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Botanical Insecticides and their Potential as Anti-Insect/Pests: Are they Successful against Insects and Pests?

Toheed Iqbal, Nazeer Ahmed, Kiran Shahjeer, Saeed Ahmed, Khalid Awadh Al-Mutairi, Hanem Fathy Khater and Reham Fathey Ali

Abstract

In low-income countries, subsistence and transitional farms frequently use botanical insecticides. The shortage or high cost of industrial pesticides also prompts their use. Botanical insecticides are also prescribed by agricultural and development programs and certain development organizations. However, since insecticidal proof of their effectiveness and protection might not be sufficient or usable, this may be called into question. While insecticidal botanicals have been extensively studied, there has yet to be a fusion that focuses especially on the domestic synthesis of biopesticides that work infield and storage effectively. In this chapter, we look at the effectiveness of botanicals (neem, garlic, and essential oil) that are used as insecticides. In addition, this chapter also focuses on research carried out on the use of these essential oils as insecticides. Processes that use variable amounts of ingredients and concentrations and ratios of active ingredients can have varying impacts on the efficacy of plant-based biological insecticides. Finally, using home-made insecticides would reduce the losses that occur during food production and enable us to use environment-friendly pest management methods.

Keywords: garlic, neem, essential oil, repellent, phytotoxicity, safety, economics

1. Introduction

In global terms, yield losses due to arthropods, diseases, and weeds are estimated to an approximately 35% of the total agricultural products. Yield losses in developing regions with limited pest management options may exceed up to 50% [1]. There are many adverse interactions between insects and plants, like insects, pests, and pathogens, leading to total or complete crop failure [2]. Crop protection has played a crucial role in ensuring food security, preserving crop productivity, and rising yields. More recently, the use of integrated pest management for pest control has become more prevalent in developed countries, but the continued use of pesticides to manage pest epidemics remains prominent [1, 3]. Increased use of synthetic pesticides is observed in the developed and transitional countries [4]. Many farmers

in developing countries lack access to synthetic pesticides [5]. Biological controls and botanical pesticides (in this case, plant products) are frequently unavailable or expensive. They are used in alternative ways, like inter-crop pest control rather than pesticide sprays to eliminate crops [6, 7].

Botanicals were used in agricultural pest control in China two thousand years ago and Greece and India before they became widely accepted [1]. Traditional botanical pest control for crop protection or storage remains widely distributed today among traditional and subsistence farmers [1, 4]. In some areas of Zimbabwe and Uganda, up to 100% of farmers use botanical products [5, 8]. Globally, there have been reports that more than 2500 plant species from 235 families have biological pest control activities [9, 10]. Notably, in many farmer surveys, using various botanical substances to control insect pests is underlined, with 10 botanicals used by farmers worldwide [5, 11].

Given the limited availability of synthetic pesticides and the prohibitive cost for farmers and transitional growers, botanicals are often a viable alternative to synthetic pesticides in the developing and subsistence agriculture sector [1]. Botanical preparations are vigorously promoted in the advisory materials of many government agricultural departments. As a result, plant-wise national extension partners, led by the CABI, sometimes use homemade pesticide products in their guidelines and extension materials (www.plantwise.org).

Different insecticidal activities such as toxicity, feeding deterrence, and repellency against other insect pests are possessed by plant secondary metabolites such as terpenoids, alkaloids, and phenols. The protection of plant species against insect herbicides has been used for many years in botanical insecticides, such as extracts and essential oils. Natural enemies are sometimes killed or injured by synthetic insecticides [1, 5, 12]. Additionally, plant extracts tend to have multiple actions and low toxicity, making them safer for non-target species. However, another significant advantage of botanical is that they tend to depend rather than on one active ingredient on closely related “suites” of active substances. It could either prevent or delay the spread of pest population resistance. Biopesticides have been utilized as a long way to keep pests under control until synthetic pesticides have replaced plant extracts. There is currently only about 1 per cent of the global use of pesticides for botanical insecticides, but that number increases due to greater attention on this class of products [13–15]. Plant extracts from common weed species are frequently produced in developing countries that are accessible and obtain labour as the only cost. However, Botanical pest management is a less expensive alternative to insecticides [16, 17].

The suitability of botanical recommendation and use can be questioned to control pests. Over the past decades, the evidence for the use of botanicals generally has been deemed consistent, but it must be re-evaluated to assess their effectiveness. Some botanicals used to control pesticides may be without active ingredients, a waste of time for little growers. Moreover, results may be unpredictable because of varying levels of active ingredients, concentrations in the used plant material, and differences in the preparing methods [7]. Despite this, their toxicity to non-targets has not been proven. While there is rising scientific evidence that some plant pesticides are less toxic to non-target species than synthetic pesticides, there is also evidence that some non-target species or ecosystems may be threatened by other botanicals, livestock, or the general environment [14]. Despite their significant prevalence, however, it is impossible to ignore the use of botanicals for pest control. There have been extensive research trials in the use of traditional pesticides and control methods conducted over the last several decades. However, a comprehensive scientific understanding of the use of conventional botanicals for insecticides, including those used by subsistence and transition farmers, is lacking.

Three distinct botanicals were investigated in this chapter to see either they worked against insects or pests, including their scientific proof for their efficacy

and reliability was discovered. The findings indicate the potential and limitations as alternatives to pesticides of selected botanical insecticides. The safety and well-being of humans are briefly mentioned, as well as considerations of cost and practicality.

2. Botanical insecticides

A substance employed to destroy pests that cause damage or obstacle to desired crops, shrubs, trees, timber, and plant growth is called insecticide. Pesticides that usually remain in nature and/end up take a long time in the body or tissue pose significant problems for humans and the environment for a wide range of environmental health and safety. Many pesticides are non-specific, so they can kill or be responsible for the death of either beneficial or destructive organisms [5].

2.1 Definition of botanical insecticide

One of the naturally occurring chemicals found in plants is referred to as botanical pesticides. Nature-oriented pesticides can be used as an alternative to synthetic formulations, but they are usually claimed to be more toxic to humans. Some of the most lethal carcinogenic substances, like deadly toxins, develop quickly and thrive in nature [18].

2.2 Mode of action of botanical insecticides

Mode of action is defined as a specific functional or physiological change in a living organism resulting from its exposure to a substance. The affected biological steps, enzymes, or proteins of the living organism are usually included in the mode of action. Most others classify pesticides as controlled, physical, or chemical characteristics; the mode of action primarily refers to how the pesticide interrupts an organism's biological processes [1, 18].

2.3 What is the significance of the mode of action?

Scientists must understand the mode of action to increase the quality and long-term viability of a product used in pest management plans. To better understand how pesticides function, it is critical to understand how the targeted system of the pest is working. Understanding how humans and other systems operate also helps us to control pests effectively. It also needs to learn the modes of action of the pesticides, which will help to prevent resistance to the specific pesticide(s) [18].

3. Botanical insecticide efficacy

3.1 Garlic (*Allium sativum*)

Sulfur-containing compounds produced by the enzymatic degradation of alliin are thought to be responsible for garlic's pesticide activity. There have been laboratory trials that have demonstrated that garlic extracts have insecticidal and acaricidal properties. They can also be used as control agents for Coleoptera, Lepidoptera, and Hemiptera insect species [19–22]. Garlic aqueous extracts were found to control Hemiptera pests, Lepidoptera pests, and mites to varying degrees in field application trials [23–26]. Other research suggests that homemade pesticides based on garlic could control fruit flies on watermelons and mites on tomatoes [27, 28].

3.2 Neem (*Azadirachta indica*)

Insects are affected by azadirachtin in two ways. At the physiological stage, azadirachtin prevents the prothoracic gland from producing and releasing molting hormones (ecdysteroids), resulting in immature insects, which causes incomplete ecdysis. A related mechanism of action is responsible for adult female insect sterility. Furthermore, azadirachtin is a powerful antifeedant for a variety of insects. It is thought that Schmutterer [29] was the first to discover the problem of swarming locusts in the desert. Still, neem trees had covered the area before then, so it was only found later that they destroyed all the local vegetation except for imported neem. Because of its exceptionally antifeedant activity in the desert locust, azadirachtin was first isolated and remained the most potent antifouling agent discovered to date. In the United States, neem has quickly become the new model for producing botanical pesticides [1].

The limonoids in neem are thought to be responsible for their insecticidal properties. Although azadirachtin is thought to be the most active compound, other limonoids may enhance its activity and activeness and inhibit resistance buildup [30]. Commercial neem extracts are commonly used to monitor a wide variety of insects and mites. Commercial neem-based products' insecticidal and acaricidal properties have been extensively demonstrated [18, 30].

Blatt dean, Hemiptera, Lepidoptera, and Thysanoptera pests have been successfully controlled with aqueous extracts produced at home using neem plant content (unformulated oil, seed cake, leaves, and seeds) [23, 31–36]. In various trials against Lepidoptera pests, aqueous neem extracts were found to be effective. Patil and Nandihalli [37] were the only researchers to demonstrate the effectiveness of aqueous neem extracts in field applications; extracts or an oil emulsion is used to combat mite pests. Both preparations decreased mite population but did not affect yield. It has been confirmed that neem oil is effective against fruit flies targeting watermelon, but no statistics have been given.

Coleopteran pests were controlled successfully and constantly in storage trials through ground neem plant material [27, 37–40]. The effectiveness of the ground neem is supported by participatory farm studies carried out by Paul et al. [41] and other earlier studies [5, 7, 9].

3.3 Mode of action

Biologically active components are difficult to pin down in neem products, as they are found in complex mixtures. Studies show that neem has insecticidal, repulsive, anti-ovipositional, growth-regulating, and toxic properties in various forms of insects. Neem serves as a natural insect repellent, preventing insects from starting to eat. It acts as a feeding deterrent, making insects avoid eating if there is a presence of deterrent factors, as part of the first “taste” ingesting food at some points (might be due to secondary hormonal or physiological effects of the deterrent substance). Neem has been proven to be strong in halting the growth of most insects through the means of disrupting chitin synthesis. Due to species' susceptibility, the effects of neem can vary widely [41].

4. Essential oils

Secondary metabolites produced by plants are superior to synthetic or synthetic pesticides as viable alternatives to a primary pest control strategy [42]. Furthermore, insecticide resistance to synthetic pesticides resulted in significant food losses due to chemical failure in pests. As a result, annual economic losses in

the billions of dollars occur worldwide [1, 5]. Furthermore, essential oils are also considered safer than synthetic pesticides by the FDA due to non-target neurotoxic, carcinogenic, teratogenic, and mutagenic effects, as well as insect multi- and cross-resistance [43]. Their popularity in organic farmers and the environmentally aware consumer has considerably increased as insecticides in essential oils derived from aromatic plants. They have repellent, antifeedant, inhibitors to oviposition and growth, ovicides, and growth-reducing effects in several insects [42–44]. Essential oils possess an exciting impact of larvicide on larvae, insecticide activity, abusive ants, cockroaches, bedbugs, moths, fluid headlice, and toxic to termites (Lepidoptera: Lymantriidae, gipsy moth). *Mentha piperita* oil repels anti-*Callosobruchus maculatus*, flies, lice, moth, and *Tribolium castrum*. *Trachysperm* sp. oil contains larvicidal effect against mosquito species *Aedes aegypti* and *Culex quinquefasciatus* [45–47].

4.1 Chemistry of essential oils

The chemistry of volatile elements in essential oils can be categorized into four major groups: benzene derivatives, hydrocarbons, terpene, and other miscellaneous compounds. Monoterpenoids constitute 90% of the essential oil, and they are the most representative molecules that allow for a wide variety of different structures. There are 10 hydrocarbons, or their related compounds, that is, cyclic alcohols (e.g., isopulegol, menthol, terpineol), acyclic alcohols (e.g., geraniol, linalool, citronellol), bicyclic alcohols (e.g., verbenol, borneol), ketones (menthone, carvone, thujone), phenols (e.g., carvacrol, thymol), acids (e.g., chrysanthemum acid), oxides (cineole), and aldehydes (citronellal, citral). Terpenes are the major group, while aromatic and aliphatic constituents are the other minor groups. Terpenes are mostly monoterpenes (C₁₀) as well as sesquiterpenes (C₁₅), but hemiterpenes (C₅), diterpenes (C₂₀), triterpenes (C₃₀), and tetraterpenes are also available (C₄₀). Phenylpropane-derived aromatic compounds are less prevalent than terpenes, for example, aldehyde: cinnamaldehyde; methylenedioxy compounds: apiole, myristicin, safrole; phenols: chavicol, eugenol; alcohol: cinnamic alcohol; methoxy derivatives: anethole, elemicin, estragole, methyl eugenols [48].

4.2 Extraction of essential oil

The oil composition varies widely, mainly depending on the way that was used to isolate it. Essential oils have a different chemical composition, depending on the type of molecules extracted and the number of molecules found within the mix. Usually, steam distillation under high pressure is used to separate essential oils using the cleverger device. Furthermore, the oil may be chemically altered during distillation due to saponification, isomerization, and other reactions due to distillation. Essential oils are extracted *via* different methods: solvent extraction, first through percolation, and then through a combination of double or single distillation or supercritical carbon dioxide. The quality, quantity, and composition of the extract obtained from the various plant materials vary with each climate and the design of the soil, organ of plants, age, and vegetative cycle stage [44].

4.3 Essential oil mode of action

Most monoterpene has a cytotoxic effect on plant and animal cells, disrupting respiration and permeability, depleting Golgi and mitochondria, and decreasing respiration and production. Similarly, many serve as chemicals to animals and insects as well, and they are volatile. Also, most monoterpenoids

act as some short-signal molecules, thus making them suitable as synonyms and alarm pheromones. Care must be taken with the number of essential oils used to destroy insects and their modes of action because of possible health hazards to humans and other vertebrates. There is still a lack of understanding about the monophenoid target sites and mode of action, and only a few studies have investigated this [1, 18, 44, 48].

4.3.1 As insecticide

Although insects are not known well for the physiological effects of essential oils, treating them with essential oils or their constituents causes symptoms that provide us information about the mode of action as a neurotoxin. Linalool, a monoterpene, has influenced ion transport and acetylcholine esterase release in insects [18].

Octopamine is a neurotransmitter, neurohormone, and circulating neurohormone—neuromodulator with many biological functions in insects [1]. Based on pharmacological parameters, octopamine works by interacting with at least two receptor groups, dubbed octopamine-1 and octopamine-2. As the octopamine system is disrupted, the nervous system of insects is wholly destroyed. As a result, the insect octopaminergic mechanism is a bio-rational priority for pest control (**Figure 1**).

Since vertebrates do not have octopamine receptors, essential oils have a solid mammalian selectivity as insecticides. The octopaminergic mechanism of insects is influenced by various important oil compounds [48].

In the cloned cells of *Drosophila melanogaster* and *Periplaneta americana*, Enan [46] found that eugenol, as octopamine, has increased intracellular levels of calcium and is mediated by octopamine receptors. In addition, eugenol toxicity is found to be increased in mutant *D. melanogaster* with no octopamine synthesis, indicating that the octopaminergic system mediates the toxicity. The insecticidal effects of eugenol are thought to be due to these cellular changes caused by the compound [48]. In *Helicoverpa armigera*, abdominal epidermal tissue [50] came to the same conclusion, suggesting that essential oil constituents can compete for octopaminergic receptor activation.

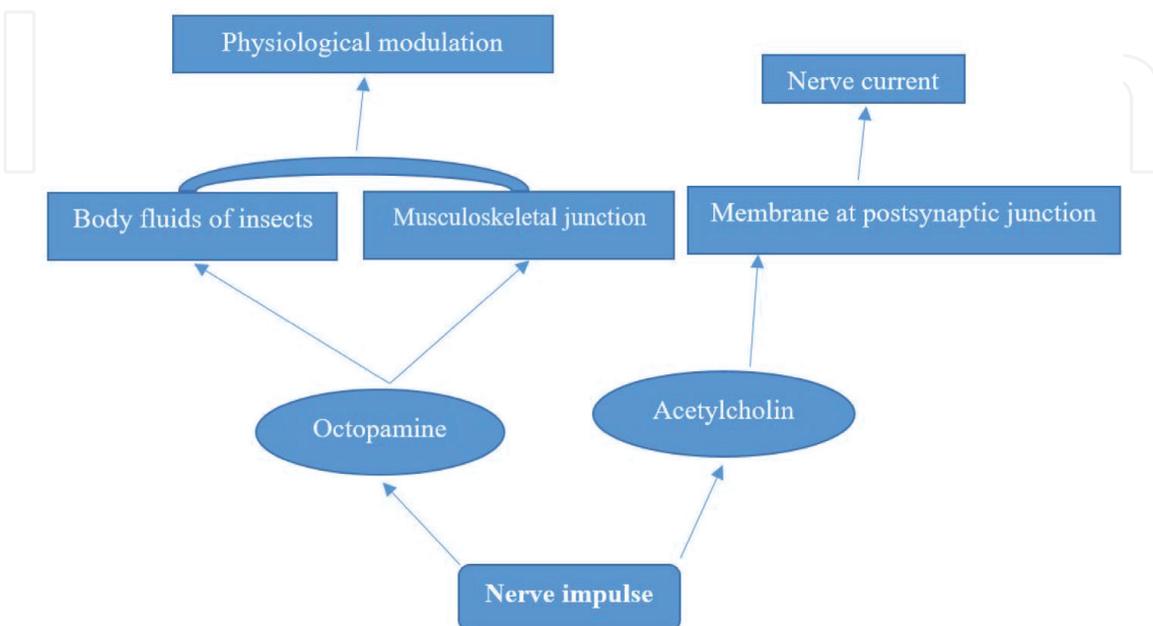


Figure 1. Essential oils' toxic activity can be mediated by neurotransmitters at target sites in insects.

4.3.2 As repellent

It is not clear if repellents function the same way in various arthropods likewise other published material discussed. Ticks, for example, can detect repellents present on their tarsi of prolegs (Haller's Organ), whereas insects can detect repellents through their antennae. Furthermore, sensitivity to the same repellent varies only in degree among different classes, orders, and families; no fundamental differences in response type are observed [18, 48]. However, in mosquitoes, the degree of differential sensitivity remained constant over several generations, suggesting that resistance is based on heritable traits. Temperature and moisture are sensitive to mosquito antennae hairs. The repellent molecules attach to the olfactory receptors of female mosquitos, preventing them from smelling. Cockroach repellent receptors are poorly understood. Death and aversion to death (repellence) have been linked to oleic acid and linoleic acid in cockroaches. A proposal has been made for the term necromone to characterize the compound responsible for this form of behavior [18, 48].

4.3.3 As fumigant

The essential oils with bioactivity as insecticides or repellents are well known for example, rosemary, thyme, clove, lemongrass, mint, oregano oils, and cinnamon. The bioactivity of certain plants, including thyme, oregano, basil, rosemary, and mint, varies widely because the composition differences in chemical compositions are reliable [48].

Understanding essential oils' mode of action is critical for insect control because it can lead to better formulations, distribution methods, and resistance management. Many essential oils and their isolated chemicals from plants have fumigant properties. *Artemisia annua* essential oil, *Curcuma longa*, *Anethum Sowa*, *Lippia alba* essential oil, and separates such as d-limonene, carvones, and 1,8-cineole have all been used as fumigants [45–47, 51]. These results suggest that the oils acted primarily in the vapor process through the respiratory system, but the exact mode of action is unknown.

There are no natural fumigants that have been proven to work against pests that attack crops, dry foods, and other agricultural products. Phosphine, methyl bromide, and DDVP are the most used fumigants (2,2-dichlorovinyl dimethyl phosphate). Phosphine is responsible for an enormous percentage of Indian suicides, as a precursor for ozone depletion is a concern. In contrast, Dichlorvos is an organophosphate widely used as an insecticide to control household pests, in public health, and protecting stored products from insects (used as the precursor for ozone-depleting treatments) poses a theoretical risk of cancer [48]. All attempts should be made to develop an alternative that can take toxic fumigation while being user-friendly and cost-effective. Many aromatic plants produce highly toxic or unpleasant chemicals but serve as some valuable deterrents for various insects. These three attributes (high molecular weight, high boiling point, and low vapor pressure of essential oils) allow large-forger fumigation to be performed by the high fumigation standards of safety and efficiency, making them better suited for large-scale fumigation than most other substances [18]. Despite essential oils having the potential for low-scale applications and single or multiple component contaminants in food, there is a lack of scientific data on food-grade applications and fusible essential oils [48].

4.3.4 Synergistic action of essential oils

The synergistic rationale for combining products assumes that the combined product's phase carries much weightage than the count of its known and unknown chemical components that result in a complex effect of multiple modes of action.

Among the essential oils and their components and other ingredients used in formulating a product, both positive and negative types of synergism may occur. This is important to keep in mind because essential oils will work together to create a synergy that may negatively affect the base product. The salinity and pH of the base product can affect the actions of the essential oils.

Low pH and a saline environment (5% NaCl) have been shown in several studies to increase the activity of the entire product. Synergistic activity has been demonstrated for essential oil combinations such as thyme, anise, and saffron [1, 18, 48, 49]. Mixed monoterpene mixtures had a synergistic impact on mortality [5, 52]. For use against foliar-feeding pests, a monoterpene blend was produced containing 0.9% active ingredient.

Monoterpenoids bind to the octopaminergic receptor, which is only found in insects. A proprietary blend of essential oils called Hexa Hydrox (EcoPCO EcoSMART Technologies, Franklin, Tennessee) with different plant essential oils was developed to significantly increase the potency of these oils in pest control. This proprietary technology, which combines oils with a normal molecular structure to target octopaminergic sites, demonstrates rapid insecticidal action (a six-membered carbon ring with an oxygenated functional group attached). The US Food and Drug Administration has listed them as GRAS (Generally Recognized as Safe) and has licensed them for use in food and beverages [18, 48].

5. Safety

The toxicity of pesticides and the exposure of applicators or users influence the risks associated with their use. Pesticides are tested during the registration process in some cases. The assessments should include the acute toxicity for formulating products to determine the effective preventive measures by the recommendations issued by the FAO, UN, and the WHO. To assess the risk of health-associated to short-term exposure, the acute toxicity and metabolites or degradations of the active substances are assessed. Reproductive and developmental toxicity, carcinogenicity, and mutagenicity should be evaluated in determining risks related to long-term exposure, sub-chronic, and chronic effects.

Furthermore, farmworker and pesticide applicator exposure and residue in crop production should be assessed to determine whether the risks associated with pesticides used are tolerable [5]. There have been no or only partial safety tests of homemade botanical insecticides except for neem products. Homemade botanical insecticides vary from industrial pesticides. The former contains an active ingredient cocktail with unknown concentrations and a long list of variable concentrations of compounds with novel properties. Furthermore, although plant material concentrations may be poor, processing exposure has not been assessed and may be very high. As a result, even though safety tests are available, it is difficult to extrapolate the risks found in laboratory trials to real-world scenarios. Many countries' plant protection laws prohibit homemade preparations, even though this is often the case in agriculture. As a result, some countries, at least for non-commercial farming, use such preparations [48].

6. Safety to the environment

In similarity with risks associated with human health, adverse pesticide uses depend on their toxicity and exposure to non-target organisms—such as pests, pollinators, birds, fish, and mammals. These risks should be evaluated to determine if they are accepted as a part of the registration process [5, 53]. For the registration

of pesticides, environmental fatality data usually are also required. The risk of bioaccumulation with homemade botanical insecticides is generally less because they contain natural materials known to degrade faster than many synthetic compounds [48].

Despite the possibility that certain homemade botanical insecticides have lower toxicity to non-target organisms than broad-spectrum insecticides, these findings illustrate the importance of the further study. The application of botanical products should consider their possible negative effects on non-target organisms if it is appropriate and handled with care. Similarly, botanical products, including pesticides, should not be used alone to combat pests. Botanical products can be used in an integrated pest management system (IPM). It may be used with other non-pesticidal tools such as plant diversification, habitat protection, and other non-pesticidal tools.

7. Conclusions

The use of botanical insecticides should not be ignored in low-income countries. In addition to synthetic pesticides, botanical insecticides may be less active. They are still an option, especially in combination with the IPM approach, in areas where farmers either have no access to commercial pesticides or have limited affordability of these synthetic pesticides. As a result, food waste in some of the most depleted areas of the world has been reduced. It is important to remember and convey the risks associated with using natural insecticides (i.e., alterable effectiveness and possible health and environmental consequences).

Botanicals: natural insecticides derived from plant sources are used as the best alternate for conventional pesticides to protect our crops, avoiding adverse effects of synthetic insecticides. Botanical insecticides have a wide range of chemicals and their modes of action; they have a variety of the impact on insects. Thus, botanical insecticides are preferred over synthetic insecticides, and organic crop producers in developed countries accept these botanical insecticides. As a result, we advocated for the use of botanical insecticides, which has been encouraged, and research is underway to identify new botanical insecticide sources.

Acknowledgements

The author is grateful to Research Scientist Dr. Chamila Darshanee (Sri Lanka) for reviewing this chapter early. The authors would like to thank the Science and Technology Development (STDF), Egypt entitled: “Eco-friendly Pesticides against Pests of Medical, Veterinary, and Agricultural Importance” ID: 41608.

Conflict of interest

The authors declare no conflict of interest.

Notes/thanks/other declarations

Authors take sole responsibility of no submission to any other source, journal, or publisher of the chapter submitted to IntechOpen.

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