval stages of Colorado potato beetle (Leptinotarsa decemlineata Say (Col. Chrysomelidae)). Journal of Agricultural Science, 23, 309–316.
Al-Rajhy, D. H., Alahmed, M. A., Hussein, H. I., & Kheir, S. M. (2003). Acaricidal effects of cardiac glycosides, azadirachtin and neem oil against the camel tick, Hyalomma dromedarii (Acari: Ixodidae). Pest Management Science, 59(11), 1250–1254. https://doi.org/10.1002/1526-4998
de Araújo, A. M. N., Faroni, D. L. R., de Oliveira, J. V., Navarro, D. M. F., Barbosa, D. R. S., Breda, M. O., & de Franca, S. M. (2017). Lethal and sublethal responses of Sitophilus zeamais populations to essential oils. Journal of Pest Science, 90(2), 589–600. https://doi.org/10.1007/s10910-016-0882-z
Aref, S. P., Valizadegan, O., & Farashiani, M. E. (2015). Eucalyptus dundasii Maiden essential oil, chemical composition and insecticidal values against Rhyzopertha dominica (F.) and Orzyzephilus surinamensis (L.). Journal of Plant Protection Research, 55, 35–43.
Arora, R., Singh, B., & Dhawan, A. K. (2012). Acheuk, F., & Doumandj-Mitiche, B. (2013). Insecticidal activity of alkaloids extract of Pergularia tomentosa (Asclepiadoaceae) against fifth instar larval of Locusta migratoria cinerascens (Fabricius 1781) (Orthoptera: Acrididae). International Journal of Science and Advanced Technology, 3(6), 8–13. Chemical composition, antifeedant, repellent, and toxicity activities of the rhizomes of galangal, Alpinia galanga Against Asian Subterranean Termites, Coptotermes gestroi and Coptotermes curvignathus (Isoptera: Rhinotermitidae). Journal of Insect Science, 15(7), 2015. Biological effects of essential oils – A review. Food and Chemical Toxicology, 46, 446–475. https://doi.org/10.1016/j.fct.2007.09.106 Natural plant chemicals: Sources of industrial and medicinal materials. Science, 7; 228(4704), 1154–1160. https://doi.org/10.1126/science.3890182 Chemical composition and phototoxicity of volatile essential oils from intact and fallen leaves of Eucalyptus citriodora. Zeitschrift für Naturforschung C, 61, 465–471. Chemical composition and phototoxicity of volatile essential oils from intact and fallen leaves of Eucalyptus citriodora. Zeitschrift für Naturforschung C, 61, 465–471. Red palm weevil pesticide development. Molecules, 22(10), 2166–2174. https://doi.org/10.3390/molecules2210169 Eucalyptus essential oil as a natural pesticide. Forest Ecology and Management, 256, 2166–2174. https://doi.org/10.1016/j.foreco.2008.08.008 Eucalyptus essential oil as a natural pesticide. Forest Ecology and Management, 256, 2166–2174. https://doi.org/10.1016/j.foreco.2008.08.008
Bhatnagar-Thomas, P. L., & Pol, A. K. (1974). Studies on the insecticidal activity of garlic oil 2. Mode of action of the oil as a pesticide in Musca domestica nebuloid Fabr and Tribolium granarium Everts. Journal of Food Science and Technology, 11, 153–158.

Bougourri, N., Djebbar, F. T., & Solunti, N. (2017). Algerian Thymus vulgaris essential oil: Chemical composition and larvicidal activity against the mosquito Culex pipiens. International Journal ofMosquito Research, 4(1), 37–42.

Bowers, M. D., & Puttick, G. M. (1989). Iridoid glycosides and insect feeding preferences: gypsy moths (Lymantria dispar, Lymantriinae) and buckeyes (Junonia coenia, Nymphalidae). Ecological Entomology, 14, 247–256. https://doi.org/10.1111/1365-2311.1989.tb00953.x

Brown, A. W. A. (1951). Insect control by chemicals (p. 817). New York, NY: London: Wiley; Chapman & Hall.

Calderone, N. W., & Spivak, M. (1995). Plant extracts for control of the parasitic mite Varroa jacobsoni (Acari: Varroidae) in colonies of the western honey bee (Hymenoptera: Apidae). Journal of Economic Entomology, 88, 1211–1215. https://doi.org/10.1093/jee/88.5.1211

CDC (Center for Disease Control and Prevention, USA). (2005). CDC adopts new repellent guidance for upcoming mosquito season. Retrieved from http://www.cdc.gov/nicd/dvbid/westnile/RepellentUpdates.htm.

Chaaban, A., de Souza, A. L. F., Martins, C. E. N., Bertoldi, F. C., & Molento, M. B. (2017). Chemical composition of the essential oil of Tagetes minuta and its activity against Cochliomyia macellaria (Diptera: Calliphoridae). European Journal of Medicinal Plants, 18(1), 1–10.

Chagas, A. C. S., Passos, W. M., Prates, H. T., Leitern, R. C., Furlong, J., & Fortes, J. C. P. (2002). Acaricide effect of Eucalyptus spp. essential oils and concentrated emulsion on Boophilus microplus. Brazilian Journal of Veterinary Research and Animal Science, 39, 247–253.

Chaubey, M. K. (2012a). Responses of Tribolium castaneum (Coleoptera: Tenebrionidae) and Stiphopterus oryzae (Coleoptera: Curculionidae) against essential oils and pure compounds. Herba Polonica, 58(3), 33–45.

Chaubey, M. K. (2012b). Biological effects of essential oils against rice weevil Sitophilus oryzae L. (Coleoptera: Curculionidae). Journal of Essential Oil Bearing Plants, 15, 809–815. https://doi.org/10.1080/0972060X.2012.10644124

Chaudhary, S., Kanwar, R. K., Sehgal, R., & Kanwar, J. R. (2017). Progress on based biopesticides in replacing synthetic toxic pesticides. Journal of Pest Science, 9, 79–84. https://doi.org/10.1002/jpes.1064

Cho, W., Lee, S. G., Park, H. M., & Ahn, Y. J. (2004). Toxicity of plant essential oils to Tetranychus urticae (Acari: Tetranychidae) and Phytonemus persimilis (Acari: Phytoseiidae). Journal of Economic Entomology, 97, 553–558. https://doi.org/10.1093/jee/97.2.553

Chu, S. S., Liu, S. L., Jiang, G. H., & Liu, Z. L. (2010). Composition and toxicity of essential oil of Illicium simonsii Maxim (Illiciaceae) fruit against the maize weevil. Records of Natural Products, 4, 205–210.

Cimanga, K., Kambu, K., Tona, L., Apers, S., De Bruyne, T., Hermans, N., Vlietinck, A. J. (2002). Correlation between chemical composition and antibacterial activity of essential oils of some aromatic medicinal plants growing in the Democratic Republic of Congo. Journal of Ethnopharmacology, 78, 213–220. https://doi.org/10.1016/S0378-8741(01)00384-1

Correa, Y. D. C. G., Faroni, L. R., Haddi, K., Oliveira, E. E., & Pereira, E. J. G. (2015). Locomotor and physiological responses induced by clove and cinnamon essential oils in the maize weevil Sitophilus zeamais. Pesticide Biochemistry and Physiology, 125, 31–37. https://doi.org/10.1016/j.pestbp.2015.06.005

Dave, H., & Lediwane, L. (2012). A review on anthraquinones isolated from Cassia species and their applications. Indian Journal of Natural Products and Resources, 3, 295–319.

Dehghani-Samani, A., Madreseh-Ghafori, S., Dehghani-Samani, A., & Pirali-Kheirabadi, K. (2015). Acaricidal and repellent activities of essential oil of Eucalyptus globulus against Dermatophagoides pteronyssinus (Acari: Mite). Journal of Herbs, Spices & Medicinal Plants, 21(4), 81–84.

Dionisio, R. K., & Soeno, R. C. (2010). Insecticidal property of flavonoid isolated from Tephrosia purpurea. International Journal of Chemical Sciences, 8(2), 777–782.

Don-Perdo, K. M. (1996). Investigation of single and joint surfactant insecticidal action of citrus peel oil components. Journal of Pest Science, 46, 79–84.

El-Nahal, A. K. M., Schmidt, G. H., & Risha, E. M. (1989). Vapours of Acorus calamus oil – A space treatment for stored-product insects. Journal of Stored Products Research, 25, 211–216. https://doi.org/10.1016/0022-4741(89)90026-X

El-Zemity, S., Hussien, R., Saher, F., & Ahmed, Z. (2006). Acaricidal activities of some essential oils and their monoterpenoid constituents against house dust mite, Dermatophagoides pteronyssinus (Acari: Pyroglyphidae). Journal of Zhejiang University Science B, 7, 957–962.

Elzen, G. W., & Hardee, D. D. (2003). United state department of agricultural-agricultural research on managing insect resistance to insecticides. Pest Management Science, 59, 770–776. https://doi.org/10.1002/(ISSN)1526-4998

Emran, A. M., Sowelam, E. S., & Megally, N. Y. (2009). Furocoumarin and quinoline alkaloid with larvicidal and antifeedant activities isolated from Ruta chapanensis leaves. Journal of Natural Products, 2, 10–22.

Enan, E. E. (2005). Molecular and pharmacological analysis of an octopamine receptor from american cockroach and fruit fly in response to plant essential oils. Archives of Insect Biochemistry and Physiology, 59, 161–171. https://doi.org/10.1002/(ISSN)1520-6327

Fradin, M. S., & Day, J. F. (2000). Comparative efficacy of insect repellents against mosquito bites. The New England Journal of Medicine, 347, 13–18. https://doi.org/10.1056/NEJM0011699

Gardulfs, A., Wohlfart, I., & Gustafson, R. (2004). A prospective cross-over field trial shows protection of lemon eucalyptus extract against tick bites. Journal of Medical Entomology, 41, 1064–1067. https://doi.org/10.1603/0022-2585-41.6.1064

Germinado, G. S., Distefano, M. G., Acuts, L. D., Pati, S., Delfine, S., Cristofaro, A. D., & Rotundo, G. (2017). Bioactivities of Lavandula angustifolia essential oil against the stored grain pest Sitophilus granarius. Bulletin of Insectology, 70(3), 129–138.

Ghavami, M. B., Pournarostoo, F., Taghiboo, I., & Mohammadi, M. (2017). Repellency effect of essential oils of some native plants and synthetic repellents against human flea, Pulex irritans (Siphonoptera: Pulicidae). Journal of Arthropod-Borne Diseases, 11(2), 105–115.

Ghori, N., & Hamadah, K. (2017). Antifeedant activity and detrimental effect of Nimbecidine (0.03% Azadirachtin) on the nutritional performance of Egyptian cotton leafworm Spodoptera littoralis Boid. (Noctuidae: Lepidoptera). Bio Bulletin, 31, 39–55.
Giner, M., Avillo, J., Balcells, M., Cocco, S., & Smagghe, G. (2012). Toxicity of alleloesters in insect cell lines and in Spodoptera littoralis larvae. Archives of Insect Biochemistry and Physiology, 79(1), 18–30. https://doi.org/10.1002/arch.20799

Goławska, S., & Łukasik, I. (2012). Antifeedant activity of luteolin and genistein against the pea aphid. Journal of Pest Science, 85, 443–450. https://doi.org/10.1007/s10340-012-0452-z

Goławska, S., Kapusta, I., Łukasik, I., & Wojcicka, A. (2008). Effect of phenolics on the pea aphid, Acrystaphis pismum (L.) population on Pismum sativum L. (Fabaceae). PestyCycl-Pesticides, 3–4, 71–77.

Goławska, S., Łukawski, I., Golawska, A., Kapusta, I., & Janda, B. (2010). Alfalfa (Medicago sativa L.) apigenin glycosides and their effect on the pea aphid (Acrystaphis pismum). Polish Journal of Environmental Studies, 19, 913–920.

Goławska, S., Łukasik, I., Kapusta, I., & Janda, B. (2012). Do the contents of luteolin, tricin, and chrysoeriol glycosides in alfalfa (Medicago sativa L.) affect the behavior of pea aphid (Acrystaphis pismum)? Polish Journal of Environmental Studies, 21, 1613–1619.

Goławska, S., Sprawka, I., Łukasik, I., & Goławska, A. (2014). Are naringenin and quercetin useful chemicals in pest-management strategies? Journal of Pest Science, 87, 173–180. https://doi.org/10.1007/s10340-013-0535-5

Gould, K. S., & Lister, C. (2006). Flavonoid functions in plants. In Flavonoids: Chemistry, biochemistry and applications (pp. 397–443). Boca Raton, FL: CRC Press LLC.

Guedes, R. N. C., Oliveira, E. E., Guedes, N. M. P., Ribeiro, B., & Serrão, J. E. (2006). Cost and mitigation of insecticide resistance in the maize weevil, Sitophilus zeamais. Physiological Entomology, 31, 30–38. https://doi.org/10.1111/pen.2006.31.issue-1

Qari, S. H., Niliy, A. H., Abed-Fattah, A. H., & Shehawy, A. A. (2017). Assessment of DNA damage and biochemical responses in Rhyzopertha dominica exposed to some plant volatile oils. Journal of Pharmacology and Toxicology, 12, 87–96. https://doi.org/10.3923/jpt.2017.87.96

Halliwell, B., & Gutteridge, J. M. C. (1999). Free radicals in biology and medicine (3rd ed.). Oxford: Oxford University Press.

Hieu, T. T., Choi, W. S., Kim, S. I., Wang, M., & Ahn, Y. J. (2015). Enhanced repellency of binary mixtures of Coleophomopsis inophyllum nut oil fatty acids or their esters and three terpenoids to Spodoptera littoralis. Pest Management Science, 71, 1213–1218. https://doi.org/10.1002/ps.2015.71.issue-9

Ho, S. H., Ma, Y., Goh, P. M., & Sim, K. X. (1992). Star anise, Illicium verum Hook F., as a potential grain protectant against Tribolium castaneum (Herbst) and Sitophilus zeamais Motschulsky and Sitophilus oryzae (L.). Postharvest Biology and Technology, 6, 341–347. https://doi.org/10.1016/0925-5214(95)00015-X

Ho, S. H., Koh, L., Ma, Y., Huang, Y., & Sim, K. Y. (1996). The oil of garlic, Allium sativum L. (Amaryllidaceae), as potential grain protectant against Tribolium castaneum (Herbst) and Sitophilus zeamais Motsch. Postharvest Biology and Technology, 9, 41–48. https://doi.org/10.1016/0925-5214(96)00018-X

Hollingworth, R. M., Johnstone, E. M., & Wright, N. (1984). Pesticide synthesis through rational approaches. In P. S. Magee, G. K. Kohn, & J. J. Menn (Eds.), ACS symposium series No. 255 (pp. 103–125). Washington, DC: American Chemical Society.

Hollingworth, R., Ahammadshahib, K., Godelhak, G., & McLaughlin, J. (1996). New inhibitors of complex I of the mitochondrial electron transport chain with activity as pesticides. Biochemical Society Transactions, 22(1), 230–233. https://doi.org/10.1042/bst0220230

Houghton, P. J., Ren, Y., & Howes, M. J. (2006). Acetylcholinesterase inhibitors from plants and fungi. Natural Product Reports, 23(2), 181–199. https://doi.org/10.1039/b508966m

Huang, Y., Lorn, S. L., & Ho, S. H. (2000). Bioactivities of essential oils from Elettaria cardamomum (L.) Maton. to Sitophilus zeamais Motschulsky and Tribolium castaneum (Herbst). Journal of Stored Products Research, 36, 107–117. https://doi.org/10.1016/S0022-474X(99)00060-5

ICIPE (International Centre of Insect Physiology and Ecology) (1997). Vision and strategic framework towards 2020. Nairobi: ICIPE Science Press.

Ileke, K. D., & Olotuah, D. F. (2012). Bioactivity of Anacardium occidentale and Allium sativum powders and oils extracts against cowpea bruchid, Callosobruchus maculatus (Fab) (Coleoptera: Bruchidae). International Journal of Biological Science, 4(1), 96–103.

Imms, A. D. (1964). Outlines of entomology (5th ed., p. 224). London: Methuen.

Isman, M. B. (2006). Botanical insecticides, deterrents, and repellents in modern agriculture and an increasingly regulated world. Annual Review of Entomology, 51, 45–66. https://doi.org/10.1146/annurev.ento.51.110104.151146

Isman, M. B., & Machial, C. M. (2006). Pesticides based on plant essential oils: From traditional practice to commercialization. In: Rai, M., Carpinella, M.C. (Eds.), naturally occurring bioactive compounds. Advances in Phytochemistry, 3, 29–44. https://doi.org/10.1016/S1572-557X(06)30029-9

Jayakumar, M., Arivali, S., Raveen, R., & Tennyson, S. (2017). Repellent activity and fumigant toxicity of a few plant oils against the adult rice weevil Sitophilus oryzae Linnaeus 1763 (Coleoptera: Curculionidae). Journal of Entomology and Zoology Studies, 5(2), 324–335.

Jose, S., & Sujatha, K. (2017). Antifeedant activity of different solvent extracts of Gliricidia sepium sepium in third instar larvae of Helicoverpa armigera (Hubner) (Lepidoptera: Noctuidae). International Journal of Advanced Research in Biological Sciences (IJARBS), 4(4), 201–204. https://doi.org/10.22192/jarbs.

Karunamoorthi, K., Girma, A., & Hayleeyesus, S. F. (2014). Mosquito repellent activity of essential oil of Ethiopian ethnomedical plant against Afro-tropical malarial vector Anopheles arabiensis. Journal of King Saud University of Science, 26, 305–310. https://doi.org/10.1016/j.jsus.2014.01.001

Kanat, M., Hakk, M., & Alma, M. (2003). Insecticidal effects of essential oils from various plants against larvae of pine processionary moth (Thaumetopoea pityocampa Schiff) (Lepidoptera: Noctuidae). Pest Management Science, 60, 173–177.

Kaufmann, C., & Briel, S. (1992). Flight performance of the malarial vectors Anopheles gambiae and Anopheles atroparous. Journal of Vector Ecology, 29(1), 140–153.

Kim, S. I., Roh, Y. J., Kim, D. H., Lee, H. S., & Ahn, Y. J. (2003). Insecticidal activities of aromatic plant extracts and essential oils against Sitophilus oryzae and Callosobruchus chinensis. Journal of Stored Products Research, 39, 291–303. https://doi.org/10.1016/S0032-474X(02)00017-6

Kimutai, A., Ng'ayo, M., Mulwa, M., Ngowi, P. G. N., Ingonga, J., Nyamwamu, L. B., & Ngumbi, P. (2017). Repellent effects of the essential oils of Cymbopogon citratus and Tagetes minuta on the sandfly, Phlebotomus duboscqi. BMC Research Notes, 10, 98. https://doi.org/10.1186/s13104-017-2396-0

Kordal, S., Hak, A., Mäki-Arvela, M., Kilic, H., & Yıldırım, A. (2006). Screening of chemical composition and antifungal and antioxidant activities of the essential oils from three Turkish artemisia species. Journal of Agricultural and Food Chemistry, 54, 1408–1416. https://doi.org/10.1021/jf048429n

Kosher, L. E., & Sed, K. A. (2001). Effect of plant volatiles on the feeding and oviposition of Thripstobac. In: R. Marullo, & L. Koud (Eds.), Thrips and Tospoviruses (pp. 185–187). Australia: CSIRO.
Koul, O., Walioli, S., & Dhillon, G. S. (2008). Essential oils as green pesticides: Potential and constraints. Bioprocesses International, 4(1), 63–84.

Kraiss, H., & Cullen, E. M. (2008). Insect growth regulator effects of azadirachtin and neem oil on survivorship, development and fecundity of Aphis glycines (Homoptera: Aphididae) and its predator, Harmonia axyridis (Coleoptera: Coccinellidae). Pest Management Science, 64(6), 660–668. https://doi.org/10.1002/ps.1526-4998

Kubo, I., & Kim, M. (1989). A review of the acceptable daily intakes of pesticides assessed by the world health organization. Regulatory Toxicology and Pharmacology, 21, 351–364.

Lucia, A., Audino, P. G., Seccacini, E., Licastri, S., Zerba, E., & Massi, H. (2007). Lorvicidal effect of Eucalyptus grandis essential oil and turpentine and their major components on Aedes aegypti larvae. Journal of the American Mosquito Control Association, 23, 299–303. https://doi.org/10.2987/8756-971X(2007)23[299:LEOEDE]2.0.CO;2

Lucia, A., Tolosa, A. C., Guzmán, E., Ortega, F., & Rubio, R. G. (2017). Novel polymeric micelles for insect pest control: Encapsulation of essential oil monoterpene inside a trilobic copolymer shell for head lice control. Peer-Reviewed Journal, 5, e3171. https://doi.org/10.7717/peepj.3171

Malek, M., & Parveen, B. (1989). Effect of insects infestation on the weight loss and viability of stored BE paddy. Bangladesh Journal of Zoology, 17(1), 83–85.

Malikjarru, N., Kivity, D. R., Jodah, D. R., Kranthi, S., & Chandra, S. (2004). Influence of foliar chemical compounds on the development of Spodoptera litura in interspecific derivatives of groundnut. Journal of Applied Entomology, 128, 321–328. https://doi.org/10.1111/jen.2004.128.issue-5

Mann, R. S., & Kaufman, P. E. (2011). Natural product pestcides: Their development, delivery and use against insect vectors. Mini-Reviews in Organic Chemistry, 9, 185–202. https://doi.org/10.2174/157019312800600473

Mathur, Y. K., Shankar, K., & Ram, S. (1985). Evaluation of some grain protectants against Callosobruchus chinensis (L.) on black gram. Bulletin of Grain Technology, 23, 255–259.

Matsumura, F. (1983). Toxicology of insecticides (2nd ed., pp. 11–43). New York, NY: Plenum Press. https://doi.org/10.1007/978-1-4613-2491-1

Mikhaylo, A. A. (2011). Potential of some volatile oils in protecting packages of irradiated wheat flour against Ephiosta kuehniella and Tribolium castaneum. Journal of Stored Products Research, 47(4), 357–364. https://doi.org/10.1016/j.jspr.2011.06.002

Min, L., Jin-Jing, X., Liu, Y., Xiang-Wei, W., Ri-Mao, H., ... Hai-Qun, C. (2016). Insecticidal activity of Melaleuca alternifolia essential oil and RNA-seq analysis of Sitophilus zeamais transcriptome in response to oil fumigation. PLoS One, 11(12), e0167484.

Mori, T., M. L., Sanna-Possino, G., Domenis, S., & Bazzoni, E. (2000). Essential oil formulations useful as a new tool for insect pest control. AAPS Pharmaceutical Science and Technology, 3(2), 13.

Morinotta, M., Kumedo, S., & Komai, K. (2009). Insect antifeedant flavonoids from Gnetum affine. Journal of Agricultural and Food Chemistry, 48, 1888–1891. https://doi.org/10.1021/jf990282q

Morison, N. I., Franz, G., Koukidou, M., Miller, T. A., Sacccone, G., Alphay, L. S., ... Polito, L. C. (2010). Genetic improvements to the sterile insect technique for agricultural pests. Asia-Pacific Journal of Molecular Biology and Biotechnology, 18(3), 107–112.

Mullens, B. A., Reifenrath, W. G., & Butler, S. M. (2009). Laboratory trials of fatty acids as repellents or antifeedants against houseflies, horn flies and stable flies (Diptera: Muscidae). Pest Management Science, 65(12), 1360–1366. https://doi.org/10.1002/ps.2155

Novarro-Llopis, V., Vocas, S., Sanchis, J., Primo, J., & Alfaro, C. (2011). Chemosterilant bait stations coupled with sterile insect technique: An integrated strategy to control the Mediterranean fruit fly (Diptera: Tephritidae). Journal of Economic Entomology, 104(5), 1647–1655. https://doi.org/10.1603/EC10448

Negahban, M., Moharramipour, S., & Sefidkon, F. (2007). Fumigant toxicity of essential oil from Artemisia sieberi Besser against three stored product insects. Journal of Stored Products Research, 43(2), 123–128. https://doi.org/10.1016/j.jspr.2006.02.002
Nerio, L. S., Olivero-Verbel, J., & Stashenko, E. (2009). Repellency activity of essential oils from seven aromatic plants grown in Colombia against Sitophilus zeamais Motschulsky (Coleoptera). Journal of Stored Products Research, 45, 212–214. https://doi.org/10.1016/j.jsprr.2009.01.002

Obeng-Ofori, D., & Amtoye, S. (2000). Efficacy of mixing vegetable oils with pirimiphos-methyl against the maize weevil, Sitophilus zeamais Motschulsky, in stored maize. Journal of Stored Products Research, 41(1), 57–66. https://doi.org/10.1016/j.jsprr.2003.11.001

Padin, S. B., Fusa, C., Urrutia, M. L., & DaBello, G. M. (2013). Toxicity and repellency of nine medicinal plants against Tribolium castaneum in stored wheat. Bulletin of Insectology, 66(1), 45–49.

Papachristos, D. P., Karamanolli, K., Stamopoulos, D. C., & Karamanolli, K. (2017). Evaluation of the toxicity and repellent activity of four indigenous products and acylurea compounds. Pest Management Science, 73, 514–520. https://doi.org/10.1002/pmst.201600116

Park, J., Jeon, Y., Lee, C., Chung, N., & Lee, H. (2017). Insecticidal activity of essential oils from Psidium guajava (Myrtaceae) leaves against insect pests. Insect Science, 24(4), 585–593. https://doi.org/10.1111/1095-0011.12214

Rahmati, T., & Hamzei, M. (2017). Repellency effect of essential oils of Mentha piperita, Rosmarinus officinalis and Coriandrum sativum on Tribolium confusum duval (Coleoptera: Tenebrionidae). Chemistry Research Journal, 2(1), 107–112. https://doi.org/10.11648/j.chemres.20120201.1

Regnault-Roger, C. (1997). The potential of botanical essential oils for insect pest control. Integrated Pest Management Reviews, 2, 25–34. https://doi.org/10.1023/A:1018472277889

Regnault-Roger, C., & Hamraoui, A. (1993). Influence d'huiles essentielles sur Acanthoscelides obtectus Say, bruche du haricot. Acta Botanica Gallica, 140, 217–222. https://doi.org/10.1016/12538078(93)1011558

Regnault-Roger, C., & Philogene, B. J. R. (2008). Past and current prospects for the use of botanicals and plant allelochemicals in integrated pest management. Pharmaceutical Biology, 46, 41–52. https://doi.org/10.1080/13880200701729794

Rotimi, O. A., Chris, O. A., Olusola, O. O., Joshua, R., & Josiah, A. O. (2011). Bioefficacy of extracts of some indigenous Nigerian plants on the developmental stages of mosquito (Anopheles gambiae). Jordan Journal of Biological Sciences, 4(6), 237–242.

Samuel, M., Oliver, S. V., Wood, O. R., Coetzee, M., & Brooke, B. D. (2015). Evaluation of the toxicity and repellence of an organic fatty acids mixture (C8910) against insecticide susceptible and resistant strains of the major malaria vector Anopheles funestus Giles (Diptera: Culicidae). Parasites & Vectors, 8, 321. https://doi.org/10.1186/s13071-015-0930-2

Santos, J. P., Maia, J. D. G., & Cruz, I. (1990). Damage to germination of seed caused by maize weevil (Sitophilus zeamais) and Anagousai grain moth (Sitotroga cerealella). Pesquisa Agropecuaria Brasileira, 25(12), 1687–1692.

Santos, P. C., Santos, V. H. M., Mecino, G. F., Andrade, A. R., Pugeiredo, P. A., Moraes, V. M. O., ... Silva, R. M. G. (2016). Larvicidal activity of Toxoptera sitophilus zeamais. Mots. International Journal of Environmental & Agriculture Research, 2(4), 31–38.

Scarpa, S., Tosi, I., Tsinou, E., Sassano, E., & Ioriatti, C. (2008). The biological efficacy of pear ester on the activity of Granulosis virus for codling moth. Journal of Pest Science, 81, 29. https://doi.org/10.1016/j.pestsci.2007.01.018

Schooohoven, A. (1978). The use of vegetable oils to protect stored beans from bruchid attack. Journal of Economic Entomology, 71(2), 254–256. https://doi.org/10.1093/jee/71.2.254

Seyoum, A., Killeen, G. F., Kabiru, E. W., Knols, B. G. I., & Mansour, A. H. (2005). A review of botanical phytochemicals with mosquitocidal potential. Journal of Agricultural and Forest Entomology, 7(1), 26–26.

Sharififard, M., Long, F., & Mansour, A. H. (2005). A review of botanical products and acylurea compounds. Pest Management Science, 61(2), S16–S20.

Sherry, K., & Mansour, A. H. (2005). A review of botanical phytochemicals with mosquitocidal potential. Journal of Agricultural and Forest Entomology, 7(1), 26–26.

Shaalan, E. A. S., Canyon, D., Younes, M. W. F., Abdel-Wahab, H., & Mansour, A. H. (2005). A review of botanical phytochemicals with mosquitocidal potential. Journal of Agricultural and Forest Entomology, 7(1), 26–26.

ShInfadl, M., Safi, F., Shiahou, A., Hamid, H., & Kassiri, H. (2016). Evaluation of some plant essential oils against the brown-banded cockroach, Supella longipalpa (Blattaria: Ectobiidae): A mechanical vector of human pathogens. Journal of Arthropod-Borne Diseases, 10(4), 528–537.

Page 4 of 16
Shelton, A. M., Zhao, J. Z., & Roush, R. T. (2002). Economic, ecological, food safety, and social consequences of the deployment of Bt-transgenic plants. Annual Review of Entomology, 47, 845–861. https://doi.org/10.1146/annurev.ento.47.091201.145309

Showler, A. T. (2017). Botanically based repellent and insecticidal effects against horn flies and stable flies (Diptera: Muscidae). Journal of Integrated Pest Management, 8(1), 1–11.

Shukla, P., Vidyasagar, P. S. P. V., Aldosari, S. A., & Abdel-Azim, M. (2011). Antifeedant activity of three essential oils against the red palm weevil, Rhynchophorus ferrugineus. Bulletin of Insectology, 65(1), 71–76.

Silva, V. C. B., Ribeiro Neto, J. A., Alves, S. N., & Li, L. A. R. S. (2015). Larvicidal activity of oils, fatty acids, and methyl esters from ripe and unripe fruit of Solanum lycocarpum (Solanaceae) against the vector Culex quinquefasciatus (Diptera: Culicidae). Revista da Sociedade Brasileira de Medicina Tropical, 48(5), 610–613. https://doi.org/10.1590/0037-8682-0049-2015

Simmonds, M. S. (2003). Flavonoid–insect interactions: Recent advances in our knowledge. Phytochemistry, 64, 21–30. https://doi.org/10.1016/S0031-9422(03)00293-0

Simmonds, M. S., & Stevenson, P. C. (2001). Effects of isoflavonoids from cicer on larvae of Heliothis paarmigera. Journal of Chemical Ecology, 27, 965–977. https://doi.org/10.1023/A:1010399104206

Singh, V. K., & Singh, D. K. (1996). Enzyme inhibition by alliin, the mullollicidial agent of Allium sativum L. (garlic). Phytotherapy Research, 10, 383–386. https://doi.org/10.1002/ptr.4900100205

Singh, D., Siddiqui, M. S., & Sharma, S. (1989). Reproduction retardant and fumigant properties in essential oils against rice weevil (Coleoptera: Curculionidae) in stored wheat. Journal of Economic Entomology, 82, 727–733. https://doi.org/10.1093/jee/82.4.3727

Sithisut, D., Fields, P. G., & Chandrapothaya, A. (2011). Contact toxicity, feeding reduction and repellency of essential oils from three plants from the ginger family (Zingiberaceae) and their major components against Sitophilus oryzae and Tribolium castaneum. The Journal of Stored Products Research, 47(4), 145–154. https://doi.org/10.1002/psr.2009577

Talukder, F. A. (2008). Plant products as potential stored-product insect management agents-A mini review. Emirates Journal of Food and Agriculture, 18(1), 17–32. https://doi.org/10.1057/ejfa.2008.3

Talukder, F., Islam, M., Hossain, M., Rahaman, M., & Alam, M. (2004). Toxicity effects of botanicals and synthetic insecticides on Tribolium castaneum (Herbst) and Rhynothera dominica (F.) Bangles. Journal of Environmental Sciences, 10(2), 365–371.

Tholl, D. (2008). Terpene synthases and the regulation, diversity and biological roles of terpene metabolism. Current Opinion in Plant Biology, 9, 297–304. https://doi.org/10.1016/jтоп.2008.03.014

Tozolo, A. C., Zygadlo, J., Cetto, G. M., Biurrun, F., Zerba, E., & Piccolo, M. S. (2006). Fumigant and repellent properties of essential oils and component compounds against permethrin-resistant Pediculus humanus capitis (Anoplura: Pediculidae) from Argentina. Journal of Medical Entomology, 43(5), 889–895. https://doi.org/10.1111/j.1537-2926.2006.00394.x

Tripathi, A. K., Prjapati, V., Aggarwal, K. K., Kumar, S., Kukreja, A. K., Dwivedi, S., & Singh, A. K. (2000). Effects of volatile oil constituents of Mentha species against stored grain pests, Callosobruchus maculates and Tribolium castaneum. Journal of Medicinal and Aromatic Plant Sciences, 22, 549–556. https://doi.org/10.1080/10920112.2000.10871670

Tripathi, A. K., Prjapati, V., Khunuj, S. P. S., & Kumar, S. (2003). Effect of d-limonene on three stored-product beetles. Journal of Economic Entomology, 96, 990–995. https://doi.org/10.1093/jee/96.3.990

Trivedi, A., Nayak, N., & Kumar, J. (2017). Fumigant toxicity study of different essential oils against stored grain pest Callosobruchus chinensis. Journal of Pharmacognosy and Phytochemistry, 6(4), 1708–1711.

Velu, L. (1996). The potential effectiveness of essential oils as a treatment for headlice. Pediculosis humanus capitis. Complementary Therapies in Nursing and Midwifery, 2, 97–101. https://doi.org/10.1016/S1353-6117(96)80083-7

Velu, K., Elumalai, D., Hemalatha, P., Babu, M., Janakia, A., & Kaleena, P. K. (2015). Phytochemical screening and larvicolic activity of peel extracts of Arachis hypogaea against chikungunya and malarial vectors. International Journal of Mosquito Research, 2(1), 01–08.

Wachira, S. W., Omar, S., Jacob, J. W., Wahome, M., Alborn, H. T., Spring, D. R., ... Torto, B. (2014). Toxicity of six plant extracts and two pyridine alkaldoids from Ricinus communis against the malaria vector Anopheles gambiae. Parasitology, 7, 3, 312. https://doi.org/10.1186/1756-3305-7-312

Waliwitiya, R., Kennedy, C., & Lowenberger, C. (2008). Larvicidal and oviposition altering activity of monoterpenoids, trans-anethole and rosemary oil to the yellow fever mosquito Aedes aegypti (Diptera: Culicidae). Pest Management Science, 64(1), 241–248. https://doi.org/10.1002/ps.1461

Watanabe, K., Shono, Y., Kakimizu, A., Okada, A., Matsuoi, S., Satoshi, A., & Nishimura, H. (1993). New mosquito repellent from Eucalyptus camaldulensis. Journal of Agricultural and Food Chemistry, 41, 2164–2166. https://doi.org/10.1021/jf00035a065

Weaver, D. K., Dunkel, F. V., Ntezurubanza, L., Jackson, L. L., & Stock, D. T. (1991). The efficacy of linalool, a major component of freshly-milled Ocimum camum Simus (Lamiaceae), for protection against postharvest damage by certain stored product Coleoptera. Journal of Stored Products Research, 27, 213–220. https://doi.org/10.1016/0022-474X(91)9003-U

Wilke, A. B. B., Nimmo, D. D. John, O., Kojijn, B. B., Capurro, M. L., & Marrelli, M. T. (2009). Mini-review: Genetic enhancements to the sterile insect technique to control mosquito populations. Asia-Pacific Journal of Molecular Biology and Biotechnology, 17(3), 65–74.

Wimmer, Z., Alexsandra, J. F. D. M. Flore, Zarevicka, M., Wimmerova, M., Sello, G., & Orsini, F. (2007). Insect pest control agents: Novel chiral butanate esters (juvenogens). Bioorganic & Medicinal Chemistry, 15(18), 6037–6042.

Wu, Y., Guo, S., Huang, D., Wang, C., Wei, J., Li, L., ... Du, S. (2017). Contact and repellent activities of zerumbone and its analogues from Zingiber zerumbet (L.) Smith against Lasioderma serricorne. Journal of Oleo Science, 66(4), 399–405. https://doi.org/10.1016/j.jos.2016166

Yousef, H., EL-Lakwah, S. F., & EL Sayed, Y. A. (2013). Insecticidal activity of linoic acid against Spodoptera littoralis (BOISD.). Egyptian Journal of Agricultural Research, 91(2), 573.

Zagrobelny, M., Bob, S., Rasmussen, A. V., Jørgensen, B., Naumann, C. M., & Møller, B. L. (2004). Cyanogenic glucosides and plant-insect interactions. Phytochemistry, 65(3), 293–306. https://doi.org/10.1016/j.phytochem.2003.10.016

Zhang, W., Zhang, Z., Chen, Z., Liang, J., Geng, Z., Guo, S., ... Deng, Z. (2017). Chemical composition of essential oils from six Zanthoxylum species and their repellent activities against two stored-product insects. Journal of Chemistry, Article ID 1287362, 7 pages.

Zhao, N. N., Zhang, H., Zhang, X. C., Luan, X. B., Zhou, C., Liu, Q. Z., ... Liu, Z. L. (2013). Evaluation of acute toxicity of essential oil of garlic (Allium sativum) and its selected major constituent compounds against overwintering Cacopsylla chinensis (Hemiptera: Psyllidae). Journal of Economic Entomology, 106, 1349–1354. https://doi.org/10.1603/EC12191
Zhao, M. P., Liu, Q. Z., Liu, Q., & Liu, Z. L. (2017). Identification of larvicidal constituents of the essential oil of *Echinops grijsii* roots against the three species of mosquitoes. *Molecules*, 22, 205. https://doi.org/10.3390/molecules22020205

Zhu, J. J., Brewer, G. J., Boxler, D. J., Friesen, K., & Taylor, D. B. (2015). Comparisons of antifeedancy and spatial repellency of three natural product repellents against horn flies, *Haematobia irritans* (Diptera: Muscidae). *Pest Management Science*, 71, 1553–1560. https://doi.org/10.1002/ps.3960