Plant-Derived Essential Oils; Their Larvicidal Properties and Potential Application for Control of Mosquito-Borne Diseases

Mahmoud Osanloo1,2, Mohammad Mehdi Sedaghat3, Alireza Sanei-Dehkordi4, Amir Amani5,6

1 Department of Medical Nanotechnology, School of Advanced Technologies in Medicine, Fasa University of Medical Sciences, Fasa, Iran.
2 Noncommunicable Diseases Research Center, Fasa University of Medical Sciences, Fasa, Iran.
3 Department of Medical Entomology and Vector Control, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran.
4 Department of Medical Entomology and Vector Control, School of Health, Hormozgan University of Medical Sciences, Bandar Abbas, Iran.
5 Natural Products and Medicinal Plants Research Center, North Khorasan University of Medical Sciences, Bojnurd, Iran.
6 Medical Biomaterials Research Center (MBRC), Tehran University of Medical Sciences, Tehran, Iran.

Abstract

Mosquito-borne diseases are currently considered as important threats to human health in subtropical and tropical regions. Resistance to synthetic larvicides in different species of mosquitoes, as well as environmental pollution, are the most common adverse effects of excessive use of such agents. Plant-derived essential oils (EOs) with various chemical entities have a lower chance of developing resistance. So far, no proper classification based on lethal concentration at 50% (LC50) has been made for the larvicidal activity of EOs against different species of Aedes, Anopheles and Culex mosquitoes. To better understand the problem, a summary of the most common mosquito-borne diseases have been made. Related articles were gathered, and required information such as scientific name, used part(s) of plant, target species and LC50 values were extracted. 411 LC50 values were found about the larvicidal activity of EOs against different species of mosquitoes. Depending on the obtained results in each species, LC50 values were summarized as follows: 24 EOs with LC50 < 10 µg/mL, 149 EOs with LC50 in range of 10-50 µg/mL, 143 EOs having LC50 within 50-100 µg/mL and 95 EOs showing LC50 > 100 µg/mL. EOs of Callitris glaucophylla and Piper betle against Ae. aegypti, Tagetes minuta against An. gambiae, and Cananga odorata against Cx. quinquefasciatus and An. dirus having LC50 of ~ 1 µg/mL were potentially comparable to synthetic larvicides. It appears that these plants could be considered as candidates for botanical larvicides. [GMJ.2019;8:e1532]

DOI:10.31661/gmj.v8i0.1532

Keywords: Volatile Oil; Pesticides; Aedes; Anopheles; Culex
Introduction

Arthropod-borne diseases are the cause of more than 17% of all human infectious diseases around the world [1]. Mosquitoes (Diptera: Culicidae) are an important family of Arthropoda phylum which is grouped into 39 genera with a total of over 3000 species [2, 3]. More than half the world’s population lives in areas where mosquito-borne diseases are common. Mosquito-borne diseases represent a critical threat for billions of people worldwide, e.g., more than 3.9 billion people in over 128 countries are at risk of dengue, with 96 million cases estimated per year. Malaria causes more than 400,000 deaths every year globally; the majority of them are children under five years of age [1, 4]. Three genera of mosquito which are very important in the transmission of human diseases include *Aedes* (Chikungunya, Dengue fever, Lymphatic filariasis, Rift Valley fever, Yellow fever, Zika), *Anopheles* (Malaria, Lymphatic filariasis) and *Culex* (Japanese encephalitis, Lymphatic filariasis, West Nile fever) [1, 5]. All mosquitoes have immature aquatic stages. Thus, larviciding could be an efficient method to reduce the population of mosquitoes and prevent the transmission of such diseases [6-8]. Larvicides reduce their population in breeding places, where they are concentrated, immobilized and accessible before they emerge into adults [9, 10]. Larviciding is usually performed by applying synthetic larvicides such as organophosphates (e.g., temephos, fenthion, and malathion) or using an insect growth regulator (IGRs) such as methoprene [11, 12]. However, indiscriminate use of these agents affects the population of their natural enemies (such as *Gambusia* fish) and causes resistance in different species of mosquitoes [10, 13]. Additionally, synthetic insecticides are usually based on a single active ingredient. Thus, resistance against them is more probable compared with botanical insecticides having multiple components [14-16]. Developing resistance against insecticides also has been linked to their tendency to remain in the environment for a long time. During this period, larva starts to produce detoxifying enzymes or change their enzymes’ structure. Thus, resistance against the larvicides may be expected [17, 18]. Moreover, synthetic insecticides leave toxic residues in the environment and make safety concerns [13, 19]. In this regards, identification of active and eco-friendly bio-pesticides is crucial for successful management of mosquito-borne diseases. Essential oils (EOs) have been suggested as alternative sources for control of insects as selective and biodegradable agents with minimal impacts on non-target organisms and environment [13, 20]. EOs are complex mixtures of volatile organic compounds which are produced as secondary metabolites in plants [21]. They are obtained from hydrodistillation or steam distillation of plant entities such as flowers, roots, barks, leaves, seeds, peels, fruits, and woods [22]. EO-based pesticides consist of a combination of molecules which can act concerted on both behavioral and physiological processes. Thus, there is very little chance of resistance development among the treated mosquitoes [10, 21, 23]. Generally, EOs have different larvicidal activity (LA) against various species of mosquitoes. The most critical factor in developing EO-based larvicides is their potency in terms of their LAs. Currently, there is a single review paper, which has gathered LA of 122 plants against mosquitoes. However, the authors have not separated the LA-based on the mosquito species [24]. In this review we have given an update to the potential of herbal larvicides, gathering data for more than 400 LC50 values of EOs. EOs have been arranged based on their LC50 against each species to provide a better understanding and comprehensive knowledge about their larvicide potential.

Common Mosquito-Borne Diseases

In Table-1, profiles of the most common mosquito-borne diseases (including vectors, pathogenic agent, common hosts in vertebrate and distribution) have been summarized. Malaria, Yellow Fever, Dengue Fever, Zika, Chikungunya, West Nile, and Japanese encephalitis accounted for almost 0.7 million deaths around the world, annually [1].

Categorizing LA of EOs Against Different Species

Tables-2 to 9 brief 411 LC50 values on LA of different EOs against different species of mos-
Table 1. Profiles of the Most Common Mosquito-Borne Diseases

| Disease     | Vectors                                                                 | Caused by                     | Vertebrate Hosts          | Distribution                                           |
|-------------|-------------------------------------------------------------------------|--------------------------------|---------------------------|--------------------------------------------------------|
| **Malaria** | *An. atroparvus*, *An. labranchiae*, *An. messeae*, *An. sacharovi*, *An. sergentii*, *An. superpictus Grassi*, *An. arabiensis*, *An. funestus*, *An. gambiae*, *An. melas*, *An. merus*, *An. moucheti*, *An. nili*, *An. barbirostris*, *An. lesteri*, *An. sinensis*, *An. aconitus*, *An. annularis*, *An. balabacensis*, *An. culicifacies*, *An. dirus*, *An. farauti*, *An. flavirostris*, *An. flaviatilis*, *An. koliensis*, *An. leucosphyrus*, *An. maculatus*, *An. minimus*, *An. punctulatus*, *An. stephensi*, *An. subpictus*, *An. sundaicus.* | Protozoan parasite; Plasmodium | Reptiles, birds, rodents, Primates and humans. | Endemic throughout most of the tropics. Ninety-five countries and territories have ongoing transmission |
| **Yellow Fever** | *Ae. aegypti*, *Ae. africanus*, *Ae. anomethea*, *Ae. albopictus*, *Ae. furcifer*, *Ae. luteocephalus*, *Ae. metallicus*, *Ae. bromeliae*, *Ae. serratus.* | Virus of the family Flaviviridae; genus Flavivirus. | Primates | Ghana, Guinea, Nigeria, Ethiopia, Liberia, Gambia, Mali, Senegal, Sudan, Togo, Uganda, Congo, Chad, Angola, Brazil, Colombia and Peru, Paraguay, Argentina, Philippines, Thailand, China, Malaysia, Japan, Pakistan, Taiwan, India, Sri Lanka, Burma, Malay Peninsula, Cambodia, Vietnam, Indonesia, India, Australia, Brazil, Venezuela, Mexico, Bolivia, Argentina, USA |
| **Dengue Fever** | *Ae. aegypti*, *Ae. albopictus*, *Ae. polynesiensis*, *Ae. scutellaris.* | Virus of the family Flaviviridae; genus Flavivirus. | Primates | Brazil, Colombia, Venezuela, Puerto Rico, Martinique, Honduras, Guadeloupe, El Salvador, French Guiana, Guinea, Bissau, Angola, Cabo Verde, Thailand, Vietnam, Singapore |
| **Zika** | *Ae. africanus*, *Ae. luteocephalus*, *Ae. aegypti*, *Ae. albopictus*, *Ae. furcifer*, *Ae. vitatus.* | The virus of the family Flaviviridae; genus Flavivirus. | Primates | |
Japanese Encephalitis [33]

West Nile [32]

Chikungunya [30, 31]

Table 1. Profiles of the Most Common Mosquito-Borne Diseases

| Disease                        | Vector(s)                          | Virus of the family | Species | Hosts                                      |
|--------------------------------|------------------------------------|---------------------|---------|-------------------------------------------|
| Benin, Burundi, Cameroon, Central African Republic, Comoros, Congo, Equatorial Guinea, Guinea, Kenya, Madagascar, Malawi, Mauritius, Mayotte, Nigeria, Senegal, South Africa, Sudan, Tanzania, Uganda, Zimbabwe, Cambodia, East Timor, India, Indonesia, Laos, Malaysia, Maldives, Myanmar, Pakistan, Philippines, Réunion, Seychelles, Singapore, Taiwan, Thailand and Vietnam. | Ae. albopictus, Ae. aegypti, Ae. henselli | Togaviridae; genus Alphavirus | Primates, birds, cattle, and rodents |
| Australia, Bangladesh, Burma, Cambodia, China, Guam, India, Indonesia, Japan, Laos, Malaysia, Nepal, North Korea, Pakistan, Papua New Guinea, Philippines, Russia, Saipan, Singapore, South Korea, Sri Lanka, Taiwan, Thailand, Timor-Leste, Vietnam. | Ae. aegypti, Cx. pipiens, Cx. quinquefasciatus, Cx. australicus, Cx. globocoxitus, Cx. tarsalis, Cx. univittatus, Cx. annulirostris | Flaviviridae; genus Flavivirus | Birds, Horses, Other Mammals |
| Cx. tritaeniorychynchus, Cx. annulirostris, Cx. vishnui, Cx. gelidus, Cx. sitiens, Cx. fuscocephela, An. subpictus, Ae. albopictus, Ae. japonicas | Virus of the family Flaviviridae; genus Flavivirus. | | |
### Table 2. Larvicidal Activity of Essential Oils Against Aedes Aegypti

| No. | Plant species               | Used part(s) | LC$_{50}$ (µg/mL) | Ref No. | Plant species               | Used part(s) | LC$_{50}$ (µg/mL) | Ref |
|-----|-----------------------------|--------------|-------------------|---------|-----------------------------|--------------|-------------------|-----|
| 1   | Callitris glaucophylla      | Unclear      | 0.69              | [34]    | Piper hostmanianum          | Leaf         | 54.00             | [64]|
| 2   | Piper betle                 | Leaf         | 0.72              | [17]    | Zanthoxylum armatum         | Seed         | 54.00             | [74]|
| 3   | Auxemama glazioviana        | Heartwood    | 2.98              | [35]    | Croton sonderianus          | Aerial parts | 54.50             | [56]|
| 4   | Mammea siamensis            | Flower       | 5.90              | [36]    | Piper aduncum               | Aerial parts | 54.50             | [75]|
| 5   | Cinnamomum rhynchophyllum   | Leaf         | 6.00              | [37]    | Carum carvi                 | Unclear      | 54.62             | [53]|
| 6   | Cinnamomum microphylum      | Leaf         | 6.70              | [37]    | Syzygium lanceolatum        | Leaf         | 55.11             | [76]|
| 7   | Anacardium occidentale      | Seed         | 9.10              | [36]    | Lippia sidoides             | Leaf         | 56.00             | [57]|
| 8   | Piper klotzschianum         | Root         | 10.00             | [38]    | Mentha spicata              | Leaf         | 56.08             | [77]|
| 9   | Cinnamomum mollissimum      | Leaf         | 10.20             | [37]    | Vitex negundo L             | Unclear      | 56.13             | [22]|
| 10  | Cananga odorata             | Flower       | 10.40             | [39]    | Salvia officinalis          | Seed         | 56.90             | [42]|
| 11  | Cinnamomum impressicostatum | Leaf         | 10.70             | [37]    | Pinus kesiya                | Leaf         | 57.00             | [78]|
| 12  | Feronia limonia             | Leaf         | 11.59             | [40]    | Lippia pedunculosa          | Unclear      | 58.00             | [18]|
| 13  | Citrus sinensis             | Fruit        | 11.92             | [14]    | Apium graveolens            | Leaf         | 59.32             | [79]|
| 14  | Cinnamomum pubescen         | Leaf         | 12.80             | [37]    | Dendropanax morbifera       | Flower       | 62.32             | [80]|
| 15  | Piper klotzschianum         | Seed         | 13.27             | [38]    | Cordia leucomalloides       | Leaf         | 63.10             | [81]|
| 16  | Tagetes patula              | Whole plant  | 13.57             | [41]    | Eugenia triquetrata         | Aerial parts | 64.80             | [82]|
| 17  | Salvia elegans              | Aerial parts | 14.40             | [42]    | Swinglea glutinosa          | Unclear      | 65.70             | [46]|
| 18  | Citrus reticulata           | Fruit        | 15.42             | [43]    | Tagetes lucida              | Unclear      | 66.20             | [46]|
| 19  | Apium graveolens            | Seed         | 16.10             | [44]    | Boswellia ovalfoliata       | Leaf         | 66.24             | [83]|
| 20  | Chloroxylon swietenia       | Leaf         | 16.50             | [45]    | Croton nepetaefolius        | Aerial parts | 66.40             | [56]|
| 21  | Cymbopogon flexuosus        | Unclear      | 17.10             | [46]    | Origanum scabrum            | Leaf         | 67.13             | [84]|
| 22  | Hiptis martiusii            | Unclear      | 18.20             | [47]    | Acorus calamus              | Root         | 67.20             | [36]|
| 23  | Allium monanthum            | Stem         | 19.38             | [48]    | Annona muricata             | Seed         | 69.25             | [36]|
| 24  | Lippia sidoides             | Unclear      | 19.50             | [47]    | Syzygium aromaticum         | Whole plant  | 77.00             | [85]|
| 25  | Piper marginatum            | Stem         | 19.90             | [49]    | Eugenia citriodora          | Unclear      | 71.20             | [46]|

Continue in next Page
| No. | Species                          | Part          | Larvicidal Activity (%) | Compound Name          | Part          | Larvicidal Activity (%) |
|-----|----------------------------------|---------------|-------------------------|------------------------|---------------|-------------------------|
| 28  | *Piper marginatum*              | Inflorescence | 19.90 [49]              | *Knema globularia*     | Seed         | 72.10 [36]              |
| 29  | *Chloroxylon swietenia*         | Stem          | 20.20 [50]              | *Capraria biflor*      | Leaf         | 73.39 [86]              |
| 30  | *Citrus sinensis*               | Unclear       | 20.60 [46]              | *Stemona tuberosa*     | Root         | 75.20 [36]              |
| 31  | *Syzigium aromaticum*           | Unclear       | 21.40 [47]              | *Samanea saman*        | Stem bark    | 79.20 [36]              |
| 32  | *Cinnamomum sorcechnii*         | Leaf          | 21.50 [37]              | *Croton jacobinensis*  | Leaf         | 79.30 [87]              |
| 33  | *Ipomoea cairica*               | Unclear       | 22.30 [51]              | *Tagetes erecta*       | Leaf Stem    | 79.78 [88]              |
| 34  | *Piper marginatum*              | Leaf          | 23.80 [49]              | *Croton nepetaefolius* | Leaf         | 84.00 [57]              |
| 35  | *Asarum heterotropoides*        | Root          | 23.82 [52]              | *Ocimum sanctum*       | Aerial parts | 85.11 [89]              |
| 36  | *Zanthoxylum limonella*          | Unclear       | 24.61 [53]              | *Cunninghamia konishii*| Wood         | 85.70 [90]              |
| 37  | *Psidium guajava*               | Leaf          | 24.70 [54]              | *Strychnos nux-vomica* | Seed         | 90.00 [36]              |
| 38  | *Plectranthus mollis*           | Whole plant   | 25.40 [55]              | *Cunninghamia konishii*| Leaf         | 91.70 [90]              |
| 39  | *Lippia sidoides*               | Aerial parts  | 25.50 [56]              | *Syzygium aromaticum*  | Bud          | 92.56 [91]              |
| 40  | *Phyllanthus pulcher*           | Leaf & twig   | 25.80 [36]              | *Syzygium aromaticum*  | Bud          | 93.56 [14]              |
| 41  | *Croton zehntneri*              | Aerial parts  | 26.20 [56]              | *Abautilon indicum*    | Root         | 94.20 [36]              |
| 42  | *Anethum graveolens*            | Leaf          | 27.40 [36]              | *Croton argyrophyloides| Aerial parts | 94.60 [56]              |
| 43  | *Croton zehntneri*              | Leaf          | 28.00 [57]              | *Eucalyptus urophylla* | Leaf         | 95.50 [59]              |
| 44  | *Cryptomeria japonica*          | Leaf          | 28.40 [58]              | *Cordia curassavica*   | Leaf         | 97.70 [81]              |
| 45  | *Salvia leucantha*              | Aerial parts  | 29.50 [42]              | *Costus speciosus*     | Root         | 98.50 [36]              |
| 46  | *Citrus hystrix*                | Fruit         | 30.07 [43]              | *Guarea scabra*        | Leaf         | 98.60 [72]              |
| 47  | *Kaempferia galanga*            | Root          | 30.70 [36]              | *Nigella sativa L*     | Seed         | 99.90 [92]              |
| 48  | *Eucalyptus camaldulensis*      | Leaf          | 31.00 [59]              | *Pinus sylvestris*     | Needles      | 100.39 [91]             |
| 49  | *Curcuma zedoaria*              | Unclear       | 31.87 [53]              | *Croton argyrophyloides| Leaf         | 102.00 [57]             |
| 50  | *Eucalyptus grandis*            | Leaf          | 32.40 [60]              | *Croton sonderianus*   | Leaf         | 104.00 [57]             |
| 51  | *Youngia japonica*              | Aerial parts  | 32.45 [61]              | *Kadsura heteroclit*   | Leaf         | 111.79 [93]             |
| 52  | *Chenopodium ambrosioides*      | Aerial parts  | 35.00 [62]              | *Lantana montevindensis| Leaf         | 117.00 [68]             |
| 53  | *Murraya exotica*               | Leaf          | 35.80 [63]              | *Guarea silvatica*     | Leaf         | 117.80 [72]             |

*Continue in next Page*
| No. | Species                      | Part          | Larvicidal Activity | Species                      | Part         | Larvicidal Activity |
|-----|------------------------------|---------------|---------------------|------------------------------|--------------|---------------------|
| 55  | *Piper permucronatum*        | Leaf          | 36.00 [64]          | *Piper gaudichaudianum*      | Leaf         | 121.00 [64]         |
| 56  | *Curcuma aromatica*         | Rhizome       | 36.30 [65]          | *Croton rhamnifoliioides*    | Leaf         | 122.35 [94]         |
| 57  | *Clausena excavata*         | Leaf          | 37.10 [66]          | *Cymbopogon citratus*        | Unclear      | 123.30 [46]         |
| 58  | *Chamaecyparis formosensis* | Heartwood     | 38.60 [67]          | *Syzygium aromaticum*        | Flower       | 124.69 [43]         |
| 59  | *Spondias purpurea*         | Leaf          | 39.70 [54]          | *Echinophora lamondiana*     | Leaf         | 138.30 [95]         |
| 60  | *Clausena excavata*         | Twig          | 40.10 [66]          | *Sphaeranthus indicus Linn*  | Leaf         | 140.00 [6]          |
| 61  | *Cinnamomum sintoc*         | Leaf          | 41.10 [37]          | *Guarea convergens*          | Branch       | 145.10 [72]         |
| 62  | *Apium graveolens*          | Unclear       | 42.07 [53]          | *Croton tetradenius*         | Leaf         | 152.00 [96]         |
| 63  | *Lippia alba*               | Unclear       | 42.20 [46]          | *Piper humaytanum*           | Leaf         | 156.00 [64]         |
| 64  | *Lantana camara*            | Leaf          | 42.30 [68]          | *Cinnamomum cordatum*        | Leaf         | 183.60 [37]         |
| 65  | *Cinnamomum porrectum*      | Wood          | 43.50 [36]          | *Myrica ovata*               | Leaf         | 192.10 [54]         |
| 66  | *Zingiber nimmonii*         | Rhizome       | 44.46 [12]          | *Eugenia piauhiensis*        | Leaf         | 230.00 [97]         |
| 67  | *Blumea eriantha*           | Leaf          | 44.82 [69]          | *Siparuna camporum*          | Leaf         | 251.00 [97]         |
| 68  | *Zingiber cernuum*          | Rhizome       | 44.88 [21]          | *Guarea silvatica*           | Branch       | 273.60 [72]         |
| 69  | *Mentha x villosa*          | Leaf          | 45.00 [70]          | *Lippia gracilis*            | Unclear      | 282.00 [97]         |
| 70  | *Artemisia absinthium*      | Leaf          | 46.33 [71]          | *Piper aduncum*              | Leaf         | 289.9 [98]          |
| 71  | *Lavandula gibsoni*         | Whole plant   | 48.30 [55]          | *Psidium myrsinites*         | Leaf         | 292.00 [97]         |
| 72  | *Guarea humaitensis*        | Branch        | 48.60 [72]          | *Croton argyrophyllus*       | Leaf         | 310.00 [99]         |
| 73  | *Zingiber zerumbet*         | Rhizome       | 48.88 [43]          | *Mentha piperita L*          | Leaf         | 367.60 [100]        |
| 74  | *Foeniculum vulgare*        | Unclear       | 49.32 [53]          | *Echinophora lamondiana*     | Flower       | >125 [95]           |
| 75  | *Plectranthus amboinicus*   | Leaf          | 51.80 [54]          | *Echinophora lamondiana*     | Stem         | >125 [95]           |
| 76  | *Eucalyptus nitens*         | Leaf          | 52.83 [73]          | *Salvia apiana*              | Seed         | >125 [42]           |
| 77  | *Cananga odorata*           | Unclear       | 52.90 [46]          | *Myrica erythroxylon*        | Leaf         | >1000 [97]          |
| 78  | *Lippia origanoides*        | Unclear       | 53.30 [46]          | *Xylopia frutescens*         | Unclear      | >1000 [18]          |
| 79  | *Kaempferia galanga*        | Rhizome       | 53.64 [43]          | *Xylopia laevigata*          | Unclear      | >1000 [18]          |
| No. | Plant species         | Used part(s) | LC₅₀ (µg/mL) | Ref | No. | Plant species         | Used part(s) | LC₅₀ (µg/mL) | Ref |
|-----|-----------------------|--------------|--------------|-----|-----|-----------------------|--------------|--------------|-----|
| 1   | Echinops grijsii      | Root         | 2.65         | [13] | 32  | Artemisia absinthium  | Leaf         | 57.57        | [71]|
| 2   | Cinnamomum microphyllum | Leaf        | 6.20         | [37] | 33  | Cupressus arizonica   | Leaf         | 64.80        | [107]|
| 3   | Cinnamomum pubescen   | Leaf         | 7.90         | [37] | 34  | Syzygium lanceolatum  | Leaf         | 66.71        | [76]|
| 4   | Tetradium glabrifolium | Fruit       | 8.20         | [101] | 35  | Pinus brutia          | Aerial parts | 67.04        | [110]|
| 5   | Cinnamomum mollissimum | Leaf        | 8.80         | [37] | 36  | Coleus aromaticus     | Leaf         | 67.98        | [111]|
| 6   | Cinnamomum impressicostatum | Leaf | 9.30         | [37] | 37  | Toddalia asiatica    | Root         | 69.09        | [112]|
| 7   | Cinnamomum rhyncophyllum | Leaf       | 11.80        | [37] | 38  | Pinus halepensis      | Aerial parts | 70.21        | [110]|
| 8   | Ocimum basilicum      | Leaf         | 11.97        | [102] | 39  | Tetraclinis articulata| Leaf         | 70.60        | [107]|
| 9   | Saussurea lappa       | Root         | 12.41        | [103] | 40  | Allium macrostemon    | Bulb         | 72.86        | [113]|
| 10  | Cinnamomum scortechinii | Leaf        | 16.70        | [37] | 41  | Pinus stankewiczii    | Aerial parts | 81.66        | [110]|
| 11  | Allium tuberosum      | Root         | 18.00        | [104] | 42  | Plectranthus barbatus | Leaf         | 87.25        | [11]|
| 12  | Ocimum gratissimum    | Leaf         | 26.10        | [10]  | 43  | Boswellia ovalifoliolata| Leaf         | 89.80        | [83]|
| 13  | Eucalyptus nitens     | Leaf         | 28.19        | [73]  | 44  | Syzygium zeylanicum   | Leaf         | 90.45        | [114]|
| 14  | Ruta chalepensis      | Leaf         | 33.18        | [105] | 45  | Pinus strobus         | Aerial parts | 127.98       | [110]|
| 15  | Eugenia uniflora      | Leaf         | 33.50        | [106] | 46  | Foeniculum vulgare    | Leaf         | 142.90       | [115]|
| 16  | Chamaecyparis formosensis | Heartwood | 34.90        | [67]  | 47  | Pinus nigra           | Aerial parts | 152.65       | [110]|
| 17  | Cinnamomum sintoc     | Leaf         | 36.50        | [37]  | 48  | Cinnamomum cordatum   | Leaf         | 160.80       | [37]|
| 18  | Cupressus benthamii    | Leaf         | 37.50        | [107] | 49  | Helichrysum italicum  | Leaf         | 178.10       | [115]|
| 19  | Heracleum sprengelianum | Leaf        | 37.50        | [108] | 50  | Cunninghamia konishii | Wood         | 189.50       | [90]|
| 20  | Cinnamomum osmophloeum | Leaf        | 40.80        | [109] | 51  | Cunninghamia konishii | Leaf         | 194.40       | [90]|
| 21  | Clausena excavata     | Twig         | 41.10        | [66]  | 52  | Achillea millefolium  | Leaf         | 211.30       | [115]|
| 22  | Clausena excavata     | Leaf         | 41.20        | [66]  | 53  | Hyptis suaveolens     | Leaf         | 240.30       | [116]|
| 23  | Chamaecyparis lawsoniana | Leaf       | 47.90        | [107] | 54  | Eucalyptus urophylla   | Leaf         | 285.80       | [59]|

Table 3. Larvicidal Activity of Essential Oils Against *Aedes albopictus*
### Table 3. Larvicidal Activity of Essential Oils Against *Aedes albopictus*

| No. | Plant species          | Used part(s) | LC₅₀ (µg/mL) | Ref | No. | Plant species          | Used part(s) | LC₅₀ (µg/mL) | Ref |
|-----|------------------------|--------------|--------------|-----|-----|------------------------|--------------|--------------|-----|
| 24  | Cryptomeria japonica   | Leaf         | 51.20        | [58]| 55  | Coriandrum sativum     | Fruit        | 421.00       | [117]|
| 25  | Cupressus macrocarpa   | Leaf         | 54.60        | [107]| 56  | Pinus canariensis      | Aerial parts | >>200        | [110]|
| 26  | Cupressus sempervirens | Leaf         | 54.70        | [107]| 57  | Pinus pinaster         | Aerial parts | >>200        | [110]|
| 27  | Eucalyptus camaldulensis | Leaf       | 55.30        | [59]| 58  | Lavandula angustifolia | Leaf         | >250         | [115]|
| 28  | Juniperus phoenicea    | Leaf         | 55.50        | [107]| 59  | Myrtus communis        | Leaf         | >250         | [115]|
| 29  | Zingiber cernua        | Rhizome      | 55.84        | [21]| 60  | Rosmarinus officinalis | Leaf         | >250         | [115]|
| 30  | Blumea eriantha        | Leaf         | 56.33        | [69]| 61  | Artemisia absinthium   | Leaf         | 57.57        | [71] |
| 31  | Cupressus torulosa     | Leaf         | 57.10        | [107]| 62  | Cupressus arizonica    | Leaf         | 64.80        | [107]|

### Table 4. Larvicidal Activity of Essential Oils Against *Anopheles stephensi*

| No. | Plant species          | Used part(s) | LC₅₀ (µg/mL) | Ref | No. | Plant species          | Used part(s) | LC₅₀ (µg/mL) | Ref |
|-----|------------------------|--------------|--------------|-----|-----|------------------------|--------------|--------------|-----|
| 1   | Kelussia odoratissima  | Aerial parts | 4.77         | [118]| 30  | Murraya exotica        | Leaf         | 56.30        | [63]|
| 2   | Kelussia odoratissima  | Aerial parts | 4.88         | [119]| 31  | Syzigium aromaticum    | Unclear      | 57.49        | [129]|
| 3   | Artemisia dracunculus  | Aerial parts | 11.36        | [8]  | 32  | Zanthoxylum armatum    | Seed         | 58.00        | [74] |
| 4   | Platycladus orientalis | Leaf         | 11.67        | [120]| 33  | Zhumeria majdae        | Leaf         | 61.34        | [130]|
| 5   | Tagetes patula         | Foliage      | 12.08        | [41] | 34  | Origanum scabrum       | Leaf         | 61.65        | [84] |
| 6   | Ferulago carshochorum  | Aerial parts | 12.78        | [121]| 35  | Boswellia ovalifoliata| Leaf         | 61.84        | [83] |
| 7   | Chloroxylon swietenia  | Leaf         | 14.90        | [50] | 36  | Lavandula gibsoni      | Aerial parts | 62.80        | [55] |
| 8   | Ipomoea cairica        | Unclear      | 14.90        | [51] | 37  | Origanum vulgare       | Leaf         | 67.00        | [4]  |
| 9   | Feronia limonia        | Leaf         | 15.03        | [40] | 38  | Lawsonia inermis       | Leaf         | 69.40        | [131]|
| 10  | Chloroxylon swietenia  | Stem         | 19.00        | [50] | 39  | Cionura erecta         | Root         | 77.30        | [132]|
| 11  | Foeniculum vulgare     | Seed         | 20.10        | [122]| 40  | Cupressus arizonica    | Leaf         | 79.30        | [133]|
| 12  | Satureja bachtariarica | Aerial parts | 24.27        | [123]| 41  | Trachyspermum ammi     | Seed         | 80.77        | [134]|
| 13  | Bunium persicum        | Seed         | 27.72        | [2]  | 42  | Eucalyptus camaldulensis| Leaf         | 89.85        | [135]|
| 14  | Plectranthus amboinicus| Leaf         | 28.37        | [124]| 43  | Coccinia indica        | Leaf         | 95.30        | [136]|

Continue in next Page
### Table 4. Larvicidal Activity of Essential Oils Against Anopheles stephensi

| No | Plant species                  | Used part(s) | LC$_{50}$ (µg/mL) | Ref  |
|----|--------------------------------|--------------|-------------------|------|
| 15 | *Citrus aurantium* Fruit       | 31.20        | 44 *Kadsura heteroclitia* Leaf 102.86 [93] |
| 16 | *Plectranthus mollis* Aerial parts | 33.50        | 45 *Stachys hyzantina* Leaf 103.29 [131] |
| 17 | *Achillea kellalensis* Flower | 35.42        | 46 *Heracleum persicum* Seed 104.80 [122] |
| 18 | *Citrus paradisi* Fruit       | 35.71        | 47 *Ajuga chamaecistus tomentella* Aerial parts 117.72 [137] |
| 19 | *Anethum graveolens* Aerial parts | 38.80        | 48 *Coriandrum sativum* Seed 120.95 [122] |
| 20 | *Achillea wilhelmsii* Leaf    | 39.04        | 49 *Cedrus deodora* Leaf 128.04 [131] |
| 21 | *Zingiber nimmonii* Rhizome   | 41.19        | 50 *Stachys setifera* Leaf 181.62 [131] |
| 22 | *Zingiber cernuum* Rhizome    | 41.34        | 51 *Thymus vulgaris* Leaf 191.33 [131] |
| 23 | *Blumea eriantha* Leaf        | 41.61        | 52 *Stachys inflata* Leaf 195.84 [131] |

### Table 5. Larvicidal Activity of Essential Oils Against Anopheles subpictus

| No | Plant species                  | Used part(s) | LC$_{50}$ (µg/mL) | Ref  |
|----|--------------------------------|--------------|-------------------|------|
| 1  | *Ocimum basilicum* Leaf        | 9.75         | [102]             |
| 2  | *Eugenia uniflora* Leaf       | 31.08        | [106]             |
| 3  | *Heracleum sprengelianum* Leaf | 33.40        | [108]             |
| 4  | *Blumea eriantha* Leaf        | 51.21        | [69]              |
| 5  | *Zingiber cernuum* Rhizome    | 51.42        | [21]              |
| 6  | *Artemisia absinthium* Leaf   | 52.02        | [71]              |
| 7  | *Zingiber officinale* Rhizome | 57.98        | [140]             |
| 8  | *Coles aromaticus* Leaf       | 60.31        | [111]             |
| 9  | *Zhumeria majdae* Leaf        | 61.34        | [130]             |
| 10 | *Rosmarinus officinalis* Shoot | 64.50        | [140]             |
| 11 | *Cinnamomum zeylanicum* Leaf  | 71.96        | [140]             |
| 12 | *Origanum vulgare* Leaf       | 74.14        | [4]               |
| 13 | *Cymbopogon citrates* Leaf    | 77.24        | [140]             |
| 14 | *Boswellia ovalifoliolata* Leaf | 82.26       | [83]              |
| 15 | *Syzygium zeylanicum* Leaf    | 83.11        | [114]             |
| 16 | *Plectranthus barbatus* Leaf  | 84.20        | [11]              |
Table 6. Larvicidal Activity of Essential Oils Against Other Species of Anopheles

| Plant species              | Used part(s)   | Target              | LC50 (µg/mL) | Ref  |
|----------------------------|----------------|---------------------|--------------|------|
| Salvia leucantha           | Aerial parts   | An. quadrimaculatus | 6.20         | [42] |
| Salvia elegans             | Aerial parts   | An. quadrimaculatus | 10.90        | [42] |
| Salvia officinalis         | Seed           | An. quadrimaculatus | 14.10        | [42] |
| Ruta chalepensis           | Aerial parts   | An. quadrimaculatus | 14.90        | [141]|
| Echinophora lamondiana     | Leaf           | An. quadrimaculatus | 26.20        | [95] |
| Echinophora lamondiana     | Flower         | An. quadrimaculatus | 46.90        | [95] |
| Echinophora lamondiana     | Stem           | An. quadrimaculatus | 65.60        | [95] |
| Salvia apiana              | Seed           | An. quadrimaculatus | >125         | [42] |
| Togeites minuta            | Unclear        | An. gambiae         | <1.50        | [142]|
| Piper capense              | Unclear        | An. gambiae         | 34.90        | [143]|
| Cinnamomum osmophloeum     | Leaf           | An. gambiae         | 35.36        | [144]|
| Plectranthus amboinicus    | Leaf           | An. gambiae         | 55.20        | [145]|
| Blumea martiniana          | Aerial parts   | An. anthropophagus  | 46.86        | [146]|
| Artemisia gilvescens       | Unclear        | An. anthropophagus  | 49.95        | [147]|
| Cananga odorata            | Flower         | An. dirus           | <1           | [39] |
| Echinops grisiis           | Root           | An. sinensis       | 3.43         | [13] |
| Juniperus procera          | Unclear        | An. arabiensis     | 14.42        | [148]|
| Piper aduncum              | Aerial parts   | An. marajoora      | 50.90        | [75] |

anum have similar LC50 values (∼ 32 µg/mL). LC50 of other EOs are > 50 µg/mL. Table-6 summarizes information about LA of some EOs against other species of Anopheles such as An. quadrimaculatus, An. gambiae, An. anthropophagus, An. dirus, An. sinensis, An. arabiensis, and An. marajoara. Two EOs show excellent LA (i.e., LC50 ~1 µg/mL): T. minuta and Cananga odorata against An. gambiae and An. dirus, respectively. LC50 of two other EOs are also worthy to note: Salvia leucantha (6.20 µg/mL) against An. quadrimaculatus and Echinops grisiis (3.43 µg/mL) against An. sinensis. Among 66 reports on LA of EOs against Cx. quinquefasciatus (Table-7), EO of Cananga odorata demonstrates to be the best result with LC50 of below 1 µg/mL. After that, LC50 of 20 EOs are in the range of 10-50 µg/mL, and LC50 of 20 EOs are between 50-100 µg/mL. LC50 of 44 EOs are higher than 50 µg/mL. From Table-8, which summarizes LA of some EOs against Cx. pипiens, EOs of K. odoratissima, Echinops grisiis and Pelargonium roseum show to have LC50 at 2.69, 3.43 and 5.49 µg/mL, respectively. They are the most potent EOs against Cx. pипiens. Among other EOs, 8 EOs have LC50 between 10-50 and others have LC50 higher than 50 µg/mL. From Table-9, which briefs the larvicidal activity of different EOs on Cx. tritaeniorhynchus. None of the EOs have LC50 below 10 µg/mL. However, EOs of Ocimum basilicum and Ipomoea cairica with LC50 ~ 14 can be considered as effective against Cx. tritaeniorhynchus. While LC50 of other EOs is in range of 36-136 µg/mL.

Potent EOs in Terms of LA

Reviewing Tables-2 to 9, some EOs demonstrate proper LA against at least two species, thus, may be suggested as attractive candidates for preparing EO-based larvicides (Table-10). For instance, LC50 of Echinops grisiis is ∼ 3 µg/mL against three species: Cx. pипiens, An. sinensis and Ae. aegypti. EO of Cananga odorata is another candidate with LC50 ~ 1 µg/mL against Cx. quinquefasciatus and An. dirus and LC50 of 10 µg/mL against Ae. aegypti. EO of K. odoratissima with LC50 of 2 and 4 µg/mL...
| No. | Plant species                  | Used part(s) | LC₅₀ (µg/mL) | Ref | No. | Plant species                  | Used part(s) | LC₅₀ (µg/mL) | Ref |
|-----|--------------------------------|--------------|--------------|-----|-----|--------------------------------|--------------|--------------|-----|
| 1   | Cananga odorata                | Flower       | <1           | [39]| 34  | Boswellia ovalifoliolata       | Leaf         | 72.47        | [83]|   |
| 2   | Mentha longifolia              | Unclear      | 17.00        | [149]| 35  | Pimenta dioica                 | Fruit & berry| 77.20        | [153]|   |
| 3   | Mentha suaveolens              | Unclear      | 17.00        | [149]| 36  | Origanum vulgare               | Leaf         | 80.35        | [4]  |   |
| 4   | Achillea kesselensis           | Flower       | 21.79        | [126]| 37  | Peumus boldus                  | Leaf         | 82.14        | [157]|   |
| 5   | Tagetes patula                 | Foliage      | 22.33        | [41]| 38  | Zhumeria majdae                | Leaf         | 88.51        | [130]|   |
| 6   | Feronia limonia                | Leaf         | 22.49        | [40]| 39  | Mentha spicata                 | Unclear      | 92.00        | [149]|   |
| 7   | Satureja montana               | Aerial parts | 25.60        | [150]| 40  | Pelargonium graveolens         | Aerial parts | 98.40        | [150]|   |
| 8   | Pimpinella anisum              | Fruit        | 26.10        | [151]| 41  | Hyssopus officinalis           | Aerial parts | 99.50        | [150]|   |
| 9   | Tanacetum persicum             | Aerial parts | 28.53        | [126]| 42  | Ravensara aromatica            | Leaf         | 101.40       | [153]|   |
| 10  | Plectranthus mollis            | Whole plant  | 29.50        | [55]| 43  | Anthemis nobilis               | Flower       | 108.70       | [153]|   |
| 11  | Rosmarinus officinalis         | Stem & Leaf  | 30.60        | [152]| 44  | Rosmarinus officinali          | Flowering herb| 111.10       | [153]|   |
| 12  | Thymus vulgar                  | Flowering top| 32.90        | [153]| 45  | Nepeta cataria                 | Flowering top| 112.40       | [153]|   |
| 13  | Satureja hortensis             | Flowering top| 36.10        | [153]| 46  | Mentha aquatica                | Unclear      | 118.00       | [149]|   |
| 14  | Murraya exotica                | Leaf         | 43.20        | [63]| 47  | Lavandula angustifolia         | Flower       | 121.60       | [153]|   |
| 15  | Thymus satureoides Boiss       | Herb         | 43.60        | [153]| 48  | Kadsura heteroclitica          | Leaf         | 121.97       | [93] |   |
| 16  | Satureja bachitica             | Aerial parts | 44.96        | [123]| 49  | Syzygium aromaticum            | Buds         | 124.42       | [91] |   |
| 17  | Zingiber nimmonii              | Rhizome      | 48.26        | [12]| 50  | Cannabis sativa                | Herb         | 127.30       | [153]|   |
| 18  | Zingiber cernuum               | Rhizome      | 48.44        | [21]| 51  | Salvia sclarea                 | Flower       | 127.50       | [153]|   |
| 19  | Blumea eriantha                | Leaf         | 48.92        | [69]| 52  | Pinus sylvestris               | Needles      | 128.00       | [91] |   |
| 20  | Zanthoxylum armatum            | Seed         | 49.00        | [74]| 53  | Sphaeranthus indicus           | Leaf         | 130.00       | [6] |   |
| 21  | Pinus nigra                    | Twig         | 49.80        | [150]| 54  | Pelargonium roseum             | Leaf         | 130.30       | [153]|   |
| 22  | Artemisia absinthium           | Unclear      | 50.57        | [71]| 55  | Nigella sativa                 | Seed         | 141.70       | [92]|   |

Continue in next Page
**Continue of Table 7. Larvicidal Activity of Essential Oils Against Culex quinquefasciatus**

| Plant species            | Used part(s) | LC50 (µg/mL) | Ref |
|--------------------------|--------------|--------------|-----|
| Kelussia odoratissima    | Aerial parts | 2.69         | [119] |
| Echinops grijsii         | Root         | 3.43         | [13]  |
| Pelargonium roseum       | Leaf         | 5.49         | [158] |
| Platycladus orientalis   | Leaf         | 18.60        | [2]   |
| Bunium persicum          | Seed         | 20.61        | [2]   |
| Asarum heterotropoides   | Root         | 21.07        | [52]  |
| Thymus teucrioides       | Aerial parts | 23.17        | [159] |
| Citrus limon             | Lemon        | 30.14        | [160] |
| Thymus leucospermus      | Aerial parts | 34.26        | [159] |
| Citrus aurantium         | Bitter orange| 39.81        | [160] |
| Oenanthe pimpinelloides  | Aerial parts | 40.26        | [161] |
| Citrus sinensis          | Sweet orange | 51.50        | [160] |
| Geranium maculatum       | Unclear      | 57.28        | [162] |
| Bupleurum fruticosum     | Aerial parts | 64.68        | [161] |
| Conopodium capillifolium | Aerial parts | 68.50        | [161] |
| Hypericum sphyndylium    | Aerial parts | 77.41        | [161] |
| Citrus bergamia          | Unclear      | 85.74        | [162] |
| Seseli montanum          | Aerial parts | 86.60        | [161] |
| Eleoselinum asclepium     | Aerial parts | 96.96        | [161] |
| Hypericum tomentosum from Tharka | Aerial parts | 102.82       | [163] |
| Hypericum tomentosum from Fernana | Aerial parts | 125.26 | [163] |
| Hypericum humilfusum     | Aerial parts | 156.80       | [163] |
| Hypericum perforatum     | Aerial parts | 194.70       | [163] |

**Table 8. Larvicidal Activity of Essential Oils Against Culex pipiens**

| Plant species                          | Used part(s) | LC50 (µg/mL) | Ref |
|----------------------------------------|--------------|--------------|-----|
| Kelussia odoratissima                  | Aerial parts | 2.69         | [119] |
| Echinops grijsii                       | Root         | 3.43         | [13]  |
| Pelargonium roseum                     | Leaf         | 5.49         | [158] |
| Platycladus orientalis                 | Leaf         | 18.60        | [2]   |
| Bunium persicum                        | Seed         | 20.61        | [2]   |
| Thymus leucospermus                    | Root         | 21.07        | [52]  |
| Asarum heterotropoides                 | Aerial parts | 23.17        | [159] |
| Citrus limon                           | Lemon        | 30.14        | [160] |
| Oenanthe pimpinelloides                | Aerial parts | 40.26        | [161] |
| Citrus sinensis                        | Sweet orange | 51.50        | [160] |
| Geranium maculatum                     | Unclear      | 57.28        | [162] |
| Conopodium capillifolium               | Aerial parts | 68.50        | [161] |
| Eoselinum asclepium                    | Aerial parts | 96.96        | [161] |
| Hypericum tomentosum from Tharka       | Aerial parts | 102.82       | [163] |
| Hypericum tomentosum from Fernana      | Aerial parts | 125.26       | [163] |
| Hypericum humilfusum                   | Aerial parts | 156.80       | [163] |
| Hypericum perforatum                   | Aerial parts | 194.70       | [163] |
Table 9. Larvicidal Activity of Essential Oils Against Culex tritaeniorhynchus

| Plant species          | Used part (s) | LC<sub>50</sub> (µg/mL) | Ref   |
|------------------------|--------------|--------------------------|-------|
| Ocimum basilicum       | Leaf         | 14.01                    | [102] |
| Ipomoea cairica        | Unclear      | 14.80                    | [51]  |
| Eugenia uniflora       | Leaf         | 36.35                    | [106] |
| Heracleum sprengelianum| Leaf         | 40.90                    | [108] |
| Zingiber cernuum       | Rhizome      | 60.20                    | [21]  |
| Blumea eriantha        | Leaf         | 61.33                    | [69]  |
| Artemisia absinthium   | Unclear      | 62.16                    | [71]  |
| Syzygium lanceolatum   | Leaf         | 72.24                    | [76]  |
| Coleus aromaticus      | Leaf         | 72.70                    | [111] |
| Origanum scabrum       | Leaf         | 78.87                    | [84]  |
| Origanum vulgare       | Leaf         | 84.93                    | [4]   |
| Plectranthus barbatus  | Unclear      | 94.34                    | [11]  |
| Boswellia ovalifoliolata| Leaf        | 97.95                    | [83]  |
| Syzygium zeylanicum    | Leaf         | 97.96                    | [114] |
| Zingiber officinalis   | Rhizome      | 98.83                    | [140] |
| Rosmarinus officinalis | Shoot        | 115.38                   | [140] |
| Cinnamomum zeylanicum  | Bark         | 124.70                   | [140] |
| Cymbopogan citrates    | Leaf         | 136.58                   | [140] |

mL against Cx. pipiens and An. stephensi respectively, could also be considered as a potent larvicide. Besides mentioned EOs, the LA of 4 EOs is comparable with classic larvicide (i.e., ~ 1 µg/mL). LC<sub>50</sub> of Callitris glaucophylla and Piper betle against Ae. aegypti are 0.69 and 0.72 µg/mL, respectively. Cananga odorata show LC<sub>50</sub> < 1 µg/mL against both of Cx. quinquefasciatus and An. Dirus. EO of T. minuta has excellent LA against An. gambiae (LC<sub>50</sub> < 1.5 µg/mL).

**Advantages of EOs as Larvicides**

To control mosquito-borne diseases such as malaria, world health organization (WHO) recommends using larvicides; nowadays using in 55 countries around the worlds [164]. Continuous use of synthetic larvicides such as malathion and temephos along with environmental pollution, lead to occurring resistance in a various population of mosquitos such as Ae. aegypti, Cx. pipiens and An. stephensi [165-168]. Furthermore, many reports may be found about the impacts of the larvicides against non-target species. For instance, dichlorvos and tetraethyl pyrophosphate (belonging to organophosphates larvicides) and carbofuran (carbamates) have an effect on acetylcholinesterase in some species of fishes including Arapaima gigas, Rachycentron canadum, Oreochromis niloticus, and Electrophorus electricus [169]. In another study, sides effects of 2 other larvicides including Temephos and Novaluron against 10 species of aquatic insect families and copepods have been evaluated. It was revealed that their impact on Velidae, Odonata, Dytiscidae are significantly higher than that of other [170]. Oudemans (Amblyseius cucumeris) is a crucial predator of mites of tetranychid while two other common pesticides, i.e., Bifenthrin and Malathion posed an extremely effect on this beneficial non-target arthropod [171]. EOs are naturally extracted aroma compounds with broad applications such as flavoring additives, medicines, antioxidants, antifungal/bacterial and also larvicides [172-177]. In the past decade, EO based formulation have been suggested as alternative sources for control of mosquitoes to be used as larvicides [8, 127]. They offer advantages such as biodegradability, negligible effects on non-target specious
Table 10. Potent Essential Oils as Larvicide Against at Least 2 Species of Mosquitoes

| Plant species          | Target                  | LC$_{50}$ (µg/mL) | Ref  |
|------------------------|-------------------------|-------------------|------|
| Ocimum basilicum       | Cx. tritaeniorhynchus   | 14.01             | [102]|
|                        | An. subpictus           | 9.75              |      |
|                        | Cx. pipiens             | 2.69              | [118,119]|
| Kelussia odoratissima  | An. stephensi           | 4.77              |      |
|                        | An. stephensi           | 4.88              |      |
|                        | Cx. pipiens             | 3.43              |      |
| Echinops grijsii       | An. sinensis            | 3.43              | [13] |
|                        | Ae. albopictus          | 2.65              |      |
| Cananga odorata        | Cx. quinquefasciatus    | <1                | [39] |
|                        | An. dirus               | <1                |      |
|                        | Ae. aegypti             | 10.40             |      |
| Cinnamomum microphyllum| Ae. albopictus          | 6.20              | [37] |
|                        | Ae. aegypti             | 10.70             |      |
| Cinnamomum pubescen    | Ae. albopictus          | 7.90              | [37] |
|                        | Ae. aegypti             | 10.20             |      |
| Cinnamomum impressicostatum | Ae. albopictus     | 9.30              | [37] |
|                        | Ae. aegypti             | 10.70             |      |
| Cinnamomum rhyncophyllum| Ae. albopictus        | 11.80             | [37] |
|                        | Ae. aegypti             | 6.00              |      |

and environment [101, 178]. Besides, resistance against larvicides is observed when a single active agent is used compared with those having multi-components, thus by using EOs, decreases the risk of occurring resistance in mosquito populations [14-16]. EOs are mixtures of many constituents such as flavonoids, alkaloids, and monoterpenes [179, 180]. Modes of action of mentioned constituents are different, for instance, main sites action of alkaloids and monoterpenes are Na-K-ATPase or Na$^+$ and K$^+$ channels [19, 181, 182], while flavonoids target acetylcholinesterase [183]. Synergistic effects of constituents of some EOs are nowadays well-known when they are used as anti-fungal or anti-bacterial agents [184, 185]. Types of synergism also reported in larvicidal studies, e.g., larvicidal activities (LC$_{50}$) of EOs of Syzygium aromaticum and K. odoratissima (57.49 and 4.77 µg/mL, respectively) significantly better than their major constituents, i.e., Eugenol (86.96 µg/mL) and Z-ligustilide (8.73 µg/mL) against An. stephensi [118, 129].

Conclusion

In this paper, mosquito-borne diseases have been reviewed. Previous studies about LA of EOs against different species of mosquitoes including Aedes, Anopheles, and Culex were investigated. For the first time, 411 LC$_{50}$ were ranked against each species, separately. LC$_{50}$ of 4 EOs are ~ 1µg/mL, including Calitris glaucophylla and Piper betle against Ae. aegypti, T. minuta against An. gambiae, and Cananga odorata against Cx. quinquefasciatus and An. dirus. The potency of mentioned EOs is comparable with synthetic larvicides, while simultaneously having some advantages such as reducing the chance of resistance and
minimum sides’ effects on non-target species. Thus, it could be considered as candidates for preparing botanical larvicides.

Acknowledgment

This study was supported by Tehran University of Medical Sciences & Health Services (grant No. 95-01-87-31860).

Conflict of Interest

There is no conflict of interest to the authors.

References

1. World Health Organization W.(2017) Fact sheet for Vector-borne diseases. Available from: http://www.who.int/mediacentre/factsheets/fs387/en/.
2. Sanei-Dehkordi A, Vatandoost H, Abaei MR, Davari B, Sedaghat MM. Chemical Composition and Larvicidal Activity of Bunium persicum Essential Oil Against Two Important Mosquitoes Vectors. J Essent Oil-Bear Plants.2016;19(2):349-357.
3. Reinert JF Revised list of abbreviations for genera and subgenera of Culicidae (Diptera) and notes on generic and subgeneric changes. J Am Mosq Control Assoc.2001;17(1):51-55.
4. Govindarajan M, Rajeswary M, Hoti SL, Benelli G. Larvicidal potential of carvacrol and terpinen-4-ol from the essential oil of Origanum vulgare (Lamiaceae) against Anopheles stephensi, Anopheles subpictus, Culex quinquefasciatus and Culex tritaeniorhynchus (Diptera: Culicidae). Res Vet Sci.2016;104:77-82.
5. World Health Organization W.(2017) Mosquito-borne diseases. Available from: http://www.who.int/neglected_diseases/vector_ecology/mosquito-borne-diseases/en/.
6. Chellappandian M, Thanigavel A, Vasantha-Srinivasan P, Edwin ES, Ponsankar A, Selin-Rani S, et al. Toxicological effects of Sphaeranthus indicus Linn. (Asteraceae) leaf essential oil against human disease vectors, Culex quinquefasciatus Say and Aedes aegypti Linn., and impacts on a beneficial mosquito predator. Environ Sci Pollut Res Int.2017;25(11):10294-10306.
7. Gutierrez PM, Antepuesto AN, Eugenio BAL, Santos MFL. Larvicidal activity of selected plant extracts against the dengue vector Aedes aegypti mosquito. Int Res J Biol Sci.2014;3(4):23-32.
8. Osanloo M, Amani A, Sereshti H, Abai MR, Esmaeili F, Sedaghat MM. Preparation and optimization nanoemulsion of Tarragon (Artemisia dracunculus) essential oil as effective herbal larvicide against Anopheles stephensi. Ind Crops Prod.2017;109:214-219.
9. Soonwera M, Phasomkusolsil S.Effect of Cymbopogon citratus (lemongrass) and Syzygium aromaticum (clove) oils on the morphology and mortality of Aedes aegypti and Anopheles dirus larvae. Parasitol Res.2016;115(4):1691-1703.
10. Sumitha KV, Thoppil JE. Larvicidal efficacy and chemical constituents of O. gratissimum L. (Lamiaceae) essential oil against Aedes albopictus Skuse (Diptera: Culicidae). Parasitol Res.2016;115(2):673-680.
11. Govindarajan M, Rajeswary M, Hoti SL, Bhattacharyya A, Benelli G. Eugenol, alpha-pinene and beta-caryophyllene from Plectranthus barbatus essential oil as eco-friendly larvicides against malaria, dengue and Japanese encephalitis mosquito vectors. Parasitol Res.2016;115(2):807-815.
12. Govindarajan M, Rajeswary M, Arivoli S, Tennyson S, Benelli G. Larvicidal and repellent potential of Zingiber nimmonii (J. Graham) Dalzell (Zingiberaceae) essential oil: an eco-friendly tool against malaria, dengue, and lymphatic filariasis mosquito vectors? Parasitol Res.2016;115(5):1807-1816.
13. Zhao MP, Liu QZ, Liu Q, Liu ZL (2017) Identification of Larvicidal Constituents of the Essential Oil of Echinops grijsii Roots against the Three Species of Mosquitoes. Molecules.2017;22(2):205.
14. Araujo AF, Ribeiro-Paes JT, Deus JT, Cavalcante SC, Nunes Rde S, Alves PB, et al. Larvicidal activity of Syzygium aromaticum (L.) Merr and Citrus sinensis (L.) Osbeck essential oils and their antagonistic effects with temephos in resistant populations of Aedes aegypti. Mem Inst Oswaldo Cruz.2016;111(7):443-449.
15. Intirach J, Junkum A, Tuetun B, Choochote
Larvicidal Activity of Essential Oils

W, Chaithong U, Jitpakdi A, et al. Chemical constituents and combined larvicidal effects of selected essential oils against Anopheles cracens (Diptera: Culicidae). Psyche (Camb Mass). 2012; ID 591616.

16. Okumu FO, Knols BG, Fillinger U. Larvicidal effects of a neem (Azadirachta indica) oil formulation on the malaria vector Anopheles gambiae. Malar J. 2007;6:63.

17. Vasantha-Srinivasan P, Senthil-Nathan S, Ponsankar A, Thanigaivel A, Edwin ES, Selin-Rani S, et al. Comparative analysis of mosquito (Diptera: Culicidae) responses to the insecticide Temephos and plant derived essential oil derived from Piper betle L. Ecotoxicol Environ Saf. 2017;139:439-446.

18. Nascimento AM, Maia TD, Soares TE, Menezes LR, Scher R, Costa EV, et al. Repellency and Larvicidal Activity of Essential oils from Xylopia laevigata, Xylopia frutescens, Lippia pedunculosa, and Their Individual Compounds against Aedes aegypti Liston. Neotrop Entomol. 2017;46(2):223-230.

19. Isman MB. Botanical insecticides, deterrents, and repellents in modern agriculture and an increasingly regulated world. Annu Rev Entomol. 2006;51:45-66.

20. Regnault-Roger C, Vincent C, Arnason JT. Essential oils in insect control: low-risk products in a high-stakes world. Annu Rev Entomol. 2012;57:405-424.

21. Rajeswary M, Govindarajan M, Alharbi NS, Kadaikunnan S, Khaled JM, Benelli G. Zingiber cernuum (Zingiberaceae) essential oil as effective larvicide and oviposition deterrent on six mosquito vectors, with little non-target toxicity on four aquatic mosquito predators. Environ Sci Pollut Res Int. 2017;25(11):10307-10316.

22. Balasubramani S, Rajendhiran T, Moola AK, Diana RKB. Development of nanoemulsion from Vetix negundo L. essential oil and their efficacy of antioxidant, antimicrobial and larvicidal activities (Aedes aegypti L.). Environ Sci Pollut Res Int. 2017;24(17):15125-15133.

23. Pavela R. Insecticidal properties of several essential oils on the house fly (Musca domestica L.). Phytother Res. 2008;22(2):274-278.

24. Pavela R (2015) Essential oils for the development of eco-friendly mosquito larvicides: a review. Ind Crops Prod. 2015;76:174-187.

25. Sinka ME, Bangs MJ, Manguin S, Rubio-Palis Y, Chareonviriyaphap T, Coetzee M, et al. A global map of dominant malaria vectors. Parasit vectors. 2012;5(1):69.

26. Monath TP, Vasconcelos PF. Yellow fever. J Clin Virol. 2015 64:160-173.

27. Guzman A, Istrariz RE. Update on the global spread of dengue. Int J Antimicrob Agents. 2010;36(S1):S40-S42.

28. Hills SL, Fischer M, Petersen LR. Epidemiology of Zika virus infection. J Infect Dis. 2017;216(S10):S868-S874.

29. Paixão ES, Barreto F, da Glória Teixeira M, da Conceição N, Costa M, Rodrigues LC. History, epidemiology, and clinical manifestations of Zika: a systematic review. Am J Public Health. 2016;106(4):606-612.

30. Weaver SC, Lecuit M. Chikungunya virus and the global spread of a mosquito-borne disease. N Engl J Med. 2015;372(13):1231-1239.

31. Petersen LR, Powers AM. Chikungunya: epidemiology. F1000Research. 2016;5.

32. Ciota AT. West Nile virus and its vectors. Curr Opin Insect Sci. 2017;22:28-36.

33. Pearce JC, Learoyd TP, Langendorf BJ, Logan RG. Japanese encephalitis: the vectors, ecology and potential for expansion. J Travel Med. 2018;25(S1):S16-S26.

34. Shaalan EA-S, Canyon DV, Bowden B, Younes MWF, Abdel-Wahab H, Mansour A-H. Efficacy of botanical extracts from Callitris glaucophylla against Aedes aegypti and Culex annulirostris mosquitoes. Trop Biomed. 2006;23(2):180-185.

35. Costa FG, Pessoa OD, Menezes EA, Santiago GM, Lemos TL. Composition and larvicidal activity of essential oils from heartwood of Auxemma glazioviana Taub.(Boraginaceae). Flavour Fragrance J. 2004;19(6):529-532.

36. Promsiri S, Naksathit A, Kruatrachue M, Thavara U. Evaluations of larvicidal activity of medicinal plant extracts to Aedes aegypti (Diptera: Culicidae) and other effects on a non target fish. Insect Sci. 2006;13(3):179-188.

37. Jantan Ib, Yalvema MF, Ahmad NW, Jamal JA. Insecticidal Activities of the Leaf Oils of Eight Cinnamomum. species Against Aedes aegypti. and Aedes albopictus. Pharm Biol. 2005;43(6):526-532.

38. do Nascimento JC, David JM, Barbosa LC, de Paula VF, Demuner AJ, David JP, et al. Larvicidal activities and chemical composition of essential oils from Piper klotzschianum (Kunth) C. DC.(Piperaceae).
39. Soonwera M (2015) Efficacy of essential oil from Cananga odorata (Lamk.) Hook.f. & Thomson (Annonaceae) against three mosquito species Aedes aegypti (L.), Anopheles dirus (Peyton and Harrison), and Culex quinquefasciatus (Say). Parasitol Res. 2012;114(12):4531-4543.

40. Senthilkumar A, Jayaraman M, Venkatesalu V. Chemical constituents and larvicidal potential of Feronia limonia leaf essential oil against Anopheles stephensi, Aedes aegypti and Culex quinquefasciatus. Parasitol Res. 2013;112(3):1337-1342.

41. Dharmagadda VS, Naik SN, Mittal PK, Vasudevan P. Larvicidal activity of Tagetes patula essential oil against three mosquito species. Bioresour Technol. 2005;96(11):1235-1240.

42. Ali A, Tabanca N, Demirici B, Blythe EK, Ali Z, Baser KH, et al. Chemical composition and biological activity of four salvia essential oils and individual compounds against two species of mosquitoes. J Agric Food Chem. 2015; 63(2):447-456.

43. Surthanan N, Choochote W, Tuetun B, Jungum A, Jitpakdi A, Chaithong U, et al. Chemical composition and larvicidal activity of edible plant derived essential oils against the pyrethroid susceptible and resistant strains of Aedes aegypti (Diptera: Culicidae). J Vector Ecol. 2010;35(1):106-115.

44. Kumar S, Mishra M, Wahab N, Warikoo R. Larvicidal, Repellent, and Irritant Potential of the Seed-Derived Essential Oil of Ajpton graveolens Against Dengue Vector, Aedes aegypti L. (Diptera: Culicidae). Front Public Health. 2014;2(2):147.

45. Ravi Kiran S, Bhavani K, Sita Devi P, Rajeswara Rao BR, Janardhan Reddy K. Composition and larvicidal activity of leaves and stem essential oils of Chromoxyx oswietiana DC against Aedes aegypti and Anopholes stephenisi. Bioresour Technol. 2006;97(18):2481-2484.

46. Vera SS, Zambrano DF, Méndez-Sanchez SC, Rodríguez-Sanabria F, Stashenko EE, Luna JED. Essential oils with insecticidal activity against larvae of Aedes aegypti (Diptera: Culicidae). Parasitol Res. 2014;113(7):2647-2654.

47. Costa J, Rodrigues F, Angélico E, Silva M, Mota M, Santos N, et al. (2005) Chemical-biological study of the essential oils of Hymis martiusii, Lippia sidoides and Syzygium aromaticum against larvae of Aedes aegypti and Culex quinquefasciatus. Rev Bras Farmacogn. 2005;15(4):304-309.

48. Moon H-I. Larvicidal activity of major essential oils from stems of Allium monanthum Maxim. against Aedes aegypti L. J Enzyme Inhib Med Chem. 2011;26(6):827-830.

49. Aurran E, Neves I, Da Silva C, Santos G, Da Câmara C, Navarro D. Chemical composition, oviposition deterrent and larvicidal activities against Aedes aegypti of essential oils from Piper marginatum Jacq. (Piperaceae). Bioresour Technol. 2009;100(7):2284-2288.

50. Kiran SR, Bhavani K, Devi PS, Rao BR, Reddy KJ. Composition and larvicidal activity of leaves and stem essential oils of Chromoxyx oswietiana DC against Aedes aegypti and Anopholes stephenisi. Bioresour Technol. 2006;97(18):2481-2484.

51. Thomas TG, Rao S, Lal S. Mosquito larvicidal properties of essential oil of an indigenous plant, Ipomoea caricina Linn. Jpn J Infect Dis. 2004;57(4):176-177.

52. Perumalsamy H, Kim N-J, Ahn Y-J. Larvicidal activity of compounds isolated from Asarum heterotropoides against Culex pipiens pallens, Aedes aegypti, and Ochlerotatus togoi (Diptera: Culicidae). J Med Entomol. 2009;46(6):1420-1423.

53. Pitawasawat B, Champakaew D, Choochote W, Jitpakdi A, Chaithong U, Kanjanapothi D, et al. Aromatic plant-derived essential oil: an alternative larvicide for mosquito control. Fitoterapia. 2007;78(3):205-210.

54. Lima MA, de Oliveira FFM, Gomes GA, Lavor PL, Santiago GM, Nagao-Dias AT, et al. Evaluation of larvicidal activity of the essential oils of plants species from Brazil against Aedes aegypti (Diptera: Culicidae). Afr J Biotechnol. 2011;10(55):11716-11720.

55. Kulkarni RR, Pawar PV, Joseph MP, Akulwad AK, Sen A, Joshi SP. Lavandula gibsoni and Plectranthus mollis essential oils: chemical analysis and insect control activities against Aedes aegypti, Anopheles sfithephensi and Culex quinquefasciatus. J Pest Sci. 2013;86(4):713-718.

56. de Lima GPG, de Souza TM, de Paula Freire G, Farias DF, Cunha AP, Ricardo NMPS, et al. Further insecticidal activities of essential oils from Lippia sidoides and Croton species against Aedes aegypti L. Parasitol Res. 2013;112(5):1953-1958.

57. Morais SM, Cavalcani ES, Bertini LM, Oliveira CLL, Rodrigues JRB, Cardoso
Larvicidal Activity of Essential Oils

58. Cheng S-S, Chua M-T, Chang E-H, Huang C-G, Chen W-J, Chang S-T. Variations in insecticidal activity and chemical compositions of leaf essential oils from Cryptomeria japonica at different ages. Bioresour Technol. 2009;100(1):465-470.

59. Cheng S-S, Huang C-G, Chen Y-J, Yu J-J, Chen W-J, Chang S-T. Chemical compositions and larvicidal activities of leaf essential oils from two eucalyptus species. Bioresour Technol. 2009;100(1):452-456.

60. Lucia A, GONZALEZ AUDINO P, Seccacini E, Licastro S, Zerba E, Masuh H. Larvicidal effect of Eucalyptus grandis essential oil and turpentine and their major components on Aedes aegypti larvae. J Am Mosq Control Assoc. 2007;23(3):299-303.

61. Liu XC, Liu Q, Chen XB, Liu QZ, Liu ZL. Larvicidal activity of the essential oil of Youngia japonica aerial parts and its constituents against Aedes albopictus. Z Naturforsch C. 2015;70(1-2):1-6.

62. Leyva M, del Carmen Marquetti M, Tacoronte JE, Scull R, Tiomno O, Mesa A, et al. Actividad larvicida de aceites esenciales de plantas contra Aedes aegypti (L.)(Diptera: Culicidae). Revista Biomed. 2009;20(1):5-13.

63. Krishnamoorthy S, Chandrasekaran M, Raj GA, Jayaraman M, Venkatesalu V. Identification of chemical constituents and larvicidal activity of essential oil from Murraya exotica L. (Rutaceae) against Aedes aegypti, Anopheles stephensi and Culex quinquefasciatus (Diptera: Culicidae). Revista Biomed. 2009;20(1):5-13.

64. de Morais SM, Facundo VA, Bertini LM, Cavalcanti ESB, dos Anjos Júnior JF, Ferreira SA, et al. Chemical composition and larvicidal activity of essential oils from Piper species. Biochem Syst Ecol. 2007;35(10):670-675.

65. Choochote W, Chayasit D, Kanjanapothi D, Rattanachanpichai E, Jitpakdi A, Tuetun B, et al. (2005) Chemical composition and mosquito potential of rhizome extract and volatile oil derived from Curcuma aromatica against Aedes aegypti (Diptera: Culicidae). J Vector Ecol. 2005;30(2):302.

66. Cheng SS, Chang HT, Lin CY, Chen PS, Huang CG, Chen WJ, et al. Insecticidal activities of leaf and twig essential oils from Clausena excavata against Aedes aegypti and Aedes albopictus larvae. Pest Manag Sci. 2009;65(3):339-343.

67. Kuo P-M, Chu F-H, Chang S-T, Hsiao W-F, Wang S-Y. Insecticidal activity of essential oil from Chamaecyparis formosensis Matsum. Holzforschung. 2007;61(5):595-599.

68. Costa J, Rodrigues F, Sousa E, Junior D, Campos A, Coutinho H, et al. Composition and larvicidal activity of the essential oils of Lantana camara and Lantana montevidensis. Chem Nat Compd. 2010;46(2):313-315.

69. Benelli G, Govindarajan M, Rajeswary M, Senthilmurugan S, Vijayan P, Alharbi NS, et al. Larvicidal activity of Blumea eriantha essential oil and its components against six mosquito species, including Zika virus vectors: the promising potential of (4E,6Z)-allo-ocimene, carvotanacetone and dodecyl acetate. Parasitol Res. 2017;116(4):1175-1188.

70. Lima TC, da Silva TK, Silva FL, Barbosa-Filho JM, Marques MO, Santos RL, et al. Larvicidal activity of Mentha x villosa Hudson essential oil, rotundifolone and derivatives. Chemosphere. 2014;104:37-43.

71. Govindarajan M, Benelli G. Artemisia absinthium-borne compounds as novel larvicides: effectiveness against six mosquito vectors and acute toxicity on non-target aquatic organisms. Parasitol Res. 2016;115(12):4649-4661.

72. Amazonas Maciel Magalhães L, da Paz Lima M, Ortiz Mayo Marques M, Facanali R, Pinto ACdS, Pedro Tadei W. Chemical composition and larvicidal activity against Aedes aegypti larvae of essential oils from four Guarea species. Molecules. 2010;15(8):5734-5741.

73. Alvarez Costa A, Naspi CV, Lucia A, Masuh HM. Repellent and Larvicidal Activity of the Essential Oil From Eucalyptus nitens Against Aedes aegypti and Aedes albopictus (Diptera: Culicidae). J Med Entomol. 2017;54(3):670-676.

74. Tiwary M, Naik SN, Tewary DK, Mittal PK, Yadav S. Chemical composition and larvicidal activities of the essential oil of Zanthoxylum armatum DC (Rutaceae) against three mosquito vectors. J Vector Borne Dis. 2007;44(3):198-204.

75. de Almeida RR, Souto RN, Bastos CN, da Silva MH, Maia JG. Chemical variation in Piper aduncum and biological properties of its dillapiole-rich essential oil. Chem
Biodivers.2009;6(9):1427-1434.

76. Benelli G, Rajeswary M, Govindarajan M. Towards green oviposition deterrents? Effectiveness of Syzygium lanceolatum (Myrtaceae) essential oil against six mosquito vectors and impact on four aquatic biological control agents. Environ Sci Pollut Res Int. 2016;25(11):10218-10227.

77. Govindarajan M, Sivakumar R, Rajeswari M, Yogalakshmi K. Chemical composition and larvicidal activity of essential oil from Mentha spicata (Linn.) against three mosquito species. Parasitol Res. 2012;110(5):2023-2032.

78. Govindarajan M, Rajeswary M, Benelli G. Chemical composition, toxicity and non-target effects of Pinus kesiya essential oil: An eco-friendly and novel larvicide against malaria, dengue and lymphatic filariasis mosquito vectors. Ecotoxicol Environ Saf.2016;129:85-90.

79. Nagella P, Ahmad A, Kim S-J, Chung I-M. Chemical composition, antioxidant activity and larvicidal effects of essential oil from leaves of Apium graveolens. Immunopharmacol Immunotoxicol. 2012;34(2):205-209.

80. Chung I-M, Seo S-H, Kang E-Y, Park S-D, Park W-H, Moon H-I. Chemical composition and larvicidal effects of essential oil of Dendropanax morbifera against Aedes aegypti L. Biochem Syst Ecol. 2009;37(4):470-473.

81. Santos RP, Nunes EP, Nascimento RF, Santiago GMP, Menezes GHA, Silveira ER, et al. Chemical composition and larvicidal activity of the essential oils of Cordia leucomalloides and Cordia curassavica from the Northeast of Brazil. J Braz Chem Soc.2006;17(5):1027-1030.

82. Mora FD, Avila JL, Rojas LB, Ramirez R, Usubillaga A, Segnini S, et al. Chemical composition and larvicidal activity of the essential oils of Cordia leucomalloides and Cordia curassavica from the Northeast of Brazil. J Braz Chem Soc.2006;17(5):1027-1030.

83. Benelli G, Rajeswary M, Vijayan P, Senthilmurugan S, Alharbi NS, Kadaikunnan S, Alharbi NS, Benelli G. Acute toxicity and repellent activity of the Origanum seabrnum Boiss. & Heldr. (Lamiaceae) essential oil against four mosquito vectors of public health importance and its biosafety on non-target aquatic organisms. Environ Sci Pollut Res Int.2016;23(22):23228-23238.

85. Barbosa JD, Silva VB, Alves PB, Guminia G, Santos RL, Sousa DP, et al. Structure-activity relationships of eugenol derivatives against Aedes aegypti (Diptera: Culicidae) larvae. Pest Manag Sci.2012;68(11):1478-1483.

86. Souza LGdS, Almeida MCS, Monte FJQ, Santiago GMP, Braz-Filho R, Lemos TLG, et al. Chemical constituents of Capraria biflora (Scrophulariaceae) and larvicidal activity of essential oil. Quim Nova. 2012;35(11):2258-2262.

87. Santos HS, Santiago GM, de Oliveira JP, Arriaga A, Marques DD, Lemos TL. Chemical composition and larvicidal activity against Aedes aegypti of essential oils from Croton zehntneri. Nat Prod Commun. 2007;2(12):1323-1336.

88. Marques MM, Morais SM, Vieira ÍG, Vieira MG, Silva ARA, De Almeida RR, et al. Larvicidal activity of Tagetes erecta against Aedes aegypti. J Am Mosq Control Assoc. 2011;27(2):156-158.

89. Gbolade A, Lockwood G. Toxicity of Ocimum sanctum L. essential oil to Aedes aegypti larvae and its chemical composition. J Essent Oil-Bear Plants.2008;11(2):148-153.

90. Cheng S, Lin C, Chung M, Liu Y, Huang C, Chang S. Larvicidal activities of wood and leaf essential oils and ethanolic extracts from Cunninghamia konishii Hayata against the dengue mosquitoes. Ind Crops Prod.2013;47:310-315.

91. Fayemiwo KA, Adeleke MA, Okoro OP, Awojide SH, Awoniyi IO. Larvicidal efficacies and chemical composition of essential oils of Pinus sylvestris and Syzygium aromaticum against mosquitoes. Asian Pac J Trop Biomed.2014;4(1):30-34.

92. Raj GA, Chandrasekaran M, Krishnamoorthy S, Jayaraman M, Venkatesalu V. Phytochemical profile and larvicidal properties of seed essential oil from Nigella sativa L. (Ranunculaceae), against Aedes aegypti, Anopheles stephensi, and Culex quinquefasciatus (Diptera: Culicidae). Parasitol Res.2015;114(9):3385-3391.

93. Govindarajan M, Rajeswary M, Benelli
Larvicidal Activity of Essential Oils

Osanloo M, et al.

G. delta-Cadinene, Calarene and .delta-4-Carene from Kadsura heteroclit.a

Essential Oil as Novel Larvicides Against Malaria, Dengue and Filariasis Mosquitoes. Comb Chem High Throughput Screen. 2016;19(7):565-571.

94. Santos GK, Dutra KA, Lira CS, Lima BN, Napoleao TH, Paiva PM, et al. Effects of Croton rhizopholoides essential oil on Aedes aegypti oviposition, larval toxicity and trypsin activity. Molecules. 2014;19(10):16573-16587.

95. Ali A, Tabanca N, Ozek G, Ozek T, Aytac Z, Bernier UR, et al. Essential Oils of Echinophora lamondiana (Apiales: Umbelliferae): A Relationship Between Chemical Profile and Biting Deterrence and Larvicidal Activity Against Mosquitoes (Diptera: Culicidae). J Med Entomol. 2015;52(1):93-100.

96. Carvalho Kda S, SL ES, de Souza IA, Gualberto SA, da Cruz RC, Dos Santos FR, et al. Toxicological evaluation of essential oil from the leaves of Croton tetradenius (Euphorbiaceae) on Aedes aegypti and Mus musculus. Parasitol Res. 2016;115(9):3441-3448.

97. Dias CN, Alves LP, Rodrigues KA, Brito MC, Rosa Cdos S, do Amaral FM, et al. Chemical Composition and Larvicidal Activity of Essential Oils Extracted from Brazilian Legal Amazon Plants against Aedes aegypti L. (Diptera: Culicidae). Evid Based Complement Altern Med. 2015;490765-490772.

98. Oliveira GL, Cardoso SK, Lara CR, Jr., Vieira TM, Guimaraes EF, Figueiredo LS, et al. (2013) Chemical study and larvicidal activity against Aedes aegypti of essential oil of Piper aduncum L. (Piperaceae). An Acad Bras Cienc. 2013;85(4):1227-1234.

99. Cruz RC, Silva SL, Souza IA, Gualberto SA, Carvalho KS, Santos FR, et al. Toxicological Evaluation of Essential Oil From the Leaves of Croton argyrophyllus (Euphorbiaceae) on Aedes aegypti (Diptera: Culicidae) and Mus musculus (Rodentia: Muridae). J Med Entomol. 2017;54(4):985-993.

100. da Silva Ramos R, Rodrigues AB, Farias AL, Simes RO, Pinheiro MT, Ferreira RM, et al. Chemical Composition and In Vitro Antioxidant, Cytotoxic, Antimicrobial, and Larvicidal Activities of the Essential Oil of Mentha piperita L. (Lamiaceae). ScientificWorldJournal. 2017;4927214.

101. Liu XC, Liu Q, Chen XB, Zhou L, Liu ZL. Larvicidal activity of the essential oil from Tetradium glabrifolium fruits and its constituents against Aedes albopictus. Pest Manag Sci. 2015;71(11):1582-1586.

102. Govindarajan M, Sivakumar R, Rajeswary M, Yogalakshmi K. Chemical composition and larvicidal activity of essential oil from Ocimum basilicum (L.) against Culex tritaeniorhynchus, Aedes albopictus and Anopheles subpictus (Diptera: Culicidae). Exp Parasitol. 2013;134(1):7-11.

103. Liu ZL, He Q, Chu SS, Wang CF, Du SS, Deng ZW. Essential oil composition and larvicidal activity of Saussurea lappa roots against the mosquito Aedes albopictus (Diptera: Culicidae). Parasitol Res. 2012;110(6):2125-2130.

104. Liu XC, Zhou L, Liu Q, Liu ZL. Laboratory Evaluation of Larvicidal Activity of the Essential oil of Allium tuberosum Roots and its Selected Major Constituent Compounds Against Aedes albopictus (Diptera: Culicidae). J Med Entomol. 2015;52(3):437-441.

105. Conti B, Leonardo M, Pistelli L, Profeti R, Ouerguemmi I, Benelli G. Larvicidal and repellent activity of essential oils from wild and cultivated Ruta chalepensis L.(Rutaceae) against Aedes albopictus Skuse (Diptera: Culicidae), an arbovirus vector. Parasitol Res. 2013;112(3):991-999.

106. Govindarajan M, Rajeswary M, Senthilmurugan S, Vijayan P, Alharbi NS, Kadaikunnan S, et al. Curzerene, trans-beta-elemenone, and gamma-elemene as effective larvicides against Anopheles subpictus, Aedes albopictus, and Culex tritaeniorhynchus: toxicity on non-target aquatic predators. Environ Sci Pollut Res Int. 2017;25(11):10272-10282.

107. Giatropoulos A, Pitarokili D, Papaioannou F, Papachristos DP, Koliotopoulos G, Emmanouel N, et al. Essential oil composition, adult repellency and larvicidal activity of eight Cupressaceae species from Greece against Aedes albopictus (Diptera: Culicidae). Parasitol Res. 2013;112(3):1113-1123.

108. Govindarajan M, Benelli G. Eco-friendly larvicides from Indian plants: Effectiveness of lavandulyl acetate and bicyclogermacrene on malaria, dengue and Japanese encephalitis mosquito vectors. Ecotoxicol Environ Saf. 2016;133:395-402.

109. Cheng SS, Liu JY, Huang CG, Hsui YR, Chen WJ, Chang ST. Insecticidal activities of leaf essential oils from
Cinnamomum osmophloeum against three mosquito species. Biore sour Technol. 2009;100(1):457-464.

10. Koutsaviti K, Giatropoulos A, Pitarokili D, Papachristos D, Michaelakis A, Tzakou O. Greek Pinus essential oils: larvicidal activity and repellency against Aedes albopictus (Diptera: Culicidae). Parasitol Res. (2015) 2015;114(2):583-592.

11. Govindarajan M, Sivakumar R, Rajeswary M, Veerakumar K. Mosquito larvicidal activity of thymol from essential oil of Coleus aromaticus Benth. against Culex tritaeniorhynchus, Aedes albopictus, and Anopheles subpictus (Diptera: Culicidae). Parasitol Res. 2013;112(11):3713-3721.

12. Liu XC, Dong HW, Zhou L, Du SS, Liu ZL. Essential oil composition and larvicidal activity of Toddalia asiatica roots against the mosquito Aedes albopictus (Diptera: Culicidae). Parasitol Res. 2013;112(3):1197-1203.

13. Liu XC, Liu Q, Zhou L, Liu ZL. Evaluation of larvicidal activity of the essential oil of Allium macrostemon Bunge and its selected major constituent compounds against Aedes albopictus (Diptera: Culicidae). Parasit Vectors. 2014;7:184.

14. Govindarajan M, Benelli G. alpha-Humulene and beta-elemene from Syzygium zeylanicum (Myrtaceae) essential oil: highly effective and eco-friendly larvicides against Anopheles subpictus, Aedes albopictus, and Culex tritaeniorhynchus (Diptera: Culicidae). Parasitol Res. 2016;115(7):2771-2778.

15. Conti B, Canale A, Bertoli A, Gozzini F, Pistelli L. Essential oil composition and larvicidal activity of six Mediterranean aromatic plants against the mosquito Aedes albopictus (Diptera: Culicidae). Parasitol Res. 2010;107(6):1455-1461.

16. Conti B, Benelli G, Flamini G, Cioni PL, Profeti R, Ceccarini L, et al. Larvicidal and repellent activity of Hypsitu suaveolens (Lamiaceae) essential oil against the mosquito Aedes albopictus Skuse (Diptera: Culicidae). Parasitol Res. 2012;110(5):2013-2021.

17. Benelli G, Flamini G, Fiore G, Cioni PL, Conti B. Larvicidal and repellent activity of the essential oil of Coriandrum sativum L. (Apiaceae) fruits against the filariasis vector Aedes albopictus Skuse (Diptera: Culicidae). Parasitol Res. 2013;112(3):1155-1161.

18. Osanloo M, Amani A, Sereshti H, Shayeghi M, Sedaghat MM. Extraction and chemical composition essential oil of Kelussia odoratissima and comparison its larvicidal activity with Z-ligustilide (major constituent) against Anopheles stephensi. J Entomol Zool Stud. 2017;5(4):611-616.
persicum and Achillea kfellalensis Against Two Medically Important Mosquitoes. J Essent Oil-Bear Plants. 2017;20(5):1254-1265.

127. Osanloo M, Sereshti H, Sedaghat MM, Amani A. Nanoemulsion of Dill essential oil as a green and potent larvicide against Anopheles stephensi. Environ Sci Pollut Res Int. 2017;25(7):6466-6473.

128. Soleimani-Ahmadi M, Gorouhi MA, Azani S, Abadi Y, Paksa A, Rashid G, et al. Larvicidal Effects of essential oil and methanol extract of Achillea wilhelmsii C. Koch (Asteraceae) against Anopheles stephensi Liston (Diptera: Culicidae), a malaria vector. J Kerman Univ Med Sci. 2017;24(1):58-67.

129. Osanloo M, Sedaghat MM, Esmaeili F, Amani A (2018) Larvicidal Activity of Essential Oil of Syzygium aromaticum (Clove) in Comparison with Its Major Constituent, Eugenol, against Anopheles stephensi. J Arthropod Borne Dis. 2018;12(4):361.

130. Sanei-Dehkordi A, Soleimani-Ahmadi M, Akbarzadeh K, Salim Abadi Y, Paksa A, Gorouhi MA, et al. Chemical Composition and Mosquito Larvicidal Properties of Essential Oil from Leaves of an Iranian Indigenous Plant Zumeria majdae. J Essent Oil-Bear Plants.2016;19(6):1454-1461.

131. Khanavi M, Vatandoost H, Khosravi Dehaghi N, Sanei Dehkordi A, Sedaghat MM, Hadjiakhoondi A, et al. Larvicidal activities of some Iranian native plants against the main malaria vector, Anopheles stephensi. Acta Med Iran.2013;51(3):141-147.

132. Mozaafari E, Abai MR, Khanavi M, Vatandoost H, Sedaghat MM, Moridnia A, et al. Chemical Composition, Larvicidal and Repellency Properties of Cionura erecta (L.) Griseb. Against Malaria Vector, Anopheles stephensi Liston (Diptera: Culicidae). J Arthropod Borne Dis. 2014;8(2):147-155.

133. Sedaghat MM, Dekhordi AS, Khanavi M, Abai MR, Mohtarami F, Vatandoost H. Chemical composition and larvicidal activity of essential oil of Cupressus arizonica E.L. Greene against malaria vector Anopheles stephensi Liston (Diptera: Culicidae). Pharmacognosy Res. 2011;3(2):135-139.

134. Pandey SK, Upadhyay S, Tripathi AK. Insecticidal and repellent activities of thymol from the essential oil of Trachyspermum ammi (Linn) Sprague seeds against Anopheles stephensi. Parasitol Res. 2009;105(2):507-512.

135. Medhi SM, Reza S, Mahnaz K, Reza AM, Abbas H, Fatemeh M, et al. Phytochemistry and larvicidal activity of Eucalyptus camaldulensis against malaria vector, Anopheles stephensi. Asian Pac J Trop Med. 2010;3(11):841-845.

136. Rajkumar S, Jebanesan A, Nagarajan R Effect of leaf essential oil of Coccinia indica on egg hatchability and different larval instars of malarial mosquito Anopheles stephensi. Asian Pac J Trop Med.2011;4(12):948-951.

137. Khanavi M, Najafi B, Sadati SN, Abai MR, Vatandoost H. Chemical Constitute and Larvicidal Activity of Fractions of Ajuga chamaecistus tomentella Plant against Malaria Vector Anopheles stephensi. J Arthropod Borne Dis.2016;11(1):116-123.

138. Mahnaz K, Alireza F, Hassan V, Mahdi S, Reza AM, Abbas H. Larvicidal activity of essential oil and methanol extract of Nepeta menthoideae against malaria vector Anopheles stephensi. Asian Pac J Trop Med.2012;5(12):962-965.

139. Maheshwaran R, Ignacimuthu S. Bioefficacy of essential oil from Polygonum hydropiper L. against mosquitoes, Anopheles stephensi and Culex quinquefasciatus. Ecotoxicol Environ Saf.2013;97:26-31.

140. Govindarajan M. Larvicidal and repellent properties of some essential oils against Culex tritaeniorhynchus Giles and Anopheles subpictus Grassi (Diptera: Culicidae). Asian Pac J Trop Med.2011;4(2):106-111.

141. Ali A, Demirci B, Kiyan HT, Bernier UR, Tsikolia M, Wedge DE, et al. Biting deterrence, repellency, and larvicidal activity of Ruta chalepensis (Sapindales: Rutaceae) essential oil and its major individual constituents against mosquitoes. J Med Entomol.2013;50(6):1267-1274.

142. Kyarimpa CM, Böhmndorfer S, Wasswa J, Kiremire BT, Ndiege IO, Kabasa JD. Essential oil and composition of Tagetes minuta from Uganda. Larvicidal activity on Anopheles gambiae. Ind Crops Prod.2014;62:400-404.

143. Matsayoh JC, Wathuta EM, Kariuki ST, Chepkorir R. Chemical composition and larvicidal activity of Piper capense essential oil against the malaria vector, Anopheles gambiae. J Asia-Pac Entomol. 2011;14(1):26-28.

144. Mdoe FP, Cheng SS, Msangi S, Nkwengulila
145. Kweka EJ, Senthilkumar A, Venkatesalu V. Toxicity of essential oil from Indian borage on the larvae of the African malaria vector mosquito, Anopheles gambiae. Parasit Vectors. 2012;5:277.

146. Zhu L, Tian YJ. Chemical composition and larvicidal effects of essential oil of Blumea martinitana against Anopheles anthropophagus. Asian Pac J Trop Med. 2011;4(5):371-374.

147. Zhu L, Tian Y. Chemical composition and larvicidal activity of essential oil of Artemisia gilvescens against Anopheles anthropophagus. Parasitol Res. 2013;112(3):1137-1142.

148. Karunamoorthi K, Girmay A, Fekadu S. Larvicidal efficacy of Ethiopian ethnomedicinal plant Juniperus procera essential oil against Afrotropical malaria vector Anopheles arabiensis (Diptera: Culicidae). Asian Pac J Trop Biomed. 2012;4(Suppl 1):S99-s106.

150. Benelli G, Pavela R, Canale A, Cianfaglione K, Ciaschetti G, Conti F, et al. Acute larvicidal toxicity of five essential oils (Pinus nigra, Hyssopus officinalis, Satureja montana, Aloysia citrodora and Pelargonium graveolens) against the filariaisis vector Culex quinquefasciatus Say (Diptera: Culicidae). Plant Protect Sci. 2014;50(1):36-42.

154. Pushpanathan T, Jebanesan A, Govindarajan M. The essential oil of Zingiber officinalis Linn (Zingiberaeaceae) as a mosquito larvicidal and repellent agent against the filarial vector Culex quinquefasciatus Say (Diptera: Culicidae). Parasitol Res. 2008;102(6):1289-1291.

155. Dua VK, Kumar A, Pandey AC, Kumar S. Insecticidal and genotoxic activity of Psoralea corylifolia Linn.(Fabaceae) against Culex quinquefasciatus Say, 1823. Parasit vectors. 2013;6(1):30.

156. Senthilkumar A, Kannathasan K, Venkatesalu V. Chemical constituents and larvicidal property of the essential oil of Blumea mollis (D. Don) Merr. against Culex quinquefasciatus. Parasitol Res. 2008;103(4):959-962.

157. de Castro DS, da Silva DB, Tiburcio JD, Sobral ME, Ferraz V, Taranto AG, et al. Larvicidal activity of essential oil of Peumus boldus Molina and its ascaridole-enriched fraction against Culex quinquefasciatus. Exp Parasitol. 2016;171:84-90.

158. Tabari MA, Youssefi MR, Esfandiarri A, Benelli G. Toxicity of beta-citronellol, geraniol and finalool from Pelargonium roseum essential oil against the West Nile and filariasis vector Culex pipiens (Diptera: Culicidae). Res Vet Sci. 2017;114:36-40.

160. Michaelakis A, Papachristos D, Kimbaris A, Koliopoulos G, Giatropoulos A, Polissiou MG. Citrus essential oils and four enantiomeric pinenes against Culex pipiens (Diptera: Culicidae). Parasitol Res. 2009;105(3):769-773.

161. Evergetis E, Michaelakis A, Kioulos E, Koliopoulos G, Haroutounian S. Chemical composition and larvicidal activity of essential oils from six Apiaceae family taxa against the West Nile virus vector Culex pipiens. Parasitol Res. 2009;105(3):769-773.

162. Zhao H, Ji G, Liu F, Werdin Gonzalez JO, Jesse EN, Yeguerman CA, et al. Polymer nanoparticles containing essential oils: new options for mosquito control. Environ Sci Pollut Res Int. 2017;24(20):17006-17015.
and larvicidal activity of several essential oils from Hypericum species from Tunisia. Parasitol Res. 2013;112(2):699-705.

164. Soltani A, Vatandoost H, Oshaghi MA, Ravasan NM, Enayati AA, Asgarian F. Resistance Mechanisms of Anopheles stephensi (Diptera: Culicidae) to Temephos. J Arthropod Borne Dis. 2015;9(1):71-83.

165. Assis CR, Linhares AG, Oliveira VM, Franca RC, Carvalho EV, Bezerra RS, et al. Comparative effect of pesticides on brain acetylcholinesterase in tropical fish. Sci Total Environ. 441:141-150.

166. Arredondo-Jimenez JJ, Valdez-Delgado KM (2006) Effect of Novaluron (Rimon 10 EC) on the mosquitoes Anopheles albimanus, Anopheles pseudopunctipennis, Aedes aegypti, Aedes albopictus and Culex quinquefasciatus from Chiapas, Mexico. Med Vet Entomol. 20(4):377-387.

167. Cheng S, Lin R, Zhang N, Yuan S, Zhou X, Huang J, et al. (2018) Toxicity of six insecticides to predatory mite Amblyseius cucumeris (Oudemans) (Acari: Phytoseiidae) in- and off-field. Ecotoxicol Environ Saf. 161:715-720.

168. Word Health Organization W. (2016) World Malaria Report. Available from: http://apps.who.int/iris/bitstream/10665/252038/1/9789241511711-eng.pdf?ua=1.

169. Ma K, Li X, Hu H, Zhou D, Sun Y, Ma L, et al. (2017) Pyrethroid-resistance is modulated by miR-92a by targeting CpCPR4 in Culex pipiens pallingens. Comp Biochem Physiol B Biochem Mol Biol. 203:20-24.

170. Goindin D, Delannay C, Gelasse A, Ramdini C, Gaude T, Faucon F, et al. (2017) Levels of insecticide resistance to deltamethrin, malathion, and temephos, and associated mechanisms in Aedes aegypti mosquitoes from the Guadeloupe and Saint Martin islands (French West Indies). Infect Dis Poverty. 6(1):38.

171. Lucia A, Zerba E, Masuh H. Knockdown and larvicidal activity of six monoterpenes against Aedes aegypti (Diptera: Culicidae) and their structure-activity relationships. Parasitology research. 2013;112(12):4267-4272.

172. Rajashekar Y, Shivanandappa T. Mode of Action of the Natural Insecticide, Decaleside Involves Sodium Pump Inhibition. PLoS One. 2017;12(1):e0170836.

173. Perumalsamy H, Jang MJ, Kim J-R,
Kadarkarai M, Ahn Y-J. Larvicidal activity and possible mode of action of four flavonoids and two fatty acids identified in Millettia pinnata seed toward three mosquito species. Parasit vectors. 2015;8(1):237.

184. Samber N, Khan A, Varma A, Manzoor N (2015) Synergistic anti-candidal activity and mode of action of Mentha piperita essential oil and its major components. Pharm Biol. 2015;53(10):1496-1504.

185. Wongsariya K, Phanthong P, Bunyapraphatsara N, Srisukh V, Chomnawang MT. Synergistic interaction and mode of action of Citrus hystrix essential oil against bacteria causing periodontal diseases. Pharm Biol.2014;52(3):273-280.