2.0 REVIEW OF LITERATURE

Mosquitoes are responsible for more diseases than any other group of arthropods. Mosquito-borne diseases, such as malaria, filariasis, dengue/DHF, yellow fever, and Japanese encephalitis, contribute significantly to disease burden, death, poverty, and social debility in tropical countries. They transmit diseases to more than 700 million people each year. Insect-transmitted disease remains a major source of illness and death worldwide. Diseases that are health care associated transmission of viruses to humans by mosquitoes are an expanding problem in tropical and subtropical regions. Some of them such as filariasis, dengue, malaria and West Nile virus are amongst the most prevalent diseases in the world (Ameer and Mehlhorn, 2006a).

2.1 Larvicidal activity

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., 2008b).

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 (Kalyanasundaram and Das, 1985).
Biological control of mosquitoes could be very promising being ecofriendly 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 bio-degradability (Govindarajan and Sivakumar, 2012a).

The larvicidal activity of *Lantana camara* and *Bauhinia racemosa* extracted in petroleum ether, chloroform and ethyl acetate were tested against mosquito larvae of *An. stephensi* (Babita et al., 2014). The larvicidal effects of leaf and stem/bark extracts of *Jatropha curcas*, *Citrus grandis* and *Tinospora rumphii* were tested on the larvae of the dengue-vector, *Ae. aegypti* (Pedro et al., 2014).

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The essential oil and an isolated compound from the leaves of *Polygonum hydropiper* against dengue vector mosquito *Ae. albopictus* (Maheswaran and Ignacimuthu, 2014). The mosquitocidal activity of different fractions and isolated compounds from the ethyl acetate extract of *Ecbolium viride* root was assessed on larvae and pupae of *Cx. quinquefasciatus* (Cecilia et al., 2014).

Larvicidal efficacy of the crude seed extracts of *Coriandrum sativum* and *Brassica nigra* with five different solvents like acetone, ethyl acetate, methanol, ethanol and chloroform was tested against the mosquito larvae of *Cx. quinquefasciatus* (Thangaraj et al., 2014). The acaricidal and insecticidal property of ethyl acetate extract and its compounds isolated from marine actinobacteria, *Streptomyces* sp. against the larvae of cattle ticks, *Haemaphysalis bispinosa* and *Rhipicephalus microplus*; fourth-

Ashraf Ahmed (2013) investigate the oxidative stress and apoptotic signs detectable by flow cytometry as proposed pathogenicity mechanisms for the mosquitocidal bacterium *Bacillus thuringiensis (Bt)* in the mosquito vector, *Cx. pipiens*. The toxicity of mosquito larvicidal activity of leaf essential oil and their major chemical constituents from *Ocimum basilicum* were evaluated against *Cx. tritaeniorhynchus*, *Ae. albopictus* and *An. subpictus* (Govindarajan *et al.*, 2013a).

The three essential oils of plant species (Camphor oil) *Cinamomum camphora*, (Clove oil) *Myrtus caryophyllus* and (Eucalyptus oil) *Eucalyptus globulus* were evaluated for their larvicidal activity of against three vector mosquito larvae *Ae.aegypti*, *An. stephensi* and *Cx. quinquefasciatus* (Pugazhvendan and Elumali, 2013). The larvicidal activity of crude extracts from the endophytic fungus *Pestalotiopsis virgulata* and the saprophytic fungus *Pycnoporus sanguineus* against the mosquitoes *Ae. aegypti* and *An. nuneztovari* (Bucker *et al.*, 2013).

The larvicidal potential of different solvent crude (hexane, chloroform, ethyl acetate, acetone and methanol) leaf extracts of five plants (*Blepharis maderaspatensis*, *Elaeagnus indica*, *Maesa indica*, *Phyllanthus wightianus* and *Memecylon edule*) was tested against the fourth-instar larvae of *Ae. aegypti* (Shivakumar *et al.*, 2013).

Larvicidal activity of flavonoid extracts of different parts of *Vitex negundo* and *Andrographis paniculata* have been studied against the late III instar larvae of *Ae. aegypti* and *An. stephensi* (Gautam *et al.*, 2013). Govindarajan *et al.* (2013b) evaluated the
toxicity of mosquito larvicidal activity of essential oil from *Coleus aromaticus* and its pure isolated constituent thymol against larvae of *Cx. tritaeniorhynchus*, *Ae. albopictus*, and *An. subpictus*. Al-Mekhlafi *et al.* (2013) studied that the methanol extracts of different plants namely, *Trichodesma africanum*, *Cleome rupicola* and *Ochradenus baccatus*, were tested for larvicidal activity against 4th instar larvae of *Ae. caspius* and *Cx. pipiens* mosquitoes.

Liu *et al.* (2013) determined the larvicidal activity of the essential oil derived from roots of *Toddalia asiatica* and the isolated constituents against the larvae of the Culicidae mosquito *Ae. albopictus*. The larvicidal activity of methanol extracts of roots, stem and leaves of *Artemisia vulgaris* against *Cx. quinquefasciatus* (Ilahi and Ullah, 2013).

The flower extracts of *Calotropis procera* indicated the presence of alkaloids, carbohydrates, saponins, phenols, tannins, terpenoids and flavonoids which are known to possess medicinal and pesticidal properties. Larvicidal effects of the flower extract of *C. procera* on the fourth instar larvae of *Anopheles* sp. and *Culex* sp. (Azmathullah *et al.*, 2013). Kimbaris *et al.* (2012) evaluated the larvicidal effect exhibited by essential oils of *Dianthus caryophyllus*, *Lepidium sativum*, *Pimpinella anisum*, and *Illicium verum* against late third to early fourth instar mosquito larvae of *Cx. pipiens*. Liu *et al.* (2012a) reported that the essential oil derived from roots of *Saussurea lappa* and the isolated constituents against the larvae of the mosquito *Ae. albopictus*.

The leaf extract of *Acalypha alnifolia* with different solvents hexane, chloroform, ethyl acetate, acetone and methanol were tested for larvicidal activity against three important mosquitoes (Kovandan *et al.*, 2012). The toxicity of mosquito larvicidal
activity of leaf essential oil (EO) and their major chemical constituents from *Mentha spicata* against *Cx. quinquefasciatus*, *Ae. aegypti*, and *An. stephensi* (Govindarajan et al., 2011a).

Govindrajlan (2011a) studied that the mosquito larvicidal and ovicidal activity of crude hexane, ethyl acetate, benzene, chloroform, and methanol extracts of the leaf of three plants, *Eclipta alba*, *Cardiospermum halicacabum*, and *Andrographis paniculata*, were tested against the early third-instar larvae of *An. stephensi*. The larvicidal and ovicidal efficacy of different extracts of *Cardiospermum halicacabum* were tested against *Cx. quinquefasciatus* and *Ae. aegypti* (Govindrajlan, 2011b)

Govindarajan et al. (2011b) evaluated the larvicidal efficacy of different solvent leaf extract of *Ficus benghalensis* against *Cx. tritaeniorhynchus* and *An. subpictus*. Govindarajan (2011c) have been reported that the larvicidal and repellant properties of EO from various parts of four plant species, namely, *Cymbopogan citrates*, *Cinnamomum zeylanicum*, *Rosmarinus officinalis*, and *Zingiber officinale* against *Cx. tritaeniorhynchus* and *An. subpictus*. Kamaraj and Rahuman (2010) studied the larvicidal and adulticidal activities of hexane, ethyl acetate and methanol extracts of *Momordica charantia*, *Moringa oleifera*, *Occimum gratissimum*, *Occimum tenuiflorum*, *Punica granatum* and *Tribulus terrestris* against *Cx. gelidus* and *Cx. quinquefasciatus*. The methanolic extracts of dried fruits of long pepper, *Piper longum* and black and white peppers, *Piper nigrum*, were proved to be toxic against *Ae. aegypti* (Kumar et al., 2010).

Ramya and Jayakumararaj (2009) evaluated the antifeedant activity of leaf aqueous extract of *A. lineata* exhibited significant larval mortality against *Helicoverpa armigera*. The leaf acetone, chloroform, ethyl acetate, hexane, and methanol extracts of
A. lineata and Eclipta prostrata showed effective larvicidal activity against fourth-instar larvae of An. subpictus and Cx. tritaeniorhynchus (Elango et al., 2009a).

The various fruit wall extracts of Momordica charantia were reported to be toxic to the larvae of An. stephensi and Cx. quinquefasciatus (Maurya et al., 2009). The methanol extract of Azadirachta indica fruits exhibited potential toxicity against Cx. quinquefasciatus (Batabyal et al., 2009). The ethanolic leaf extract of Cassia obtusifolia (Rajkumar and Jebanesan, 2009) and the larvicidal efficacy of the crude leaf extract of Ficus benghalensis with three different solvents like methanol, benzene, and acetone was tested against the early second, third, fourth-instar larvae of Cx. quinquefasciatus, Ae. aegypti, and An. stephensi.

Larvicidal activity of crude hexane, ethyl acetate, petroleum ether, acetone, and methanol extracts of the leaf of five species of Cucurbitaceous plants, Citrullus colocynthis, Coccinia indica, Cucumis sativus, Momordica charantia, and Trichosanthes anguina, were tested against the early fourth instar larvae of Ae. aegypti and Cx. quinquefasciatus (Rahuman and Venkatesan, 2008). Karunamoorthi et al. (2008) have reported that the petroleum ether (60–80 °C) extracts of the leaves of Vitex negundo were evaluated for larvicidal activity against larval stages of Cx. tritaeniorhynchus.

The acetone, chloroform, ethyl acetate, hexane and methanol leaf extracts of Acalypha indica, Achyranthes aspera, Leucas aspera, Morinda tinctoria and Ocimum sanctum were studied against the early fourth-instar larvae of Ae. aegypti and Cx. quinquefasciatus (Bagavan et al., 2008). Rahuman et al. (2009) reported that the larvicidal activity of crude acetone, hexane, ethyl acetate, methanol, and petroleum ether
extracts of the leaf of *Datura metal* were assayed for their toxicity against the early fourth-instar larvae of *Cx. quinquefasciatus*.

The leaf extract of *Acalypha indica* with different solvents benzene, chloroform, ethyl acetate, and methanol has been tested for larvicidal, ovicidal activity, and oviposition attractancy against *An. stephensi* (Govindarajan *et al.*, 2008b). The methanol extracts of *Abutilon indicum, Aegle marmelos, Euphorbia thymifolia, Jatropha gossypifolia*, and *Solanum torvum* were assayed for their toxicity against the early fourth-instar larvae of *Cx. quinquefasciatus* (Rahuman *et al.*, 2008a).

Larvicidal activity was found ever since the discovery of the larvicidal potential of the petroleum ether extract of *Artemisia nilagirica* and *Galinsoga quadriradiata* (Sakthivadivel and Daniel, 2008). Das and Goswami (2007) showed that the ethanol leaf extract of *Annona squamosa* was found to have the most promising larvicidal activity against *Cx. quinquefasciatus* larvae.

Amer and Mehlhorn (2006b) have reported that the 136 oils from 41 plants (camphor, thyme, amyris, lemon, cedarwood, frankincense, dill, myrtle, juniper, black pepper, verbena, helichrysum, and sandalwood) induced 100% mortality after 24 h against third-instar larvae of *Ae. aegypti, An. stephensi*, and *Cx. quinquefasciatus*. Govindarajan *et al.* (2005) have tested extracellular secondary metabolite of different soil fungi against late third-instar larvae of *Cx. quinquefasciatus*.

Beninger *et al.* (2004) reported that the leaves of *Chrysanthemum morifolium* extracted sequentially with hexane, ethyl acetate, and methanol were found to reduce the growth of *Trichoplusia ni* larvae. The methanol extracts of *Pelargonium citrosa* leaf were
tested for their biological, larvicidal, pupicidal, adulticidal, antiovipositional activity, repellency, and biting deterrency against *An. stephensi* (Jeyabalan *et al.*, 2003).

Muthukrishnan and Puspalatha (2001) evaluated the larvicidal activity of extracts from *Calophyllum inophyllum*, *Rhinacanthus nasutus*, *Solanum suratense* and *Samadera indica*, *Myriophyllum spicatum* against *An. stephensi*. Murugan and Jeyabalan (1999) reported that *Leucas aspera*, *O. santum*, *Azadirachta indica*, *Allium sativum* and *Curcuma longa* had a strong larvicidal, antiemergence, adult repellency and anti reproductive activity against *An. stephensi*. Nirmal Sharma *et al.* (1998) studied that the larvicidal activity of *Gliricidia sepium* crude ethanol extracts of dried leaves, fresh leaves, dried petioles and stem bark were tested for their activities against third instar larvae of *An. stephensi*, *Ae. aegypti* and *Cx. quinquefasciatus*.

The ethanol extract of *Eucalyptus paniculata* was tested for larvicidal activity against *Ae. fluviatilis* (Macedo *et al.*, 1997). Methanol extracts from leaves showed significant larvicidal and growth regulatory activities, even at very low concentrations, on *Cx. quinquefasciatus* (Muthukrishnan *et al.*, 1997). The larvicidal activity of various plant extracts such as *Pendalim murax*, *Cleome icosondra* and *Dictyosa dietotoma* have been found to be promising against *Cx. quinquefasciatus* and *An. stephensi* (Kalyanasundaram and Das, 1985).

### 2.2 Ovicidal activity

The ovicidal, larvicidal and adulticidal activities of crude hexane, ethyl acetate, benzene, chloroform and methanol extracts of root of *Asparagus racemosus* were assayed for their toxicity against three important vector mosquitoes, viz., *Cx. quinquefasciatus*, *Ae. aegypti* and *An. stephensi* (Govindarajan and Sivakumar, 2014a)
The larvicidal, ovicidal, and oviposition-deterrent activities of petroleum ether and ethyl acetate extracts of the leaves of *Eugenia jambolana*, *Solidago canadensis*, *Euodia ridleyi*, and *Spilanthes mauritiana* were assayed against the three vector mosquito specie (Prathibha *et al*., 2014). Ramar *et al.* (2014) reported Ovicidal and oviposition response activities of plant volatile oils against *Cx. quinquefasciatus* Ten oils viz., aniseed, calamus, cinnamon oil, citronella, clove oil, lemon, orange, thyme, tulsi and vertiver respectively.

The larvicidal and ovicidal activities of acetone, benzene, hexane and methanol leaf extracts of *Basella rubra* and *Cleome viscosa* against dengue vector, *Ae. aegypti* (Krishnappa and Elumalai, 2013). Larvicidal, ovicidal, and repellent activities of marine sponge *Cliona celata* extracts against *Cx. quinquefasciatus* and *Ae. aegypti* (Reegan *et al*., 2013). The larvicidal, pupicidal, ovicidal and ovipositional deterrent activity of methanol leaves extract of *Spathodea campanulata* against *Ae. aegypti* (Karthikadevi *et al*., 2013).

The ovicidal and repellent activities of acetone, benzene, ethyl acetate, hexane and methanol extracts of *Melothria maderaspatana* against *Aedes aegypti* (Baluselvakumar *et al*., 2012). Govindarajan *et al.* (2011c) evaluated the ovicidal and repellent activities of methanol leaf extract of *Ervatamia coronaria* and *Caesalpinia pulcherrima* against *Cx. quinquefasciatus, Ae. aegypti* and *An. stephensi*.

The hexane extracts of *Aegle marmelos* and *Andrographis paniculata* revealed potential repellent, ovicidal, and oviposition activity against *Cx. tritaeniorhynchus* (Elango *et al*., 2010). The leaf extract of *C. fistula* with different solvents viz., methanol,
benzene, and acetone was studied for the larvicidal, ovicidal, and repellent activity against *Ae. aegypti* (Govindarajan, 2009).

Samidurai *et al.* (2009) observed that the leaf extracts of *Pemphis acidula* were evaluated for larvicidal, ovicidal, and repellent activities against *Cx. quinquefasciatus* and *Ae. aegypti*. Elango *et al.* (2009b) evaluated the leaf acetone, ethyl acetate, and methanol extracts of *Aegle marmelos*, *Andrographis lineate* and *Cocculus hirsutus* were tested for oviposition-deterrent, ovicidal, and repellent activities against *An. subpictus*.

The leaf extract of *Acalypha indica* with different solvents viz., benzene, chloroform, ethyl acetate, and methanol was tested for larvicidal, ovicidal activity, and oviposition attractancy against *An. stephensi* (Govindarajan *et al.*, 2008b). Luz *et al.* (2007) studied that the *M. anisopliae* and other fungi exhibit ovicidal activity in *Ae. aegypti* under laboratory conditions. The toxicity of dichloromethane, petroleum ether, and methanol extracts from *Vitex negundo* seed and leaf to the second- and fourth-instar larvae showed oviposition-deterrent effects on *Plutella xylostella* (Yuan *et al.*, 2006).

Essential oil of *Cinnamomum zeylanicum* showed oviposition-deterrent and repellent activities, and the essential oils of *Zingiber officinale* and *Rosmarinus officinalis* also showed both ovicidal and repellent activities against *An. stephensi*, *Ae. aegypti*, and *Cx. quinquefasciatus* (Prajapati *et al.*, 2005). Al-Doghairi *et al.*, (2004) have reported that the methanolic extracts of *Solenostemma argel* were tested oviposition, egg hatchability, and larval viability against *Cx. pipiens*.

The active components dymalol, nymania-3, and triterpenes isolated from the extract of *Dysoxylum malabaricum* act as an oviposition repellent and deterrent to
An. stephensi (Hisham et al., 2001). The active components dymalol, nymania-3, and triterpenes isolated from the extract of Dysoxylum malabaricum act as an oviposition repellent and deterrent to An. stephensi (Govindachari et al., 1999).

Su and Mulla (1998) have reported that the ovicidal activity of the Neem product azadirachitin against the mosquitoes Cx. tarsalis and Cx. quinquefasciatus. Ovicidal effects of the seed extract of Atriplex canescens was reported against Cx. quinquefasciatus (Ouda et al., 1998).

2.3 Adulticidal activity

Mosquito knock-down and adulticidal activities of essential oils by vaporizer, impregnated filter paper and aerosol methods Aniseed (Pimpinella anisum), Calamus (Acorus calamus), Camphor (Cinnamomum camphora), Cinnamon (Cinnamomum verum), Citronella (Cymbopogon nardus), Clove (Myrtus caryophyllus), Eucalyptus (Eucalyptus globulus), Geranium (Pelargonium graveollens), Lemongrass (Cymbopogon flexuosus), Luchi (Gaultheria fragrantissima), Pine (Pinus radiate) and Tulsi (Ocimum sanctum) (Ramar et al., 2014).

Mavundza et al. (2014) evaluated the adulticidal activity of Aloe ferox, Sclerocarya birrea, Balanites maughamii, Croton menyaarthii, Melia azedarach, Trichilia emitica, Olax dissitiflora, Clausena anisata, Atalaya alata, and Lippia javanica against An. stephensi in South Africa. Sivakumar and Govindarajan (2013) evaluated the toxicity of mosquito adulticidal activity of hexane, ethyl acetate, benzene, chloroform and methanol extracts of Coccinia indica against Cx. quinquefasciatus.
The adulticidal, repellent, and ovicidal potential of the crude hexane, ethyl acetate, benzene, aqueous, and methanol solvent extracts from the medicinal plants *Andrographis paniculata*, *Cassia occidentalis*, and *Euphorbia hirta* against the medically important mosquito vector, *An. stephensi* (Panneerselvam and Murugan, 2013). The adulticidal activity of hexane, ethyl acetate, benzene, chloroform and methanol leaf extracts of *C. halicacabum* against *Cx. quinquefasciatus*, *Ae. aegypti* and *An. stephensi* (Govindarajan and Sivakumar 2012b).

Ravindran *et al*. (2012) reported that the intrinsic toxicity of hexane, ethyl acetate and methanol crude extracts of *Ageratum houstonianum* leaves against adult *An. stephensi*, *Ae. aegypti* and *Cx. quinquefasciatus* mosquitoes. The larvicidal, adulticidal, and repellent activities of the root bark acetone extracts from *Hiptage benghalensis* against three mosquito vectors namely, *Ae. albopictus*, *An. barbirostris*, and *Cx. quinquefasciatus* (Lalrotluanga *et al*., 2012).

Amerasan *et al*. (2012) have reported that the adulticidal and repellent activities of crude hexane, chloroform, benzene, acetone, and methanol extracts of the leaf of *Cassia tora* were assayed for their toxicity against three important vector mosquitoes, viz., *Cx. quinquefasciatus*, *Ae. aegypti*, and *An. stephensi*. The adulticidal and repellent activities of crude hexane, ethyl acetate, benzene, chloroform, and methanol extracts of leaf of *E. alba* and *A. paniculata* were assayed for their toxicity against two important vector mosquitoes viz., *Cx. quinquefasciatus* and *Ae. aegypti* (Govindarajan and Sivakumar, 2012a).

The adult emergence inhibition (EI) and adulticidal activity of the leaf hexane, chloroform, ethyl acetate, acetone, and methanol extracts of *Aegle marmelos*
Andrographis lineata, A. paniculata, Cocculus hirsutus, Eclipta prostrate and Tagetes erecta were tested against Japanese encephalitis vector, Cx. tritaeniorhynchus (Elango et al., 2012). Nawaz et al. (2011) evaluated the Olive (Olea vera), Linseed (Linum usitatissimum) and Black pepper (Piper nigera) plant extracts have potential to kill adult mosquitoes of An. stephensi and Ae. aegypti under laboratory conditions.

Misni et al. (2011) examined the insecticidal activity of P. aduncum essential oil in aerosol cans for spraying against the adult Ae. aegypti and Ae. albopictus in a simulated room of an ordinary Malaysian house. Zahir et al. (2010a) studied the adult emergence inhibition and adulticidal activities of hexane, chloroform, ethyl acetate, and acetone leaves extracts of Anisomeles malabarica, Euphorbia hirta, Ocimum basilicum, Ricinus communis, Solanum trilobatum, Tridax procumbens and seeds of Gloriosa superba against An. stephensi.

Hafeez et al. (2010) reported that the adulticidal action of ten citrus oils against Ae. albopictus through exposure tube method. The essential oil of Lantana camara was tested against adulticidal activity of Ae. aegypti, Cx. quinquefasciatus, An. culicifacies, An. fluviatilis, and An. stephensi mosquitoes (Dua et al., 2010). Zahir et al. (2010b) reported that the crude hexane, chloroform, ethyl acetate, acetone, and methanol extracts of Anisomeles malabarica exhibited acaricidal and insecticidal activities against the adult of Haemaphysalis bispinosa and Hippobosca maculata.

The adulticidal activity of methanol extracts from three Malaysian plants namely Acorus calamus, Litsea elliptica and Piper aduncum against adult of Ae. aegypti were studied (Hidayatulfathi et al., 2004). Sulaiman et al. (2001) studied that the essential oils of Melaleuca cajuputi and Cymbopogon nardus have adulticidal effects on Aedes
mosquito at high-rise flats in Kuala Lumpur. Zaridah et al. (2001) have reported that the aqueous extract from the dried leaves of A. paniculata showed the strongest activity against adult worms of Brugia malayi.

2.4 Repellent activity

Control of mosquitoes is something of utmost importance in the present day with rising number of mosquito borne illnesses. Deforestation and industrialized farming are also two of the factors causing an alarming increase in the range of mosquitoes. Specialty products like mosquito repellent used to combat mosquitoes are required. Each of the products used for mosquito control have varying degrees of effectiveness. Carbon dioxide and lactic acid present in sweat in warm-blooded animals act as an attractive substance for mosquitoes. The perception of the odor is through chemo receptors present in the antennae of mosquitoes. Insect repellents work by masking human scent; a number of natural and chemical mosquito repellents were studied in this review that work to repel mosquitoes. Chemical mosquito repellents has a remarkable safety profile, but they are toxicity against the skin and nervous system like rashes, swelling, eye irritation, and worse problems, though unusual including brain swelling in children, anaphylactic shock, and low blood pressure. Hence it was concluded that natural mosquito repellents were preferred over chemical mosquito repellents.

Repellent activity of essential oils derived from 10 Thai native plants, belonging to three families were evaluated against female Ae. aegypti and Cx. quinquefasciatus (Phukerd and Soonwera, 2014). Karunamoorthi et al. (2014) evaluated the repellency of Ethiopian ethno medicinal plant Juniperus procera, against Afro-tropical malarial vector, An. arabiensis respectively. The essential oils extracted from fresh leaves of wild and
cultivated plants of *Ruta chalepensis* were evaluated for larvicidal and repellent activity against the Asian tiger mosquito, *Ae. albopictus* (Conti *et al.*, 2013). The repellent efficacy of the flower extracts of *Calotropis gigantea* against *Cx. quinquefasciatus* mosquito and to screen the bioactive compounds present in the flower extract (Dhivya and Manimegalai, 2013). The ethanolic extracts of leaves of *Datura stramonium* were evaluated for larvicidal and mosquito repellent activities against *Ae. aegypti*, *An. stephensi* and *Cx. quinquefasciatus* (Swathi *et al.*, 2012).

The larvicidal, pupicidal, repellent, and adulticidal activities of methanol crude extract of *Artemisia nilagirica* were assayed for their toxicity against *An. stephensi* and *Ae. aegypti* (Panneerselvam *et al.*, 2012). The mosquito repellent activities of essential oils from *Hyptis spicigera*, *Striga hermonthica* and *Ocimum basilicum* against *An. gambiae* and *Cx. quinquefasciatus* (Baba *et al.*, 2012).

The repellent activities of the essential oils of *Thymus* and *Mentha* species against *Ochlerotatus caspius* were evaluated by Koc *et al.* (2012). The essential oil (EO) extracted from fresh leaves of *Hyptis suaveolens*, and its main constituents were evaluated for larvicidal and repellent activity against the Asian tiger mosquito, *Ae. albopictus* (Conti *et al.*, 2012). The mosquito repellent activity of phytochemical extracts from Peels of five citrus fruit species, *Citrus sinensis*, *Citrus limonum*, *Citrus aurantifolia*, *Citrus reticulata* and *Citrus vitis*, was investigated (Effiom *et al.*, 2012).

The larvicidal and repellent properties of essential oils from various parts of four plant species *Cymbopogan citrates*, *Cinnamomum zeylanicum*, *Rosmarinus officinalis*, and *Zingiber officinale* against *Cx. tritaeniorhynchus* and *An. subpictus* (Govindarajan, 2011c). Govindarajan (2009) reported that the leaf methanol, benzene, and acetone
extracts of *Cassia fistula* were studied for the larvicidal, ovicidal, and repellent activities against *Ae. aegypti*. Petroleum ether extracts of the leaves of *Vitex negundo* were acted as a promising repellent against *Cx. tritaeniorhynchus* (Karunamoorthi *et al.*, 2008).

Mullai *et al.* (2008a) have reported that the leaf extract of *Citrullus vulgaris* with different solvents viz., benzene, petroleum ether, ethyl acetate, and methanol were tested for larvicidal, ovicidal, repellent, and insect growth regulatory activities against *An. stephensi*. The essential oil of *Z. officinalis* as a mosquito larvicidal and repellent agent against the filarial vector *Cx. quinquefasciatus* (Pushpanathan *et al.*, 2008).

The essential oils extracted by steam distillation from leaves of five plant species *Centella asiatica, Ipomoea cairica, Momordica charantia*, *Psidium guajava* and *Tridax procumbens* were evaluated for their topical repellency effects against malarial vector *An. stephensi* (Rajkumar and Jebanesan, 2007). The essential oils extracted from *Z. officinale* was evaluated for repellent activity against the three cockroach species *Periplaneta americana, Blattella germanica*, and *Neostylopyga rhombifolia* under laboratory conditions (Thavara *et al.*, 2007).

The efficacy of DEET (N,N-diethyl-3-methylbenzamide) in providing a long-lasting protection against many mosquito species has been documented in several studies (Klun *et al.*, 2006). Essential oil of *Cinnamomum zeylanicum, Z. officinalis*, and *Rosmarinus officinalis* showed oviposition deterrent, ovicidal, and repellent activities against *An. stephensi, Ae. aegypti*, and *Cx. quinquefasciatus* (Prajapati *et al.*, 2005).

Trongtokit *et al.* (2005) have assessed repellent activity of 38 Thai essential oils and found that an effective time of repellency strongly depended on the concentrations, experiment designs, and mosquito species. Choochote *et al.* (2004) studied that the crude
seed extract of celery *Apium graveolens* for repellent activity against *Ae. aegypti*. It showed repellency against *Ae. aegypti*. Moore *et al.* (2004) studied that the efficacy of low-cost repellent containing PMD and lemongrass oil (with fixatives) for up to 6 h, which was more effective than DEET, against *An. darlingi*.

Yang *et al.* (2004) investigated the repellent activity of methanol extracts from 23 aromatic medicinal plant species and a steam distillate against female blood-starved *Ae. aegypti*. The repellent activity of active compound octacosane from *Moschosma polystachyum* against the filariasis vector *Cx. quinquefasciatus* (Rajkumar and Jebanesan, 2004a). Das *et al.* (2003) evaluated the repellent properties of three plant extracts and essential oil (steam distillate) of *Zanthoxylum limonella* (fruits), *Citrus aurantifolia* (leaf), and petroleum ether extract of *Z. limonella* (fruits) against *Ae. albopictus* mosquitoes in mustard (Dhara) and coconut (parachute) oil base under laboratory conditions. Thyme and clove oils were the most effective mosquito repellents.

Rajkumar and Jebanesan (2002) reported that the knocking down and killing effect of *Solanum aerianthum* exhibited repellent activity against *Cx. quinquefasciatus*. Seyoum *et al.* (2002) evaluated the traditional use of mosquito repellent plants and their evaluation in semi-field experimental huts against *An. gambiae*. The mosquito repellents on the skin is one of the oldest and commonest tools for personal protection, and in many circumstances, it is the only way to avoid mosquito bites (Fradin and Day, 2002). *Cymbopogon excavatus* gave 100% repellency for 2 h, when it was evaluated in the laboratory against *An. arabiensis* and its repellency decreased to 59.3% after 4 h (Govere *et al.*, 2000).
Barnard (1999) studied that the repellency of five essential oils (Bourbon geranium, cedarwood, clove, peppermint, and thyme) singly applied at different concentrations or in combinations against two mosquito species *Ae. aegypti* and *An. albimanus*. The repellent properties of *Zanthoxylum armatum*, *Z. alatum*, *Curcuma aromatica*, and *Acalypha indica* against mosquitoes in two bases of mustard oil and coconut oil (Das *et al*., 1999). Jantan and Zaki (1998) reported that the four essential oils of *Litsea elliptica*, *Cinnamomum mollissimum*, *Cymbopogon nardus* and *Pogostemom cablin*, respectively, for their repellency effect against *Ae. aegypti*.

The chemicals derived from plants have been projected as weapons in future mosquito control program as they are shown to function as general toxicant, growth and reproductive inhibitors, repellents and oviposition-deterrent (Sukumar *et al*., 1991). Repellency properties of nepetalactone (cyclopentanoid monoterpane) isolated from the catnip plant, *Nepeta cataria*, against 17 species of insects were reported by (Eisner 1964).

**2.5 Mosquitocidal compounds**

The larvicidal activities of *Ipomoea carnea* stem extracts, their different fractions and dibutyl phthalate, which is a secondary metabolite isolated from the extract. These were screened against mosquito species *Ae. aegypti* and *Cx. quinquefasciatus* (Elija *et al*., 2014). Tikar *et al.* (2014) evaluated the oviposition deterrent activity of three mosquito repellents namely diethyl phenyl acetamide (DEPA), diethyl benzamide (DEB) along with diethyl toluamide (DEET) against *Ae. aegypti*, *Ae. albopictus*, and *Cx. quinquefasciatus* mosquitoes. The effective root compound of plumbagin of *Plumbago zeylanica* was evaluated for chemical constituent and antimalarial effect against the fourth instar larvae of *An. stephensi* (Pradeepa *et al*., 2014).
Cecilia et al. (2014) reported the mosquitocidal activity of different fractions and isolated compounds from the ethyl acetate extract of *Ecbolium viride* root was assessed on larvae and pupae of *Cx. quinquefasciatus*.

The essential oil and its chemical constituents from *Feronia limonia* leaf was evaluated for mosquito larvicidal activity against the larvae of *An. stephensi, Ae. aegypti* and *Cx. quinquefasciatus* (Senthilkumar et al., 2013). Mahesh Kumar et al. (2013) reported the *Orthosiphon thymiflorus* leaf extract and the bacterial insecticide spinosad, testing the first to fourth instars larvae and pupae of two important vector mosquitoes *Ae. aegypti* and *An. stephensi*. Govindarajan et al. (2013b) evaluated the toxicity of mosquito larvicidal activity of essential oil from *Coleus aromaticus* and its pure isolated constituent thymol against larvae of *Cx. tritaeniorhynchus, Ae. albopictus,* and *An. subpictus*. Larvicidal activity of the essential oil derived from roots of *Toddalia asiatica* the isolated constituents against the larvae of mosquito *Ae. albopictus* respectively (Liu et al., 2013).

The toxicity of mosquito larvicidal activity of leaf essential oil and their major chemical constituents from *Ocimum basilicum* were evaluated against *Cx. tritaeniorhynchus, Ae. albopictus,* and *An. subpictus* (Govindarajan et al., 2013a). Liu et al. (2012a) reported that the essential oil derived from roots of *Saussurea lappa* and the isolated constituents against the larvae of the mosquito *Ae. albopictus*. The toxicity of mosquito larvicidal activity of leaf essential oil (EO) and their major chemical constituents from *M. spicata* against *Cx. quinquefasciatus, Ae. aegypti,* and *An. stephensi* (Govindarajan et al., 2011a). *Blumea densiflora* was investigated for their chemical composition and larvicidal activity against *Anopheles anthropophagus*, the primary
vector of malaria in China and other East Asian countries. Totally, 46 compounds were identified by gas chromatography (GC) and mass spectroscopy (MS). The major chemical compounds identified were borneol (11.43 %), germacrene D (8.66 %), β-caryophyllene (6.68 %), γ-terpinene (4.35 %), sabinene (4.34 %), and β-bisabolene (4.24 %). A series of concentrations of EO (that ranged from 6.25 to 150 ppm) were tested against *An. anthropophagus* fourth instar larvae (Zhu and Tian, 2011).

They are complex mixtures of volatile secondary metabolites that can mainly be categorized as phenylpropanoids or mono-, sesqui-, and diterpenes (Baser and Buchbauer, 2010). *Five cucurbitacins*, kuguacins A–E (1–5), together with three known analogues, 3beta, 7beta, 25-trihydroxycucurbita-5, (23E)-dien-19-al (6), 3beta, 25-dihydroxy-5beta, 19-epoxycucurbita-6, (23E)-dien (7), and momordicine I (8), were isolated from the roots of *Momordica charantia*; the compounds 3 and 5 showed moderate anti-HIV-1 activity and minimal cytotoxicity against C8166 cells (Chen *et al*., 2008). Non-ribosomal peptides (NRPs) or polyketides are metabolites with important biological functions. The key enzymes needed for their production belong to the family of polyketide synthases (PKSs) and nonribosomal peptide synthases (NRPSs) that are generally known to be post-translationally modified by PPTases such as 4-phosphopantetheinyl transferase1 (PPT1) (Marquez-Fernandez *et al*., 2007). Mosquito larvicidal activity of plant-derived isolated compounds have been reported such as spipnoohine, pipyahyine, leptostachyol acetate, diterpenoid furans 6alpha-hydroxyvouacapan-7beta, 17beta-lactone, 6alpha, 7beta-dihydroxyvouacapan-17beta-olic acid and methyl 6alpha, 7beta-dihydroxyvouacapan-17beta-oate, rotenone and tetranortriterpenoids (Yenesew *et al*., 2006). Repellent properties of several EO appear to
be associated with the presence of monoterpenoids and sesquiterpenes \cite{Jaenson2006}. The essential oil of \textit{V. zinzanoides} with known biological activity against insects include sesquiterpenes (3-4%), sesquiterpenols (18-25%) and sesquiterpenones (7-8%) \cite{ChauhanRaina2005}. 1, 8-cineole compound isolated from the leaves of essential oils of \textit{Hyptis martiusii} showed pronounced insecticidal effect against \textit{Ae. aegypti} larvae and \textit{Bemisia argentifolii} \cite{Araujo2003}; Seven flavonoid compounds were isolated and identified from the flowers of \textit{Abutilon indicum} \cite{MatlawskaSikorska2002}.

The petroleum ether and EtOAc-soluble extracts of the seeds of \textit{Ziziphus jujuba} were evaluated for their inhibitory effects against both cyclooxygenase-1 (COX-1) and cyclooxygenase-2 (COX-2) \cite{Su2002}. Thymol, alpha-Amyrin, Carvacrol + beta-Caryophyllene isolated from the petroleum ether fraction of \textit{Thymus capitatus} were proven to have high larvicidal potency against the \textit{Culex pipiens} \cite{Mansour2000}. Essential oils (EO) extracted from aromatic plants are a potential source of pharmacologically active compounds such as analgesics, anti-inflammatoryics, antitumorals, antibiotics and digestives \cite{ZygadloJuliani2000}. Gossypetin 8 and 7 glucosides, cyanidin-3-rutinoside, \(\beta\)-pipene, cincole, farnesol, borneol from oil, eudesmol, geramiol, caryophyllene from flower extract, gallic acid, allantolactone and isoalantolactone were isolated from \textit{A. indicum} \cite{RastogiMehrotra1995}; Clomiphene citrate, centchroman, and embelin were isolated from the methanolic extracts of \textit{A. indicum} and \textit{Butea monosperma} and studied on uterotropic and uterine peroxidase activities in ovariectomized rats \cite{Johri1991}.

Plant products or plant-derived compounds are promising alternatives to synthetic insecticides in controlling insect pests of medical importance.
Chitin is essentially a homopolymer of N-acetylglucosamine (with occasional glucosamine residues) joined by \( \beta-1,4 \)-glycosidic linkages. It is an important structural component of arthropod cuticle and of fungal cell walls. In insects it makes up 20-50\% of the procuticle and is deposited as microfibrils originating from the tips of the microvilli of the epidermal cells (Andersen, 1979).

2.6 Plant description

2.6.1 *Albizia lebbeck* (L.) Benth. (Family: Fabaceae)

**Common name**

Tamil- Vaagai, Vagai; English- Soros-tree, Womans tongue, Raom tree, East India walnut, Lebbek tree, Siris tree, East Indian Walnut, Black Siris; Hindi- Siris; Kannada-Baage; Malayalam- Karimthakara, Vaga, Vaka, Karivaka, Nenmenivaka, Kattuvaka; Manipuri- Khok, Siris Tree.

**Description**

*Albizia lebbeck* is a fast-growing, medium-sized deciduous tree with a spreading umbrella-shaped crown of thin foliage and smoothish, finely fissured, grayish-brown bark. Depending on site conditions, annual height growth ranges from 0.5 to 2.0 m; on good sites, individual trees attain an average height of 10 to 15 m. The species grows well from sea level to 1500 m on sites receiving between 500 and 2500 mm annual rainfall and tolerates both light frosts and drought. While it grows poorly on heavy clay soils, it tolerates saline sites. The tree grows best on moist, well-drained soils. *A. lebbeck*, a valued timber species within its native Asian range, was previously exported to Europe under the trade name East Indian walnut. It is used for furniture, flooring and a variety of
agricultural implements. Flowers usually appear with new leaves over an extended period beginning at the end of the dry season; in the Caribbean region this season occurs between April and September. Flowering can occur on trees as young as 10 months. The fragrant, cream colored flowers develop on lateral stalks in rounded clusters 5 to 7.5 cm across the many threadlike, spreading, whitish-to-yellow stamens tipped with light green, borne at the ends of lateral stalks 4 to 10 cm long.

The fruits, flattened pods 10 to 20 cm long and 2.5 to 3.8 cm broad, are produced in large numbers and each contains several seeds. Immature pods are green, turning straw-colored on maturity, usually 6 to 8 months after flowering. The dry pods remain on the tree well into the following season.

Seeds are released from the mature, dehiscent pods while still attached to the tree or from wind blown pods that later split open or decompose. The mature pods may be collected by hand from the ground or low branches or clipped with pruning poles. Seeds are easily extracted from the pods by hand or by crushing the pods and winnowing. *A. lebbeck* seeds are small, oblong, approximately 9 by 7 mm long and broad, compressed, and light brown in color with a smooth, hard testa. Seeds average from 7,000 to 11,000 per kg. Seeds can be stored for up to 5 years in sealed containers at room temperature with only moderate reduction in percentage viability.

**Uses**

*A. lebbeck* is a tree well known in the Indian subcontinent for its range of uses. *A. lebbeck* is used in Indian traditional system and folk medicine as well to treat several inflammatory pathologies such as asthma, arthritis and burns (Ayurvedic Pharmacopoeia of India, 2001). *A. lebbeck* inhibited the passive cutaneous anaphylaxis and mast cell
degranulation in rat. Moreover, it could protect the sensitized guinea pig from antigen-induced anoxic convulsion (Baruach et al., 1997). Recently, it was found that the alcoholic extract of *A. lebbeck* has antihistaminic property, by neutralizing the histamine directly or due to corticotrophic action as evidenced by raising cortisol levels in plasma. It is also reported in Indian folk medicine that *A. lebbeck* has antiseptic, antidysentric and anti-tubercular activities (Ayurvedic Pharmacopoeia of India, 2001). Moreover, Saponins of *A. lebbeck* have been claimed to be useful in treatment of Alzheimer’s and Parkinson’s diseases (Sanjay, 2003).

Leaves have been claimed to have anticonvulsant activity and nootropic effect (Chintawar et al., 2002) which may be due to the presence of certain important compounds like alkaloids and flavanoids. Moreover, the aqueous extract of *A. lebbeck* leaves showed antioxidant activity in diabetic rats (Resmi et al., 2006). The saponins of the seeds of *A. lebbeck* exhibited antiovulatory properties. The seeds had anti-fertility effect on male rats (Singh et al., 1991) and antidiarhoeal activity studied on conventional rodents models of diarrhea (Besra et al., 2002).

2.6.2 *Delonix elata* (L.) Gamble (Family: Fabaceae)

**Common name**

Tamil- Perungondrai, Vadanarayanan; English- White Gulmohar, White Poincian Peacock; Hindi- Waykaran, Samrsro, Sanesro, Sandeshra; Kannada- kempukenjiga, nirangi, vatanarayana; Marathi- sanchaila, sankasura, Sanskrit: Siddhesvara;Telugu- Chenna seribiseri, Chitti keshwaramu.
**Description**

*D. elata* plant is about 2.5-15 m tall, trunk of the tree is smooth, ash colored, leaves compound, 15-30 cm long rachis, bipinnate usually 4-6 pairs, leaflets are 10-20 pairs with spreading, rounded crown, crooked poor stem form and drooping branches. Bark has smooth, shining and flaking appearance.

Leaves are 3-8 or more, Leaflets are 1.25-4 mm wide. Flowers yellowish white in terminal corymbiform racemes, small pods, seeds are 4-8 in number.

**Uses**

The leaves of which are used both internally and for external application in cases of inflammatory joints by applying paste or by taking the expressed juice by local people. Medicated oil prepared from the leaves is marketed under the name of “Vathanarayana”. Leaves are used as a folklore remedy for inflammatory joint disorders.

**2.6.3 Pithecellobium dulce (Roxb.) Benth(Family: Fabaceae)**

**Common name**

Tamil- Kodukkappuli; English- Manila Tamarind; Hindi- Jangal Jalebi; Kannada- Seeme hunase; Marathi- Vilayatichinch; Gujarati- Vilayati ambli.

**Description**

Leaves are parpinnate with one single pair of pinnae and one single pair of leaflets per pinnae, leaflets is 2.0-3.5 cm long x 1.0-1.5 cm wide. There are small thorns 2.0-15.0 mm long in axillary pairs inserted on each side of the leaves' pedicels. Thorn
less individuals do occur. Leaves are deciduous but foliage is persistent, as the new leaves appear while the old ones are being shed; so that the tree looks like an evergreen.

Flowers are disposed in small spherical glomerules of ca 1 cm in diameter, forming short axillary panicles of 5-30 cm in length. Flowers are white-greenish slightly fragrant 1.0-1.5 mm in diameter, with a hairy corolla, 50 thin stamina, connate in a tube at their basis, surrounded by the green calyx. Legumes are greenish-brown to red or pinkish, rather thin, 10-15 cm long x 1-2 cm wide. There are 10 seeds per pod; Pods are irregular in shape and flattened, set in a spiral of 1 to 3 whorls and strangled between the seeds (lomentaceous). Pods are 10-15 x1.5 cm; the color becoming spiral and reddish-brown as they ripen.

Each pod contains 5-10 shiny black seeds up to 2 cm long. The grey bark and tightly-coiled seed pods are characteristics of this tree, and make it easy to distinguish.

Uses

Tannin can be extracted from the bark, leaves and seeds, which can be used to soften leather. The seeds are stated to be eaten raw or in curries and seed oil is suitable for edible purposes and for soap manufacture (CSIR, 2003). Presence of steroids, saponins, triterpene oligoglycosides such as mixture of oleanolic acid and echinocystic acid glycosides, lipids, phospholipids, glycosides, glycolipids and polysaccharides has been reported in the seeds (Nigam et al., 1997). A lysozyme has been isolated, purified and identified from *P. dulce* seeds with antifungal activity (Narumon et al., 2011). The stem bark and leaves of *P. dulce* were reported to possess α-glucosidase inhibitory activity (Tanasorn et al., 2008). In our earlier study, we have reported antioxidant and free radical scavenging activity of extracts of *P. dulce* seeds (Dnyaneshwar et al., 2012). Traditionally the tender leaf paste is mixed with the seeds powder of *P. dulce* and is given orally in empty stomach to cure diabetes (Arul Manikandan et al., 2006).