Mosquito Larvicidal Potential of Medicinal Plants

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Abstract

Mosquitoes act as vectors for many life-threatening diseases like malaria, yellow fever, dengue fever, chikungunya, filariasis, encephalitis, West Nile virus infection, etc. Vector control is by far the most successful method for reducing the incidence of mosquito-borne diseases, but the emergence of widespread insecticide resistance and the potential environmental issues associated with some synthetic insecticides has indicated that additional approaches to control the proliferation of mosquito population would be an urgent priority research. Mosquitoes develop genetic resistance to synthetic insecticides and even to biopesticide such as *Bacillus sphaericus*. Also synthetic insecticides adversely affect the environment by contaminating air, water, and soil. There is an urgent need to find alternatives to the synthetic insecticides which are more potent and low cost. Plants are a rich source of alternative agents for control of mosquitoes, because they possess bioactive chemicals, which act against a limited number of species including specific target insects and are eco-friendly. Traditionally, plant-based products have been used in human communities for many centuries for managing insects. Several secondary metabolites present in plants serve as a defense mechanism against insect attacks. These bioactive chemicals may act as insecticides, antifeedants, molting hormones, oviposition deterrents, repellents, juvenile hormone mimics, growth inhibitors, antimolting hormones, as well as attractants. Plant-based pesticides are less toxic, and there is a delay in the development of resistance because of their new structure and easy biodegradability. In present article, the local and traditional uses of plants in mosquito control, current state of knowledge on phytochemical sources, and the mosquitocidal properties of secondary metabolites have been reviewed.

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3.1 Introduction

Mosquitoes are the major vector for the transmission of malaria, dengue, yellow fever, filariasis, and Japanese encephalitis (JE) (Das and Ansari 2003). In India, malaria is one of the most important causes of direct or indirect infant, child, and adult mortality with approximately two to three million new cases arising every year. *Anopheles stephensi* is the primary vector of malaria in India and other West Asian countries, and improved methods of control are urgently needed (Burfield and Reekie 2005). Malaria infects more than 500 million humans each year, killing approximately 1.2–2.7 million/year. About 90 % of all malaria cases occur in Africa, as does approximately 90 % of the world's malaria-related deaths (Breman et al. 2004). Malaria, caused by *Plasmodium falciparum*, is one of the leading causes of human morbidity and mortality from infectious diseases, predominantly in tropical and subtropical countries (Snow et al. 2005).

Dengue, transmitted by *Aedes aegypti*, is one of the most significant viral diseases which afflicts humans worldwide whose symptoms are ranging from mild fever to a severe and potentially life-threatening hemorrhagic disease. *Aedes aegypti* is of supreme concern because of its wide distribution and close association with humans (Ravikumar et al. 2011). *Aedes aegypti* is present in heavy polluted areas like Asia, America, and some Pacific Islands and infested about 2/3 of the world's population (Hahn et al. 2001). *Culex quinquefasciatus* is the principal vector of filariasis, and it is reported to infect more than a hundred million people every year in more than 110 countries in the tropics (WHO 2006). New control methodologies aim at reducing mosquito breeding sites and biting activity by using a combination of chemical-biological methods to reduce the population of mosquito and to reduce the man-vector contact (Service 1983).

3.2 Vector Control

The past century has witnessed intense activities in unraveling the mystery of the transmission of mosquito-borne diseases. Though therapeutic measures have been identified and used for treatment of diseases, sustainable interruption in transmission of these mosquito-borne diseases has been an eluding success. Vector control still remains an integral and significant part in disease control programs. Organized mosquito control is necessary to prevent mosquito-borne diseases, for which new strategies must be added to our armory of control. Vector control may be directed toward preventing the occurrence of disease, suppressing epidemics, or controlling already existing endemic mosquito-borne disease (John Williams 2007).

3.3 Disadvantage of Chemical Insecticides

For several decades, chemical insecticides were preferred for the control of sudden outbreak of the vectors. The repeated use of the chemical insecticides fosters many environmental hazards including development of resistance in the vectors to these chemicals and the disruption of natural biological control systems (Pushpanathan et al. 2008). Moreover, these chemicals persist in the environment for unpredictable period of time. Mosquito control has been becoming increasingly difficult because of the indiscriminate uses of synthetic chemical insecticides which have an adverse impact on the environment and disturb ecological balance. Majority of the chemical pesticides are harmful to man and animals, some of which are not easily degradable and spreading toxic effects. Due to the increased use of these, insecticides may enter into the food chain, and thereby, the internal organs like the liver, kidney, etc., may be irreversibly damaged. They even result in mutation of genes and these changes become prominent only after a few generations (Sivakumar et al. 2011). Chemical insecticides are also very costly. In larval mosquito control, application of insecticides in ponds, wells, and other water bodies may cause health hazards to human and larvivorous fishes.

Nowadays, mosquito coils containing pyrethroids and other synthetic compounds cause so many side effects, such as breathing problem, eye irritation, headache, asthma, itching, and sneez-

ing to the users. With the use of mosquito repellent, people complained of ill health effect and sometimes required medical treatment. In addition, pests were becoming resistant to chemical treatments. Indoor residual spraying of insecticides stains the walls and leaves a long-lasting unpleasant odor. Mosquitoes are still the world's number one vectors of human and animal diseases and are conspicuous nuisance pests as well, even after massive efforts of eradication or control. The extensive use of chemical pesticides or insecticides resulted in inducing resistance by insect pests besides residue contamination of human food, mammalian toxicity, and environmental pollution. These factors have created the need for environmental safe, degradable, and target-specific agents for pest control purposes. Plant extracts have gained importance in insect control, being considered environmentally safe, less hazardous to nontarget biota, and inexpensive, and can be applied effectively by using techniques more suitable for developing countries (Mohamed et al. 2003).

3.4 Advantage of Botanical Insecticides

Phytochemicals are botanicals which are naturally occurring insecticides obtained from floral resources. Applications of phytochemicals in mosquito control were in use since the 1920s (Shahi et al. 2010), but the discovery of synthetic insecticides such as DDT in 1939 sidetracked the application of phytochemicals in mosquito control program. After facing several problems due to injudicious and overapplication of synthetic insecticides in nature, refocus on phytochemicals that are easily biodegradable and have no ill effects on nontarget organisms was appreciated. Since then, the search for new bioactive compounds from the plant kingdom and an effort to determine its structure and commercial production have been initiated. At present phytochemicals make up to 1 % of world's pesticide market (Isman 1997).

Botanicals are basically secondary metabolites that serve as a means of defense mechanism of the plants to withstand the continuous selection pressure from herbivore predators and other environmental factors. Several groups of phytochemicals such as alkaloids, steroids, terpenoids, essential oils, and phenolics from different plants have been reported previously for their insecticidal activities (Shaalan et al. 2005). Insecticidal effects of plant extracts vary not only according to plant species, mosquito species, geographical varieties, and parts used but also due to extraction methodology adopted and the polarity of the solvents used during extraction. A wide selection of plants from herbs, shrubs, and large trees was used for extraction of mosquito toxins. Phytochemicals were extracted either from the whole body of herbs or from various parts like fruits, leaves, stems, barks, roots, etc., of larger plants or trees. In all cases where the most toxic substances were concentrated upon, found and extracted for mosquito control. Plants produce numerous chemicals, many of which have medicinal and pesticidal properties. More than 2000 plant species have been known to produce chemical factors and metabolites of value in pest control programs.

3.5 Medicinal and Insecticidal Properties of Plants

Herbs are staging a comeback and herbal "renaissance" is happening all over the globe. The herbal products today symbolize safety in contrast to the synthetics that are regarded as unsafe to human and environment. Although herbs had been priced for heir medicinal, flavoring, and aromatic qualities for centuries, the synthetic products of the modern age surpassed their importance, for a while. However, the blind dependence on synthetics is over and people are returning to the naturals with hope of safety and security.

Of the 250,000 higher plant species on earth, more than 80,000 are medicinal. India is one of the world's 12 biodiversity centers with the presence of over 45,000 different plant species. India's diversity is unmatched due to the presence of 16 different agroclimatic zones, 10 vegetation zones, 25 biotic provinces, and 426 biomes (habitats of specific species). Of these, about 15,000–20,000 plants have good medicinal value.

However, only 7000–7500 species are used for their medicinal values by traditional communities. In India, drugs of herbal origin have been used in traditional systems of medicines such as *Unani* and *Ayurveda* since ancient times. The *Ayurveda* system of medicine uses about 700 species, *Unani* 700, *Siddha* 600, Amchi 600, and modern medicine around 30 species. The drugs are derived either from the whole plant or from different organs, like leaves, stem, bark, root, flower, seed, etc. Some drugs are prepared from excretory plant product such as gum, resins, and latex. Even the allopathic system of medicine has adopted a number of plant-derived drugs which form an important segment of the modern pharmacopoeia. Some important chemical intermediates needed for manufacturing the modern drugs are also obtained from plants (e.g., diosgenin, solasodine, b-ionone). Not only that plant-derived drug offers a stable market worldwide but also plants continue to be an important source for new drugs.

3.6 Botanical Used for Mosquito Control

A large number of plant extracts have been reported to have mosquitocidal or repellent activity against mosquito vectors (Sukumar et al. 1991) but very few plant products have shown practical utility for mosquito control. Plant products can be obtained either from the solvents. Botanicals are used as larvicides and growth inhibitors; some plants possess repellent properties and they are used as repellents against mosquitoes. Biological control of mosquito was very popular during the early part of the twentieth century, but with the development and availability of chemicals such as the organochlorines and organophosphates, it was replaced by insecticidal control. However, because of problems with insecticide resistance and greater awareness of environmental contamination, there has been renewed interest in biological (biological control) methods. Plants and plant derivatives have tremendous advantages over synthetic insecticides.

3.7 Larvicidal Activity of Plants

Larviciding is a general term for killing immature mosquitoes by applying agents, collectively called larvicides, to control mosquito larvae and/or pupae. Larval source management (LSM) involves both the modification of water habitats, often referred to as source reduction, and the direct application of larvicides to control mosquito production. Most mosquito species spend much of their life cycle in the larval stage when they are highly susceptible to both predation and control efforts. They often are concentrated within defined water boundaries, immobile with little ability to disperse, and accessible. Adult mosquitoes, in contrast, fly in search of mates, blood meals, or water sources for egg laying and are often inaccessible, not concentrated, and widely distributed. Therefore, effective larviciding can reduce the number of adult mosquitoes available to disperse, potentially spread disease, create a nuisance, and lay eggs which leads to more mosquitoes. The effective control of larvae and/or pupae is a basic principle of integrated pest management (IPM). Effective IPM involves understanding the local mosquito ecology and patterns of arbovirus transmission and then selecting the appropriate mosquito control tools. The most common methods of IPM include environmental management or source reduction, larviciding, and adulticiding. Other mosquito control principles include biocontrol, as well as additional methods not discussed here such as herbiciding and hand removal of aquatic plants. These methods may be used to control immature mosquitoes indirectly, usually when there is an obligatory association between the larvae/pupae and specific host plants (Govindarajan et al. 2008).

Several different types of larvicides are available for controlling mosquitoes. Generally, these larvicides are least effective in wastewater systems. The flow-through nature of many wastewater treatment, reuse, and recycling operations rapidly diminishes the effectiveness of many larvicides. Bacteria and other components of wastewater quickly break down or inactivate some larvicides. Increasing the dosage rate and the

number of applications or using slow-release formulations may be required to achieve adequate control. At sites where mosquito outbreaks are large and frequent, larvicides may provide only temporary control and may not be cost effective. Larvicide operations must be supported with a quality inspection program. Potential mosquito production sites must be identified and frequently inspected. Larvicide applications should be integrated with other mosquito abatement measures, such as aquatic plant management and water quality improvement. Larvicides should not interfere with the level of mosquito control already provided by natural predators and parasites. Biological control of mosquitoes could be very promising being eco-friendly as well as cost effective. Hence, there is a constant need for developing biologically active plant materials as insecticides, which are expected to reduce the hazards to humans and other organisms by minimizing the accumulation of harmful residues in the environment. Natural products of plant origin are generally preferred because of their less harmful nature to nontarget organisms and their innate biodegradability (Govindarajan 2011) (Table 3.1).

The larvicidal activity of various plant extracts such as *Pedalium murex*, *Cleome icosandra*, and *Dictyota dichotoma* has been found to be promising against *Cx. quinquefasciatus* and *An. stephensi* (Kalyanasundaram and Das 1985). Among many well-known phytochemicals, azadirachtin (a tetranortriterpenoid compound) is one of the most extensively studied biological insecticides extracted from the seed kernel of the neem tree *Azadirachta indica* (Schmutterer 1990). Susceptibility tests were carried out in *Cx. quinquefasciatus* larvae using peel oil extracts of *Citrus aurantium*, *C. sinensis*, and *Citrus limon* (Mwaiko 1992); the extracts of *O. canum* were effective in killing the larvae *Anopheles gambiae* (Lukwa 1994).

The metabolites of *Cucumis sativus* exhibited insecticidal activities to many insect pests, including *Ae. gossypii*, *Tetranychus viennensis*, and larvae of *Pieris rapae* (Zhang et al. 1998). Nirmal Sharma et al. (1998) reported that larvicidal activity of *Gliricidia sepium* crude ethanol extracts of dried leaves, fresh leaves, dried petioles, and stem bark was tested for their activities against third instar larvae of *An. stephensi*, *Ae. aegypti*, and *Cx. quinquefasciatus*. Pushpalatha and Muthukrishnan (1999) evaluated that the methanol seed and leaf extract showed significant larvicidal and growth regulatory activities even at very low concentrations against *An. stephensi*. Murugan and Jeyabalan (1999) studied the effect of some indigenous plants on the larvicide and ovipositional properties on *An. stephensi*.

Rahuman et al. (2000) have reported that a bioassay-guided fractionation of the acetone extract of *Feronia limonia* dried leaves afforded a potent mosquito larvicide, identified as n-hexadecanoic acid, and found to be effective against fourth instar larvae of *An. stephensi*; Vahitha et al. (2002) studied the larvicidal efficacy of *Pavonia zeylanica* and *Acacia ferruginea* against *Cx. quinquefasciatus*. The crude chloroform extract of seeds of *Millettia dura* showed high activity against second instar larvae of *Ae. aegypti* (Yenesew et al. 2003). Essential oils of leaf and bark of *Cryptomeria japonica* demonstrated high larvicidal activity against *Ae. aegypti* larvae (Cheng et al. 2003). The petroleum ether extract showed larvicidal activity against *Ae. aegypti*, *Cx. quinquefasciatus*, *An. dirus*, and *Mansonia uniformis* (Komalamisra et al. 2005). The ethanolic extracts of the orange peel (*C. sinensis*) were tested for the toxicity effect on the larvae of the yellow fever mosquito *Ae. aegypti* (Amusan et al. 2005); the ethanolic and acetone extracts of *Nerium indicum* and *Thuja orientalis* have been studied against third instar larvae of *An. stephensi* and *Cx. quinquefasciatus* (Sharma et al. 2005). The larvicidal activity of methanol extracts of dried root powder of *Chamaecyparis obtusa* was tested against three vector mosquitoes (Jang et al. 2005).

The methanolic extracts of the fresh leaf extract of *Calotropis procera* (Singh et al. 2005), the aqueous extract from the roots of *Hibiscus abelmoschus* (Dua et al. 2006) and the petroleum ether, carbon tetrachloride, and methanol extract of *Artemisia annua*, *Chenopodium album*, and *Sonchus oleraceus* (Sharma et al. 2006) were

Table 3.1 Efficacy of plant extracts against vector mosquitoes

Plants	Family	Plant parts used	Target mosquito species	Lethal concentrations/biological activity	References
Acacia nilotica	Fabaceae	Leaf	*An. stephensi*, *Ae. aegypti*, and *Cx. quinquefasciatus*	LC_{50} value was 55.72 ppm and LC_{90} value was 194.58 ppm	Sakthivadivel and Daniel (2008)
Acalypha alnifolia	Euphorbiaceae	Leaf	*An. stephensi*, *Ae. aegypti*, and *Cx. quinquefasciatus*	LC_{50} values were 125.73, 127.98, and 128.55 ppm against fourth instar larvae of three mosquito species at 24 h	Kovendan et al. (2012)
Acalypha indica	Euphorbiaceae	Leaf	*An. stephensi*	LC_{50} value was 19.25 ppm at 24 h	Govindarajan et al. (2008)
Ageratina adenophora	Asteraceae	Twigs	*Ae. aegypti* and *Cx. quinquefasciatus*	At 24 h, LC_{50} value of the extract was found to be 356.70 ppm for *Ae. aegypti* and 227.20 ppm for *Cx. quinquefasciatus*	Raj Mohan and Ramaswamy (2007)
Ageratina adenophora	Asteraceae	Leaf	*Cx. quinquefasciatus*, *Ae. aegypti*, and *An. stephensi*	The LC_{50} and LC_{90} values of crude methanol extract of leaves of *A. adenophora* on *Cx. quinquefasciatus*, *Ae. aegypti*, and *An. stephensi* larvae in 24 h were 144.86, 132.82, and 113.08 and 250.70, 231.12, and 198.81 mg/l, respectively	Rajeswary and Govindarajan (2013)
Ageratum conyzoides	Asteraceae	Leaf	*Cx. quinquefasciatus*	Potent larvicidal activity was noticed	Saxena et al. (1992)
Aloe barbadensis	Liliaceae	Leaf	*An. stephensi*	LC_{50} values were 29.06 and 22.59 ppm for 24 and 48 h	Maurya et al. (2007)
Annona crassiflora	Annonaceae	Root wood	*Ae. aegypti*	LC_{50} value was 0.71; LC_{90} value was 5.12 µg/ml	Omena et al (2007)
Annona squamosa	Annonaceae	Bark	*Cx. quinquefasciatus* and *An. stephensi*	LC_{50} values of 28.18 and 43.07 ppm against *An. stephensi* and *Cx. quinquefasciatus*, respectively	Kamaraj et al. (2010)
Apium graveolens	Umbelliferae	Seed	*Ae. aegypti*	LD_{50} and LD_{95} values of 81.0 and 176.8 mg/l, respectively, for fourth instar larvae	Choochate et al. (2004)
Argemone mexicana	Papaveraceae	Leaf	*Cx. quinquefasciatus*	Causes 100 % mortality at 250 ppm of each extracts	Karmegan et al. (1997)
Artemisia annua	Asteraceae	Leaf	*Anopheles stephensi*	LC_{50} value was 16.85 ppm after 24 h and 11.45 ppm after 48 h of exposure	Sharma et al. (2006)

Artemisia cina	Compositae	Leaf	*Cx. pipiens*	The EC_{50} for the mosquito at 24 h after treating with extract was 4.0 g/l	Aly and Bardan (1996)
Asparagus racemosus	Asparagaceae	Root	*Culex quinquefasciatus*, *Aedes aegypti*, and *Anopheles stephensi*	The LC_{50} and LC_{90} values were 115.13, 97.71, and 90.97 ppm and 210.96, 179.92, and 168.82 ppm, respectively	Govindarajan and Sivakumar (2013b)
Atlantia monophylla	Rutaceae	Leaf	*An. stephensi*	LC_{50} value of 0.05 mg/l. Insect growth regulating activity with EI_{50} value of 0.065 mg/l	Sivagnaname and Kalyanasundaram (2004)
Atlantia monophylla	Rutaceae	Leaf	*Cx. quinquefasciatus*	Larvae were found susceptible with LC_{50} value of 0.14 mg/l	Sivagnaname and Kalyanasundaram (2004)
Atlantia monophylla	Rutaceae	Leaf	*Ae. aegypti*	Larval growth regulating activity of this extract was found to be pronounced with EI_{50} value of 0.002 mg/l	Sivagnaname and Kalyanasundaram (2004)
Azadirachta indica	Meliaceae	Leaf	*Cx. fatigans*	In comparison with malathion (LC_{50} value was 0.45 ppm), the LC_{50} value of neem fraction (NLX) was found to be higher to the third instar larvae at 390 ppm	Azmi et al. (1998)
Azadirachta indica	Meliaceae	Leaf	*Ae. aegypti*	LC_{50} value is 8.32 mg/ml	Mgbemena (2010)
Caesalpinia pulcherrima	Fabaceae	Leaf	*Cx. tritaeniorhynchus*, *Ae. albopictus*, and *An. subpictus*	The LC_{50} and LC_{90} values were 150.47, 135.24, and 119.27 ppm and 282.57, 261.55, and 243.37 ppm, respectively	Govindarajan et al. (2013a)
Cardiospermum halicacabum	*Sapindaceae*	Leaf	*Culex quinquefasciatus* and *Aedes aegypti*	The LC_{50} values were 174.24, 193.31, 183.36, 150.44, and 154.95 ppm and 182.51, 200.02, 192.31, 156.80, and 164.54 ppm, respectively	Govindarajan (2011)
Carica papaya	Caricaceae	Seed	*Cx. quinquefasciatus*	LC_{50} value of 0.15, 0.11, 0.07, and 0.20 % against first, second, third, and fourth instar larvae	Rawani et al. (2009)
Cassia fistula	Fabaceae	Leaf	*Cx. tritaeniorhynchus* and *Anopheles subpictus*	The LC_{50} and LC_{90} values of *C. fistula* against early third instar of *Cx. tritaeniorhynchus* and *An. subpictus* were 45.57 and 33.76 ppm and 82.05 and 60.63 ppm, respectively	Govindarajan et al. (2011a)

(continued)

Table 3.1 (contniued)

Plants	Family	Plant parts used	Target mosquito species	Lethal concentrations/biological activity	References
Cassia fistula	Fabaceae	Flowers	*Cx. tritaeniorhynchus*, *Ae. albopictus*, and *An. subpictus*	LC_{50} and LC_{90} values of *C. fistula* flower against early third instar of *Cx. tritaeniorhynchus*, *Ae. albopictus*, and *An. subpictus* were 136.59, 118.64, and 96.51 ppm and 243.67, 231.79, and 174.39 ppm, respectively	Govindarajan (2013)
Cassia obtusifolia	Leguminosae	Seed	*Ae. aegypti*, *Ae. togoi*, and *Cx. pipiens* pallens	Showed a strong larvicidal activity of 100 % mortality at 25 mg/l. The biologically active component was emodin. The LC_{50} values of emodin were 1.4, 1.9, and 2.2 ppm, respectively	Yang et al. (2003)
Cassia obtusifolia	Leguminosae	Leaf	*An. stephensi*	LC_{50} and LC_{90} values were 52.2 and 108.7 mg/ l	Rajkumar and Jebanesan (2009)
Cassia tora	Caesalpiniaceae	Seed	*Ae. aegypti* and *Cx. pipiens* pallens	LC_{50} value was 20 mg/l for both the larval species	Jang et al. (2002)
Centella asiatica	Umbelliferae	Leaf	*Cx. quinquefasciatus*	LC_{50} ranged between 6.84 ppm at 19 °C and 1.12 ppm at 31 °C. LC_{90} varied from 9.12 to 3.63 ppm at the two temperatures, respectively	Rajkumar and Jebanesan (2005)
Cestrum diurnum	Solanaceae	Leaf	*An. stephensi*	The LC_{50} value of the active ingredient was determined as 0.70, 0.89, 0.90, and 1.03 mg/100 mL for first, second, third, and fourth instar larva, respectively, in 24 h study period	Ghosh and Chandra (2006)
Chamaecyparis obtusa	Cupressaceae	Leaf	*An. stephensi*	The bioactive component in the leaf extract was characterized as beta-thujaplicin by spectroscopic analyses. The LC_{50} value of beta-thujaplicin was 2.91 ppm	Jang et al. (2005)
Chrysanthemum indicum	Asteraceae	Leaf	*Cx. tritaeniorhynchus*	LC_{50} value was 42.29 mg/ml after 24 h	Kamaraj et al. (2010)

Citrullus vulgaris	Cucurbitaceae	Leaf	*Ae. stephensi*	100 % mortality was exerted at 250 ppm and the corresponding LC_{50} value was 18.56 ppm	Mullai et al. (2008)
Citrus aurantium	Rutaceae	Fruit peel	*Cx. quinquefasciatus*	LC_{90} values were 53.80 and 32.52 ppm after 24 and 48 h of treatment	Kassir et al. (1989)
Citrus reticulata	Rutaceae	Seed	*Cx. quinquefasciatus* and *Ae. aegypti*	LC_{50} value against *Ae. aegypti* and *Cx. quinquefasciatus* larvae was 2,267.71 and 2,639.27 ppm, respectively	Sumroiphon et al. (2006)
Citrus sinensis	Rutaceae	Fruit peel	*An. subpictus*	LC_{50} value was 58.25 and LC_{90} value was 298.31 ppm	Bagavan et al. (2009)
Clausena anisata	Rutaceae	Leaf	*Anopheles subpictus* and *Aedes albopictus*	The LC_{50} values of β-pinene, sabinene, germacrene D, estragole, and linalool appeared to be most effective against *Anopheles subpictus* (LC_{50} – 24.68, 20.93, 17.16, 12.25, 36.26 ppm) followed by *Aedes albopictus* (LC_{50} – 28.10, 22.66, 19.51, 13.01, 39.99 ppm)	Govindarajan and Sivakumar (2013a)
Coccinia indica	Cucurbitaceae	Leaf	*Cx. quinquefasciatus*	The LC_{50} and LC_{90}values of hexane, ethyl acetate, benzene, chloroform, and methanol extracts of *C. indica* against adults of *Cx. quinquefasciatus* were 146.65, 133.68, 122.38, 112.85, and 68.88 ppm and 259.86, 246.34, 225.99, 212.48, and 129.56 ppm, respectively	Sivakumar and Govindarajan (2013a)
Coccinia indica, *Cucumis sativus*, and *Momordica charantia*	Cucurbitaceae	Leaf	*Cx. quinquefasciatus* and *Ae. aegypti*	LC_{50} values of the respective plants were 377.69, 623.80, and 207.61 and 309.46, 492.73, and 199.14 ppm against the two vector species	Rahuman and Venkatesan (2008)
Coleus aromaticus	Lamiaceae	Oil	*Cx. tritaeniorhynchus*, *Ae. albopictus*, and *An. subpictus*	24.83 and 22.06 LC_{50} values of 72.70, 67.98, and 60.31 µg/mL, respectively	Govindarajan et al. (2013b)
Curcuma aromatica	Zingiberaceae	Rhizome	*Ae. aegypti*	LC_{50} value was 36.30 ppm	Choochate et al. (2005)

(continued)

Table 3.1 (contniued)

Plants	Family	Plant parts used	Target mosquito species	Lethal concentrations/biological activity	References
Cybistax antisyphilitica	Bignoniaceae	Stem wood	*Ae. aegypti*	A natural quinone identified as 2-hydroxy-3-(3-methyl-2-butenyl)-1.4-naphthoquinone (lapachol) was quite potent with LC_{50} value of 26.3 µg/ml	Rodrigues et al. (2005)
Aloe turkanensis	Asphodelaceae	Leaf	*An. gambiae*	100 % mortality was achieved at a concentration of 0.2 mg/ml and it had a LC_{50} value of 0.11 mg/ml	Matasyoh et al. (2008)
Delonix elata	Fabaceae	Leaf	*An. stephensi* and *Ae. aegypti*	LC_{50} and LC_{90} values being 93.59 and 111.83 and 163.69 and 202.77 ppm, respectively	Govindarajan et al. (2012a)
Delonix elata	Fabaceae	Leaf, seed	*Cx. quinquefasciatus*	The LC_{50} and LC_{90} values of *D. elata* against early third instar of *Cx. quinquefasciatus* were 124.84 and 147.86 mg/L and 213.88 and 289.43 mg/L, respectively	Govindarajan et al. (2012b)
Dysoxylum malabaricum	Meliaceae	Leaf	*An. stephensi*	4 % concentration of leaf extract killed more than 97 % of first instars, 92 % of fifth instars, 93 % of pupae, and 91 % of adults	Senthil Nathan et al. (2006a)
Eucalyptus globulus	Myrtaceae	Seed, leaf	*Cx. pipiens*	Both the extracts at a dose of 1000 ppm caused 100 % and 80 % mortality to the tested larvae	Sheeren (2006)
Eclipta alba	Asteraceae	Leaf	*Cx .quinquefasciatus*	The methanol extract and the LC_{50} and LC_{90}values were 119.83 and 234.19 ppm, respectively, followed by chloroform, benzene, and ethyl acetate, and hexane extracts with the LC_{50} and LC_{90} values were 134.65, 140.72, 144.11, and 157.97 ppm and 257.29, 260.60, 274.43, and 291.21 ppm, respectively	Sivakumar and Govindarajan (2013b)

Ervatamia coronaria	Apocynaceae	Leaf	*An. stephensi*, *Ae. aegypti*, and *Cx. quinquefasciatus*	The LC_{50} and LC_{90} values were 79.08, 89.59, and 96.15 ppm and 150.47, 166.04, and 174.10 ppm, respectively	Govindarajan et al. (2011b)
Erythrina indica	Fabaceae	Leaf	*An. stephensi*, *Ae. aegypti*, and *Cx. quinquefasciatus*	LC_{50} and LC_{90} values of 69.43, 75.13, and 91.41 ppm and 125.49, 134.31, and 167.14 ppm, respectively	Govindarajan and Sivakumar (2013c)
Eucalyptus citriodora	Myrtaceae	Leaf	*An. stephensi*, *Ae. aegypti*, and *Cx. quinquefasciatus*	The LC_{50} values against fourth instar larvae of three species were 69.86, 81.12, and 91.76 ppm, respectively, after 24 h and 26.7, 29.9, and 38.8 ppm, respectively, after 72 h	Singh et al. (2007)
Eucalyptus globulus	Myrtaceae	leaf, seed	*Culex pipiens*	Both the extracts at a dose of 1000 ppm caused 100 and 80 % mortality to the tested larvae	Sheeren (2006)
Euphorbia hirta	Euphorbiaceae	Stem bark	*Cx. quinquefasciatus*	LC_{50} value was 424.94 and LC_{90} value was 1314.01 ppm	Rahuman et al. (2007)
Euphorbia tirucalli	Euphorbiaceae	Stem bark	*Cx. pipiens* pallens	LC_{50} value was 200.76 and LC_{90} value was 343.515 mg/l	Yadav et al. (2002)
Feronia limonia	Rutaceae	Leaf	*Cx. quinquefasciatus*, *An. stephensi*, and *Ae. aegypti*	LC_{50} values of 129.24, 79.58, and 57.23 ppm for three mosquito species, respectively	Rahuman et al. (2000)
Ficus benghalensis	Moraceae	Leaf	*Culex quinquefasciatus*, *Aedes aegypti*, and *An. stephensi*	LC_{50} values of 41.43, 58.21, and 74.32 ppm; 56.54, 70.29, and 80.85 ppm; and 60.44, 76.41, and 89.55 ppm for three mosquito species, respectively	Govindarajan (2010a)
Ficus benghalensis	Moraceae	Leaf	*Cx. tritaeniorhynchus* and *An. subpictus*	The LC_{50} and LC_{90} values of *F. benghalensis* against early third instar of *Cx. tritaeniorhynchus* and *An. subpictus* were 100.88 and 159.76 ppm and 56.66 and 85.84 ppm, respectively	Govindarajan et al. (2011c)
Hemidesmus indicus	Asclepiadaceae	Root	*Cx. quinquefasciatus*	80 % mortality was observed in 5 % concentration after 1 day of exposure	Khanna and Kannabiran (2007)
Jatropha curcas	Euphorbiaceae	Leaf	*Cx. quinquefasciatus*	LC_{50} value was 11.34 and LC_{90} value was 46.52 ppm	Rahuman et al. (2007)

(continued)

Table 3.1 (contniued)

Plants	Family	Plant parts used	Target mosquito species	Lethal concentrations/biological activity	References
Kaempferia galanga	Zingiberaceae	Rhizome	*Cx. quinquefasciatus*	LC_{50} value was 42.33 ppm	Choochate et al. (1999)
Khaya senegalensis	Meliaceae	Leaf	*Cx. annulirostris*	LC_{50} value was 5.86 mg/l	Shaalan et al. (2005)
Melia azedarach	Meliaceae	Leaf, seeds	*An. stephensi*	The extract showed strong larvicidal activity	Senthil Nathan et al. (2006b)
Mentha spicata	Lamiaceae	Leaf	*Cx. quinquefasciatus*, *Ae. aegypti*, and *An. stephensi*	LC_{50} values of 62.62, 56.08, and 49.71 ppm and LC_{90} values of 118.70, 110.28, and 100.99 ppm, respectively	Govindarajan et al. (2012c)
Millettia dura	Leguminosae	Seed	*Ae. aegypti*	Rotenoids, deguelin, and tephrosin isolated from the seeds of this plant showed potent activities, with LC_{50} values of 1.6 and 1.4 µg /ml at 24 h, respectively	Yenesew et al. (2003)
Millingtonia hortensis	Bignoniaceae	Leaf	*An. stephensi*, *Ae. aegypti*, and *Cx. quinquefasciatus*	LC_{50} values of 104.70, 138, and 83.18 ppm for second instar larvae of three species at 24 h of bioassay	Kaushik and Saini (2008)
Momordica charantia	Cucurbitaceae	Fruit	*An. stephensi*	LC_{50} value was 0.50 and LC90 value was 1.54 % concentration of the extract	Singh et al. (2006)
Momordica charantia	Cucurbitaceae	Leaf	*Cx. quinquefasciatus*	LC_{50} value was 465.85; LC_{90} value was 2421.46 ppm	Prabakar and Jebanesan (2004)
Moringa oleifera	Moringaceae	Bark	*Cx. gelidus*	LC_{50} value was 38.47 µg/ml	Kamaraj and Rahuman (2010)
Myrtus communis	Myrtaceae	Flower and leaf	*Cx. pipiens* molestus	LC_{50} value was 16 mg/l. Thymol, carvacrol, (1R)–(+)- -pinene, and (1S)–(−)- -pinene were the most effective toxic compounds with LC_{50} values of 36–49 mg /l	Traboulsi et al. (2002)

Nyctanthes arbor-tristis	Nyctantheceae	Flower	*Cx. quinquefasciatus*	LC_{50} values were 25.67 and 22.19, 38.60 and 28.95, 53.14 and 42. 14, and 72.60 and 61.82 ppm and for the isolated compound NCS-2 were 73.31 and 65.48, 83.02 and 67.02, 97.26 and 81.84, and 14.68 and 99.02 ppm for first, second, third, and fourth instar larvae, respectively, at 24 and 48 h postexposure	Khatune et al. (2001)
Ocimum sanctum	Lamiaceae	Leaf	*Ae. aegypti* and *Cx. quinquefasciatus*	The LC_{50} value of *O. sanctum* against the larvae of *Ae. aegypti* was 425.94 and against the larvae of *Cx. quinquefasciatus* was 592.60 ppm	Anees (2008)
Ocimum basilicum	Lamiaceae	Leaf	*An. stephensi* and *Cx. quinquefasciatus*	LC_{50} values of 8.29 and 87.68 ppm, respectively	Maurya et al. (2009b)
Ocimum basilicum	Lamiaceae	Oil	*Cx. tritaeniorhynchus*, *Ae. albopictus*, and *An. subpictus*	LC_{50} values of 14.01, 11.97, and 9.75 ppm and LC_{90} values of 23.44, 21.17, and 18.56 ppm, respectively	Govindarajan et al. (2013c)
Ocimum gratissimum	Lamiaceae	Leaf	*Cx. gelidus* and *Cx. quinquefasciatus*	LC_{50} values were 39.31 and 66.28 µg/ml against fourth instar larvae after 24 h	Kamaraj and Rahuman (2010)
Paullinia clavigera	Sapindaceae	Leaf	*An. benarrochi*	LC_{50} (24 h) value was 0.81; LC_{50} (12 h) value was1.19 %	Iannacone and Pérez (2004)
Pavonia zeylanica	Malvaceae	Leaf	*Cx. quinquefasciatus*	After 24 h of treatment, the LC_{50} value was 2214.7 ppm	Vahitha et al. (2002)
Piper longum	Piperaceae	Fruit exocarp	*Ae. aegypti*	LC_{50} value of 2.23 ppm	Chaithong et al. (2006)
Piper nigrum	Piperaceae	Seed	*Cx. pipiens*	LC_{50} value was 2.6 mg/l	Shaalan et al. (2005)
Piper retrofractum	Piperaceae	Unripe and ripe fruit	*Cx. quinquefasciatus* and *Ae. aegypti*	LC_{50} value of 135 against *Cx. quinquefasciatus* and 79 ppm against *Ae. aegypti*	Chansang et al. (2005)
Pithecellobium dulce	Fabaceae	Leaf, seed	*An. stephensi* and *Ae. aegypti*	The LC_{50} and LC_{90} values are145.43 and 155.78 mg/l and 251.23 and 279.73 mg/l, respectively	Govindarajan et al. (2013d)

(continued)

Table 3.1 (contniued)

Plants	Family	Plant parts used	Target mosquito species	Lethal concentrations/biological activity	References
Plumbago zeylanica, *P. dawei*, and *P. stenophylla*	Plumbaginaceae	Root	*An. gambiae*	LC_{50} values were 4.1, 6.4, and 6.7 mg/ml, respectively. LC_{90} values were 10.6, 26.2, and 15.6 mg/ml, respectively	Maniafu et al. (2009)
Rhizophora mucronata	Rhizophoraceae	Bark, pith, and stem wood	*Ae. aegypti*	LC_{50} values of 157.4, 168.3, and 1003.4 ppm for bark, pith, and stem wood at 48 h, respectively	Kabaru and Gichia (2001)
Solanum xanthocarpum	Solanaceae	Root	*Cx. pipiens* pallens	LC_{50} and LC_{90} values were 64.99 and 252.43 ppm and 59.20 and 186.15 ppm after 24 and 48 h of exposure, respectively	Mohan et al. (2006)
Sida acuta	Malvaceae	Leaf	*Cx. quinquefasciatus*, *Ae. aegypti*, and *An. stephensi*	In terms of lethal concentrations for 50 % mortality (LC_{50}), crude extract of *S. acuta* appeared to be most effective against *An. stephensi* (LC_{50}=38.64 mg/L) followed by *Ae. aegypti* (LC_{50}=42.08 mg/L) and *Cx. quinquefasciatus* (LC_{50}=47.91 mg/L)	Govindarajan (2010b)
Solanum nigrum	Solanaceae	Dried fruit	*An. Culicifacies*, *An. stephensi*, *Cx. quinquefasciatus*, and *Ae. aegypti*	The LC_{50} values against fourth instar larvae of four species were 9.04, 6.25, 12.25, and 17.63 ppm, respectively	Raghavendra et al. (2009)
Solanum nigrum	Solanaceae	Leaf	*Cx. quinquefasciatus*	LC_{50} value was 17.04 ppm against fourth instar larvae after 24 h	Rawani et al. (2010)
Solanum villosum	Solanaceae	Leaf	*An. stephensi*, *Cx. quinquefasciatus*, and *Ae. aegypti*	The protein compound responsible for mosquitocidal property was isolated with LC_{50} values of 644.75, 645.75, and 747.22 ppm	Chowdhury et al. (2009)

Solenostemma argel	Apocynaceae	Aerial parts	*Cx. pipiens*	LC_{50} values of 0.037, 0.031, 0.009, and 0.007 ppm and the LC_{95} values were found as 0.394, 0.293, 0.065, and 0.030 ppm, after 1, 2, 4, and 7 days against the larva of *Cx. pipiens* under laboratory conditions	Al-Doghairi et al. (2004)
Thymus capitatus	Lamiaceae	Leaf	*Cx. pipiens*	The volatile oil, thymol, and the unsaponifiable portion proved high larvicidal potency (LC_{50} value was 49.0 ppm)	Mansour et al. (2000)
Tridax procumbens	Compositae	Leaf	*An. subpictus*	LC_{50} value of 39.98 mg/l	Kamaraj et al. (2011)
Vitex negundo	Verbenaceae	Leaf	*Cx. quinquefasciatus*	LC_{50} value was 212.57 ppm	Krishnan et al. (2007)
Zingiber officinalis	Zingiberaceae	Rhizome	*Cx. quinquefasciatus*	The LC_{50} value was 50.78 ppm. Skin repellent test at 1.0, 2.0, 3.0, and 4.0 mg/cm2 concentration of *Z. officinalis* gave 100 % protection up to 15, 30, 60, and 120 min	Pushpanathan et al. (2008)

tested against *An. stephensi*. The dried root power methanol extract of *R. nasutus* was tested against the larvae of *Ae. aegypti* and *Cx. quinquefasciatus* (Rongsriyam et al. 2006). Pandey et al. (2007) report extensive investigations of the larvicidal efficacy of the crude extracts of three *Spilanthes* species (*S. acmella*, *S. calva*, and *S. paniculata*) tested against *An. stephensi*, *An. culicifacies* species, and *Cx. quinquefasciatus* Say mosquito larvae and the larvicidal potential of the petroleum ether root extract of *Solanum xanthocarpum* (Mohan and Ramaswamy 2007). Petroleum ether (60–80 °C) extracts of the leaves of *Vitex negundo* were evaluated for larvicidal activity against larval stages of *Cx. tritaeniorhynchus* in the laboratory (Karunamoorthi et al. 2008). The crude acetone, hexane, ethyl acetate, methanol, and petroleum ether extracts of the leaf of *Centella asiatica*, *Datura metel*, *Mukia scabrella*, and *Toddalia asiatica* of whole plant of *Citrullus colocynthis* and *Sphaeranthus indicus* were assayed for their toxicity against the early fourth instar larvae of *Cx. quinquefasciatus* (Rahuman et al. 2008a).

The methanol extract of *Ocimum canum* and the acetone extract of *O. sanctum* were reported to have a toxic effect against the larvae of *Spodoptera litura*, *Ae. aegypti*, and *Cx. quinquefasciatus* (Bagavan et al. 2008). Antifeedant and larvicidal activity of acetone, chloroform, ethyl acetate, hexane, and methanol peel, leaf, and flower extracts of *Citrus sinensis*, *Ocimum canum*, *Ocimum sanctum*, and *Rhinacanthus nasutus* were studied using fourth instar larvae of *Helicoverpa armigera*, *Sylepta derogata*, and *An. stephensi* (Kamaraj et al. 2008). The compound gluanol acetate isolated from the bark acetone extract of *Ficus racemosa* was assayed for their toxicity against the larvae of *An. stephensi* (Rahuman et al. 2008b); the larvicidal potential of the extracts of commonly available medicinal plants *Saraca indica/asoca*, *Nyctanthes arbortristis*, and *Clitoria ternatea* against *An. stephensi*, *Cx. quinquefasciatus*, and *Ae. aegypti* (Mathew et al. 2009); and the larvicidal potential of the various fruit wall extracts of *Momordica charantia* (Cucurbitaceae) against two species of mosquito vectors, *An. stephensi* and *Cx. quinquefasciatus* (Maurya et al. 2009a).

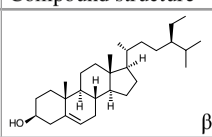
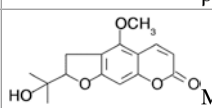
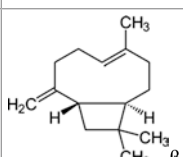
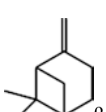
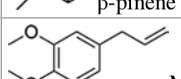
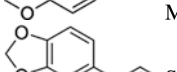
3.8 Plant-derived Insecticides

Plants have been used through human history in cooking, medicines, cosmetics, and insecticides and have a rich source of chemicals and drugs for man. During the twentieth century, a few of these natural compounds like nicotine, rotenone, and pyrethrins have been used commercially as insecticides (Ware 1978). However, plants produce thousands of other compounds that are insecticidal and have diverse modes of action like hormonal, neurological, nutritional, or enzymatic actions (Rosenthal and Janzen 1979). A number of plant families are known to produce alkaloids, phenolics, and oils which have been used for insect control since a long time. They were called as insect killers and were used by Romans and Chinese (Heitz and Downum 1987). Another group of plant products discovered in the last two decades are known as secondary metabolites. These were considered as waste products from plants for a long time, because they were of no nutritional significance to insect. These secondary plant metabolites having insecticidal/pesticidal properties are of several types, viz., repellent, antifeedants, ovicidal, phagostimulants, and toxins. Alkaloids and phenolics are two important groups of secondary plant metabolites that regulate the tolerance level of host-plant acceptance by insects (Table 3.2).

3.9 Conclusion

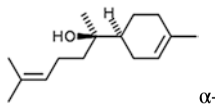
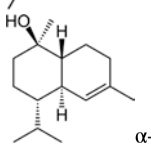
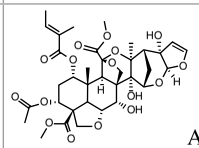
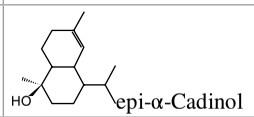
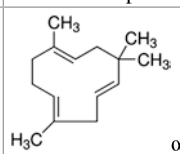
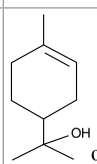
Whole plants have been demonstrated to be more active than the isolated active compounds as larvicides against mosquitoes. The high bioactivity of plants shows the feasibility of production of a low-cost larvicide without the need to isolate an active compound, which is an expensive process. However, the selection of chemical markers is essential for the quality control of herbal products. Although these natural products have been

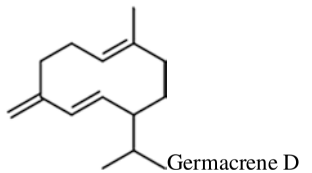
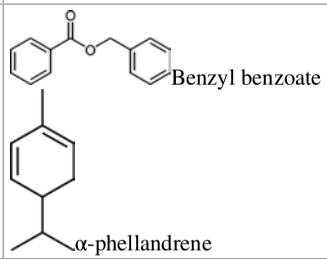
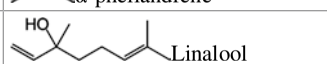
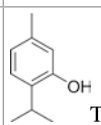
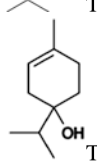
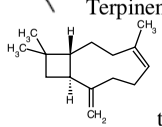
Table 3.2 Mosquitocidal properties of active ingredients

Plants	Active ingredient	Mosquito	LC/LD values	Compound structure	References
Abutilon indicum	β-Sitosterol	*Ae. aegypti*, *An. stephensi*, and *Cx. quinquefasciatus*	LC_{50} values of 11.49, 3.58, and 26.67 ppm, respectively	 β-sitosterol	Rahuman et al. (2008a)
Aegle marmelos	Marmesin	*An. gambiae*	LC_{50} and LC_{90} values of 0.082 and 0.152 mg/l	 Marmesin	Joseph et al. (2004)
Alpinia purpurata	β-Caryophyllene and β-pinene	*Ae. aegypti*	LC_{50} value of 80.7 mg/L	 β-Caryophyllene  β-pinene	Santos et al. (2012)
Asarum heterotropoides	Methyleugenol and safrole	*Ae. aegypti*	LC_{50} value of 23.82 mg/L	 Methyleuge  Safrol	Perumalsamy et al. (2010)

(continued)

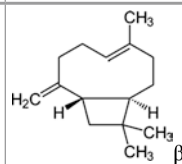
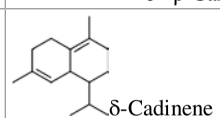
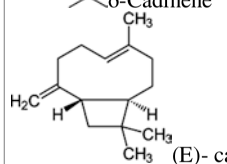
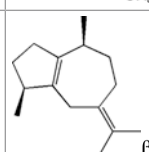
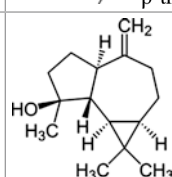
Table 3.2 (continued)

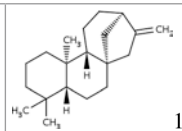
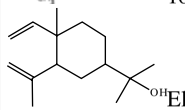
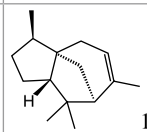
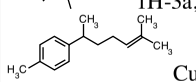
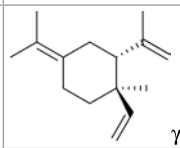
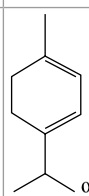
Plants	Active ingredient	Mosquito	LC/LD values	Compound structure	References
Auxemma glazioviana	α-Bisabolol and α-cadinol	*Ae. aegypti*	LC_{50} value of 2.53 mg/L	 α-Bisabolol  α-cadinol	Costa et al. (2004)
Azadirachta indica	Azadirachtin	*An. stephensi*	EC_{50} values of 0.014, 0.021, 0.028, and 0.034 ppm against first, second, third, and fourth instar larvae, respectively	 Azadirachtin	Senthil Nathan et al. (2005)
Bauhinia acuruana	epi-α-Cadinol and spathulenol	*Ae. aegypti*	LC_{50} value of 56.22 mg/L	 epi-α-Cadinol	Góis (2010)
Capraria biflora	α-Humulene	*Ae. aegypti*	LC_{50} value of 73.39 mg/L	 α-Humulene	Souza et al. (2012)
Chenopodium ambrosioides	α-Terpineol	*Ae. aegypti*	LC_{50} value of 35 mg/L	 α-Terpineol	Leyva et al. (2009)

Chloroxylon swietenia	Germacrene D	*An. gambiae*, *Cx. quinquefasciatus*, and *Ae. aegypti*	LD_{50} values of 1.8, 2.1, and 2.8×10^{-3}	 Germacrene D	Kiran and Devi (2007)
Cinnamomum impressicostatum	Benzyl benzoate and α-phellandrene	*Ae. aegypti*	LC_{50} value of 10.7 mg/L	 Benzyl benzoate α-phellandrene	Jantan et al. (2005)
Cinnamomum scortechinii	β-Phellandrene and linalool	*Ae. aegypti*	LC_{50} value of 21.5 mg/L	 Linalool	Jantan et al. (2005)
Coleus aromaticus	Thymol, terpinen-4-ol, and trans-caryophyllene	*Cx. tritaeniorhynchus*, *Ae. albopictus*, and *An. subpictus*	LC_{50} values of 28.19, 24.83, and 22.06 µg/mL, respectively	 Thymol  Terpinen-4-ol  trans-Caryophyllene	Govindarajan et al. (2013b)

(continued)

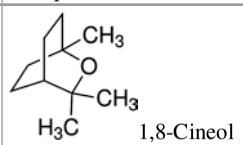
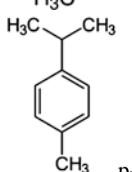
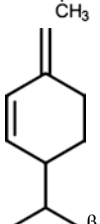
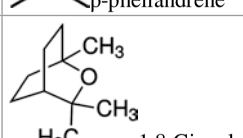
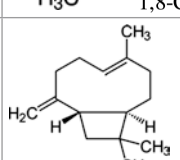
Table 3.2 (continued)

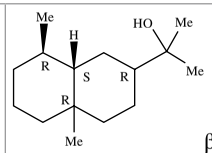
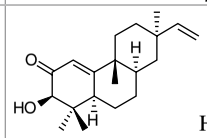
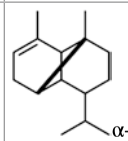
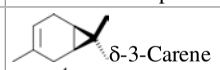
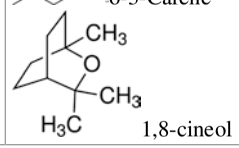
Plants	Active ingredient	Mosquito	LC/LD values	Compound structure	References
Copaifera multijuga	β-Caryophyllene	*Ae. aegypti*	LC_{50} value of 18 mg/L	 β-Caryophyllene	Trindade et al. (2013)
Cordia leucomalloides	δ-Cadinene and (E)-caryophyllene	*Ae. aegypti*	LC_{50} value of 63.1 mg/L	 δ-Cadinene  (E)- caryophyllene	Santos et al. (2006)
Croton argyrophylloides	β-trans-Guaiene	*Ae. aegypti*	LC_{50} value of 94.6 mg/L	 β-trans-Guaiene	Lima et al. (2013)
Croton sonderianus	Spathulenol	*Ae. aegypti*	LC_{50} value of 54.5 mg/L	 Spathulenol	Lima et al. (2013)

Cryptomeria japonica	16-Kaurene and elemol	*Ae. aegypti*	LC_{50} values of 28.4–56.7 mg/L	 16-Kaurene  Elemol	Cheng et al. (2009)
Curcuma aromatica	1H-3a,7-Methanoazulene and curcumene	*Ae. aegypti*	LC_{50} value of 36.3 mg/L	 1H-3a,7- Methanoazulene  Curcumene	Choochate et al. (2005)
Dendropanax morbifera	γ-Elemene	*Ae. aegypti*	LC_{50} value of 62.32 mg/L	 γ-Elemene	Chung et al. (2009)
Eucalyptus camaldulensis	α-Terpinene	*Ae. aegypti*	LC_{50} value of 14.7 μg/mL	 α-terpinene	Lucia et al. (2008)

(continued)

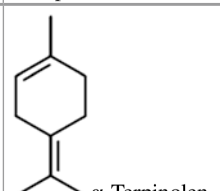
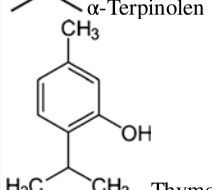
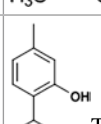
Table 3.2 (continued)

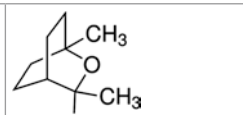
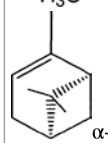
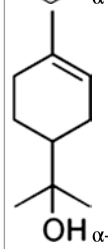
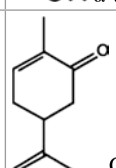
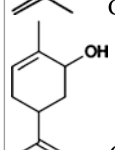
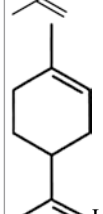
Plants	Active ingredient	Mosquito	LC/LD values	Compound structure	References
Eucalyptus camaldulensis	1,8-Cineol, p-cymene, and β-phellandrene	*Ae. aegypti*	LC_{50} value of 26.75 mg/L	 1,8-Cineol  p-cymene  β-phellandrene	Lucia et al. (2008)
Eucalyptus globulus	1,8-Cineol	*Ae. aegypti*	LC_{50} value of 52.9 mg/L	 1,8-Cineol	Massebo et al. (2009)
Guarea scabra	cis-Caryophyllene	*Ae. aegypti*	LC_{50} value of 98.6 mg/L	 cis-Caryophyllene	Magalhães et al. (2010)

Guatteria friesiana	β-Eudesmol	*Ae. aegypti*	LC_{50} value of 52.6 mg/L	 β-Eudesmol	Aciole et al. (2011)
Hugonia castaneifolia	Hugorosenone	*An. gambiae*	LC_{50} values of 0.3028 mg/ml	 Hugorosenon	Baraza et al. (2008)
Hymenaea courbaril	α-Copaene and spathulenol	*Ae. aegypti*	LC_{50} value of 14.8 mg/L	 α-Copaene	Aguiar et al. (2010)
Hyptis martiusii	δ-3-Carene and 1,8-cineol	*Ae. aegypti*	LC_{50} value of 18.5 mg/L	 δ-3-Carene  1,8-cineol	Costa et al. (2005)

(continued)

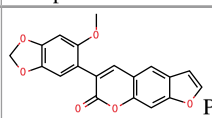
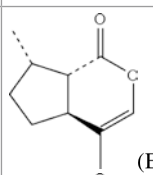
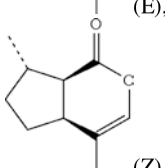
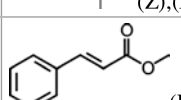
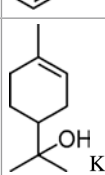
Table 3.2 (continued)

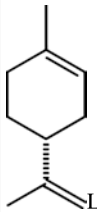
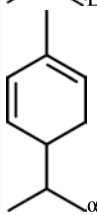
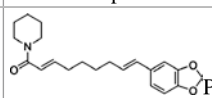
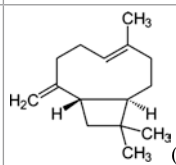
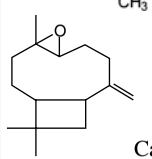
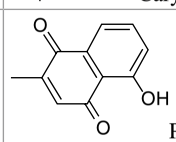
Plants	Active ingredient	Mosquito	LC/LD values	Compound structure	References
Lavandula gibsoni	α-Terpinolene and thymol	*Ae. aegypti*	LC_{50} value of 48.32 mg/L	 α-Terpinolen  Thymol	Kulkarni et al. (2013)
Lippia sidoides	Thymol	*Ae. aegypti*	LC_{50} value of 19.5 mg/L	 Thymol	Costa et al. (2005)

Melaleuca leucadendron	1,8-Cineol, α-pinene, and α-terpineol	*Ae. aegypti*	LC_{50} value of 41 mg/L	 1,8-Cineol  α-pinene  α-terpineol	Leyva et al. (2008)
Mentha spicata	Carvone, *cis*-carveol, and limonene	*Cx. quinquefasciatus*, *Ae. aegypti*, and *An. stephensi*	The LC_{50} values of carvone, cis-carveol, and limonene appeared to be most effective against *An. stephensi* (LC_{50} 19.33, 28.50, and 8.83 ppm) followed by *Ae. aegypti* (LC_{50} 23.69, 32.88, and 12.01 ppm), and *Cx. quinquefasciatus* (LC_{50} 25.47, 35.20, and 14.07 ppm)	 Carvone  *Cis*-carveol  Limonene	Govindarajan et al. (2012c)

(continued)

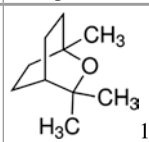
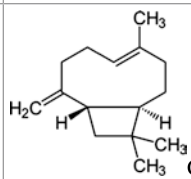
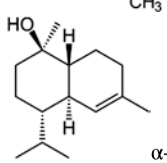
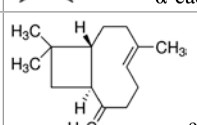
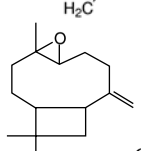
Table 3.2 (continued)

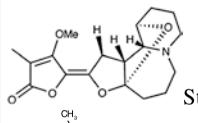
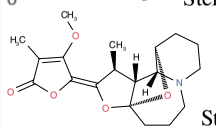
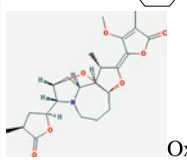
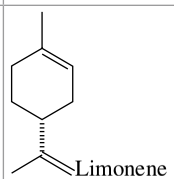
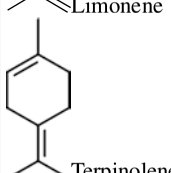
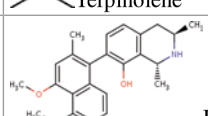
Plants	Active ingredient	Mosquito	LC/LD values	Compound structure	References
Neorautanenia mitis	Pachyrrhizine	*An. gambiae*	LC_{50} value of 0.007 mg/ml	 Pachyrrhizine	Joseph et al. (2004)
Nepeta cataria	(E),(Z)-Nepetalactone and (Z),(E)-nepetalactone	*Ae. aegypti*	LC_{50} value of 70 mg/L	 (E),(Z)-Nepeta cataria  (Z),(E)-nepetalactone	Zhu et al. (2006)
Ocimum americanum	(E)-Methyl-cinnamate	*Ae. aegypti*	LC_{50} value of 67 mg/L	 (E)-Methyl-cinnamate	Cavalcanti et al. (2004)
Pinus longifolia	K-terpineol	*Ae. aegypti*	LC_{50} value of 82.1 mg/L	 K-terpineol	Ansari et al. (2005)

Piper klotzschianum	1-Butyl-3,4-methylenedioxybenzene, limonene, and α-phellandrene	*Ae. aegypti*	LC_{50} value of 13.27 mg/L	 Limonene  α-phellandrene	Nascimento et al. (2013)
Piper longum	Pipernonaline	*Ae. aegypti* and *Cx. pipiens*	LC_{50} values of 0.25 and 0.21 mg/l, respectively	 Pipernonalin	Lee (2000)
Piper nigrum	(E)-Caryophyllene and caryophyllene oxide	*Ae. aegypti*	LC_{50} value of 50 mg/L	 (E)-Caryophyllene  Caryophyllene	Amer and Mehlhorn (2006)
Plumbago zeylanica	Plumbagin	*An. gambiae*	LC_{50} value of 1.9 µg/ml	 Plumbagin	Maniafu et al. (2009)

(continued)

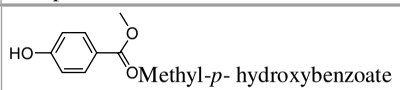
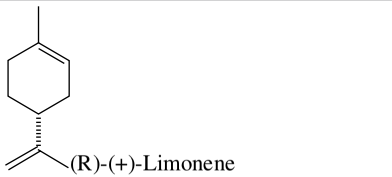
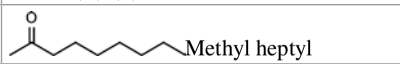
Table 3.2 (continued)

Plants	Active ingredient	Mosquito	LC/LD values	Compound structure	References
Psidium rotundatum	1,8-Cineol	*Ae. aegypti*	LC_{50} value of 63 mg/L	 1,8-Cineol	Aguilera et al. (2003)
Spondias purpurea	Caryophyllene oxide and α-cadinol	*Ae. aegypti*	LC_{50} value of 39.7 mg/L	 Caryophyllene oxide  α-cadinol	Lima et al. (2011)
Stemodia maritima	β-Caryophyllene and caryophyllene oxide	*Ae. aegypti*	LC_{50} value of 22.9 mg/L	 β-Caryophyllene  Caryophyllene	Arriaga et al. (2007)

Stemona curtisii	Stemocurtisine, stemocurtisinol, and oxyprotostemonine	*An. minimus*	LC_{50} values of 18, 39, and 4 ppm, respectively	 Stemocurtisine  Stemocurtisinol  Oxyprotostemonine	Mungkornasawakul et al. (2009)
Tagetes patula	Limonene and terpinolene	*Ae. aegypti*	LC_{50} value of 13.57 mg/L	 Limonene  Terpinolene	Dharmagadda et al. (2005)
Triphyophyllum	Dioncophylline-A peltatum	*An. stephensi*	LD_{50} values of 0.5, 1.0, and 2.0 mg/L concentrations at 3.33, 2.66, and 1.92 h	 Dioncophylline-A peltatum	Francois et al. (1996)

(continued)

Table 3.2 (continued)

Plants	Active ingredient	Mosquito	LC/LD values	Compound structure	References
Vitex trifolia	Methyl-*p*-hydroxybenzoate	*Cx. quinquefasciatus* and *Ae. aegypti*	LC_{50} values of 5.77 and 4.74 ppm, respectively	 Methyl-*p*- hydroxybenzoate	Kannathasan et al. (2011)
Zanthoxylum limonella	(R)-(+)-Limonene	*Ae. aegypti*	LC_{50} value of 24.6L	 (R)-(+)-Limonene	Pitasawat et al. (2007)
Zanthoxylum oxyphyllum	Methyl heptyl ketone	*Ae. aegypti*	LC_{50} value of 7.52 mg/L	 Methyl heptyl	Borah et al. (2012)

widely investigated, less number of patents has been applied regarding the production of formulations for use against mosquito larvae in the field. This review demonstrates the need for standardization of methodologies for the evaluation of larvicides against mosquitoes. The research regarding the search for new larvicides should be performed in a standardized manner. The features from plants (collection, extraction, chemical constitution) and insects (collection, age) and the methodological procedures must be well defined in research. We need to overcome the barriers to commercialization of new botanical insecticides. There has to be a paradigm shift in natural product research, in which studies are conducted with the ultimate goal of producing plant-based larvicides for use in public health programs.

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