Available online on 15.05.2022 at http://jddtonline.info

Journal of Drug Delivery and Therapeutics

Open Access to Pharmaceutical and Medical Research

Open Access Full Text Article

Review Article

Essential oils: As Potential Larvicides

Meenakshi Gupta, Diptee Gupta*

University Institute of Pharmacy, Chhatrapati Shahu Ji Maharaj University, Kalyanpur, Kanpur- 208024, Uttar Pradesh, India

Article Info:

Article History:

Received 17 March 2022
Reviewed 18 April 2022
Accepted 22 April 2022
Published 15 May 2022

Cite this article as:

Gupta M, Gupta D, Essential oils: As Potential Larvicides, Journal of Drug Delivery and Therapeutics. 2022; 12(3):193-201
DOI: http://dx.doi.org/10.22270/jddt.v12i3.5313

*Address for Correspondence:
Diptee Gupta, Department of Pharmaceutics, *University Institute of Pharmacy*, Chhatrapati Shahu Ji Maharaj University, Kalyanpur, Kanpur-208024, Uttar Pradesh, India

Abstract

Multiple synthetic products are used against mosquitoes to kill them and inhibit the transmission of these vector-borne diseases. The continuous use of these products produces detrimental effects on the environment and non-target organisms, which also develops resistance in the mosquito. In the last few decades, there has been a continuous exploration of herbal extract-based insecticides. These plants extract essential oils that have emerged as a potential eco-friendly alternative for the killing of larvae, the immature form of adult mosquitoes. In this review article, we focused on the larvicidal activity (LC_{50} values) of plant extracts obtained from various parts of plants. We evaluated results obtained from numerous essential oil larvicidal activities against prominent vectors belonging to the genera *Anopheles*, *Aedes*, and *Culex*, among others, that had been reported in various scientific data bases. The mode of action of these plant extracts are also discussed with reference to insecticidal activity. The major limitation of essential oils with their overcome solutions through formulation development is also highlighted. This review article reported that essential oils are potential substitutes for the development of larvicides, which may be employed in vector-borne illness control programmes. Overall, this remarkable summary and organization of data may be used to design, develop, and optimise herbal-based formulations with potential larvicidal efficacy.

Keywords: Essential oils; Larvicidal Activity; Herbal extract; Vector born-diseases.

Introduction:

Mosquitoes act as vectors for the transmission of various life threatening diseases caused by parasites, human pathogens, and veterinary pathogens. It have a crucial role in the spread of multiple diseases, including malaria, dengue, yellow fever, viral encephalitis, chikungunya, leishmaniasis, and filariasis. These diseases have an elevated mortality rate, which has a negative impact on the global economy[1].

There are approximately 3556 mosquito species that exist worldwide, which are further classified into 112 genera. *Aedes aegypti, Culex quinquefasciatus*, and *Anopheles stephensi* [2] are the three primary mosquito vectors that infect half of the world's population. Mosquitoes have been designated as the "Public Enemy Number One" by the World Health Organization. Apart from mosquito bites, allergic reactions such as urticaria and angioedema can also be triggered by mosquito bites[3].

As per WHO, 2012 report, almost world's 40% population under the risk of dengue virus illness transmitted by *Aedes aegypti*. Dengue become endemic to more than hundred countries of tropical and subtropical areas and every year 50-100 million cases of dengue virus infection reported[4]. According to a survey, dengue haemorrhagic fever causes more than fifty million infections each year, with half a million people being hospitalised. As per European Centre for Disease Prevention and Control (ECDC), 2021 survey, there have been over one million dengue virus disease cases confirmed in 2021 till august in Europe.

Malaria caused by plasmodium parasites which spread by bites of infected female mosquito *Anopheles stephensi*. According to World malaria report 2019, approximately 229 million cases reported globally. It primarily affects children under the age of five, accounting for 67 % (274000) of all malaria fatalities globally.

Yellow fever mainly endemic in tropical regions of Africa and South America while Chikungunya fever emerged in over sixty countries throughout Asia, Africa, Europe and the America. These also cause high global impact on economy and cause high rate of mortality[5]. In the last few decades, west Nile virus has arisen in the Americas, becoming endemic throughout the territory, while the Japanese encephalitis virus has disseminated to the Indian subcontinent and Australasia, predominantly affecting children[6].

Preventive and control measures for mosquito control:

For an effective mosquito eradication plan, a variety of preventative measures based on various approaches are available. These are as;

Mosquito repellents:

These are products that, whether synthetic (eg. DEET) or natural (eg. Herbal products), protect the individual from mosquito bites. When mosquito repellents are applied to skin or clothing of individuals, the vapour layer emits an unpleasant odour or taste. This unpleasant smell repels the mosquito from human that prevents the spread of infection. Although it is a very important tactic for protecting individuals from mosquito bites, its efficiency is slow[7]. Other effective approaches to restrict mosquito access in specific regions and preventing individual bites include insecticidal treated nets and window screens.

Preventing the mosquito breeding:

Breeding habitats include sewage water, stagnant water, septic tanks, natural and built containers such as pools, gutters, bamboo stumps, leaf axils, water tanks, etc. Various synthetic insecticides used to eradicate these mosquito breeding site. These breeding sites for the egg hatching and larvae development which efficient eliminate via the spraying insecticides or larvicides. It is one of the most effective and commonly utilised approaches[8].

Biological Control of mosquitoes:

Larvivorous fishes, such as *Gambusia affinis* and *Poecillia reticulate* (Guppy), exist in nature and feed on mosquito larvae. WHO included these fishes in the biological management of malaria vectors and are put into stocking ponds, rivers, and water storage areas where people live[9].

In the Biotechnology field, there are some biological techniques developed towards the elimination of mosquitoes such as the Sterile Insect Technique (known as "boosted SIT"),[10] and World Mosquito Program's *Wolbachia* method[11]. These approaches utilized the genetically modified mosquito strain for the vector population reduction or replacement. Toxins produced by bacteria, the soil-dwelling bacteria *Bacillus thuringiensis Berliner var. israelensis* (Bti) [12] has been economically employed in recent decades. These toxins are specifically utilized in water lodging sites to kill the larvae of *A. ageypti* and *A. alobipctus* mosquitoes. Despite the fact that it is an effective approach, incidences of resistance have been documented in certain publications[13].

Synthetic insecticides like tempheos, melathion, pyrethrin are frequently used in public health programme and significant response have been reported[14]. However, continued usage of these insecticides products developed resistance in the mosquito vector and also developed harmful impact on non-target organism and environment.

Thus, there is a need to develop eco-friendly tool for the mosquito larvae control which provides maximum results with least adverse effect. Plants based extracts or essential oils (EOs) proved as beneficial alternative source for mosquito control. Various herbal products frequently utilized in repellent products in various forms. These products provide efficient result as compare to chemical repellents and more safe[15].

However, plant based products as larvicides showed to be more satisfactory results as these are eco-friendly, non-toxic, safe to use, and inexpensive. Plants have extraordinary properties in the form of multiple metabolites with high efficacy as insecticides. There are many scientific database exist that reported the efficacy of EOs as larvicidal, ovicidal, pupicidal, and oviposition deterrent activity.

Essential oils (EOs):

Essential oils are defined as volatile, natural, complex compounds having a very intense odour, flavour. These are produced by aromatic plants as their "secondary metabolites" or "by-products" of plants. These oily aromatic liquids components synthesized and stored in different parts of plants like roots, stem, leaves, bark, rhizome, flowers, and fruits and stored in complex structure like secretory cavities, epidermic cells or glandular trichomes[16]. Commonly hydro or steam distillation methods are preferred for the extraction of essential oils.

As per literature survey, around 17,500 aromatic plant species spread worldwide synthesized essential oils; belonging to families including *Solanaceae, Asteraceae, Cladophoraceae, Labiatae, Miliaceae, Oocystaceae, lamiaceae, Myrtaceae* and *Rutaceae* [17].

Essential oils are very diverse natural compositions that comprise twenty–sixty components in varying concentrations. Two or three primary constituents are found in significant quantities (20–70%), whereas others are present in negligible proportions. These high concentrated chemical constituents contributed in the biological attributes of essential oils[16]. The constituents include two groups of diverse bio-synthetic origin in which major group have terpenes, terpenoids and the other one aromatic / aliphatic constituents[18].

Use of Essential oils:

According to Code of Federal Regulations, US Food and Drug Administration (FDA) recognized essential oils as GRAS (Generally Recognized as Safe) and some other compounds also preferred as antibacterial additives[19, 20].

During the middle ages, essential oils have been utilised for bactericidal, virucidal, fungicidal, antiparasitic, insecticidal, therapeutic, and aesthetic uses. Due to its aromatic fragrance, commercially utilized in perfumery, cosmetic products, and dentistry products. Essential oils are being used in the pharmaceutical sector in a variety of pharmaceutical formulations such as capsules, ointments, syrups, lotions, suppositories, aerosols, and sprays to treat a variety of illnesses.

In the food industry, demand for essential oils as food preservatives is increasing, as is advancement in food packaging and the fight against microorganisms that cause deadly food poisoning[21] such as *Listeria monocytogenes, Salmonella typhimurium, Clostridium perfringens, Pseudomonas putida and staphylococcus aureus*.

Major Limitation of Essential oils:

Apart from various benefits, the proper uses of essential oils are very complicated because it requires suitable storage conditions and appropriate precautions. There are certain limitations with essential oils use such as:

- It's highly volatile nature.
- Rapid oxidation and degradation on exposure to air
- Poorly soluble in water.
- React with metal and plastic container
- Require protection from heat and direct light

These reasons makes it unsuitable for the directly use of essential oils as larvicides, there is a need to develop such type of pharmaceutical formulation that entrap essential oil and increase its efficacy as larvicidal.

Ghosh *et al.* 2010 [22] conducted a comprehensive investigation on the larvicidal efficacy of over 100 plant extracts against various therapeutically significant mosquitoes, primarily from the genera Aedes, Anopheles, and Culex. According to the findings of this study, the tested larva variants were shown to be vulnerable to the selected plant species to varying degrees as mention in table 1.

The literature review accomplished by analysing published literature in various scientific databases, such as Web of science, Scopus, PubMed, Science Direct, ACS Publication, Bentham Sciences, Wiley Online Library, Springer and Google Scholar. The keywords used to search literature including "Herbal larvicidal, Plant based larvicidal, Essential oils, Essential oils as larvicidal formulation, Mosquito larvicides formulation".

Table 1: Plant essential oils with their potential larvicidal activity

S. No.	Plant Name	Family	Part of plant used	Solvent used	Target Organism	LC_{50} (ppm)	Ref
1.	*Clitoria ternatea*	Fabaceae	Seed	Methanol	*A. stephensi,* *A. aegypti,* *C. quinquefasciatus.*	65.2 154.5 54.4	24
2.	*Allium cepa*	Amaryllidaceae	Peel	Aqueous, Chlorofom Methanol	*A. stephensi*	52.08, 61.59 48.23	25
3.	*Citrullus colocynthis,* *Coccinia indica,* *Cucumis sativus,* *Momordica charantia,* *Trichosanthes anguina,*	Cucurbitaceae		Petroleum ether Methanol Methanol Methanol Acetone	*A. aegypti,* *C. quinquefasciatus.*	74.57 309.46 492.73 199.14 554.20 88.24 377.69 623.80 207.61 842.34	26
4.	*Cymbopogon citratus* *Cymbopogon winterianus* *Eucalyptus citriodora* *Eucalyptus camaldulensis*	Poaceae Myrtaceae	Leave	Ethanol	*A. aegypti,*	120.6 38.8 104.4 33.7	27
5.	*Allium Sativum* *Ferula asafoetida*	Amaryllidaceae Apiaceae.	Bulb, Gum oleoresin	Water	*C. Restuans* *C. Pipiens*	2.7 10.5 7.5 13.5	28
6.	*Calotropis gigantea*	Apocynaceae	Leave	Water	*C. gelidus* *C. tritaeniorhynchus*	137.90 110.05	29
7.	*Cinnamomum zeylanicum*	Lauraceae	-	Ethanol	*Anopheles stephensi.*	37	30
8.	*Clinopodium macrostemum*	Lamiaceae	Leave	Water (Hydro-distillation)	*C. quinquefasciatus*	22.49	31
9.	*Ocimum basilicum*	Lamiaceae	Leave	Water (Hydro-distillation)	*C. tritaeniorhynchus,* *A. albopictus* *A. subpictus*	14.01, 11.97 9.75	32
10.	*Carica papaya*	Caricaceae	Leave	Methanol	*A. aegypti*	82.18	33
11.	*Trachyspemum ammi* *Echinophora spinosa*	Apiaceae	Fruits Roots	Water (hydro distillation)	*C. quinquefasciatus*	17.6 18.9	34
12.	*Tagetes patula*	Asteraceae	Fresh	Water	*A. ageypti*	13.57	35

			foliage	(Hydro-distillation)	*Anopheles stephensi* *C. quinquefasciatus*	12.08 22.33	
13.	*Ammi visnaga*	Umbelliferae	Seeds	Methanol	*C. quinquefasciatus*	18.00	36
14.	*Argemone mexicana*	Papaveraceae	Flower	Ethanol	*C. quinquefasciatus*	18.61	37
15.	*Zanthoxylum piperitum*	Rutaceae	Bark	Methanol	*C. pipiens pallens*	10.50	38
16.	*Menthe spicata*	Lamiaceae	Leaves	Water (Hydro-distillation)	*Anopheles stephensi,* *A. ageypti* *C. quinquefasciatus*	49.71, 56.08 62.62	39
17.	*Bunium persicum*	Apiaceae	Fruits	Water (Hydro-distillation)	*Anopheles stephensi*	27.42	40
18.	*Artemisia vulgaris*	Apiaceae	Leaves	Water (Hydro-distillation)	*A. aegypti*	6.87	41
19.	*Hyptis suaveolens* *Lantana camara* *Nerium oleander* *Tecoma stans*	Lamiaceae Verbenaceae Apocynaceae Bignoniaceae	Leaves	Petroleum ether Petroleum ether Methanol Petroleum ether	*C. quinquefasciatus*	38.39 10.63 35.82 19.26	3
20.	*Myristica fragrans*	Myristicaceae	Seeds	Water (Hydro-distillation)	*A. aegypti*	28.2	42
21.	*Foeniculum vulgare*	Apiaceae	Seeds	Water (hydro distillation)	*C. pipiens*	40.00	43
22.	*Ocimum sanctum*	Lamiaceae	Leaves, Flowers	-	*C. quinquefasciatus*	76.61	44
23.	*Cassia fistula*	Fabaceae	Leaves	Methanol	*C. quinquefasciatus* *Anopheles stephensi*	17.97 20.57	45
24.	*Momordica charantia*	Cucurbitaceae	Fruits	Hexane	*Anopheles stephensi* *C. quinquefasciatus*	66.05 96.11	46
25.	*Artemisia annua* *Cassia fistula* *Centella asiatica* *Datura stramonium* *Eucalyptus globulus*	Asteraceae Fabaceae Apiaceae Solanaceae Myrtaceae	Leaves	Ethanolic Water	*Anopheles stephensi*	1.77 3.30 1.53 9.31 1.15	47
26.	*Zingiber officinale Roscoe*	Zingiberaceae	Leaves	-	*A. aegypti*	46	48
27.	*Stemodia maritima*	Scrophulariaceae	Stem	-	*A. aegypti*	23	49
28.	*Tinospora crispa*	Menispermaceae	Stem	Water	*C. quinquefasciatus*	16.95	50
29.	*Piper betle*	Piperaceae	Leaves	Water (Hydro-distillation)	*A. aegypti*	0.63	51

30.	*Ocimum basilicum*	Lamiaceae	Leaves	Water (Hydro-distillation)	*C. tritaeniorhynchus* *A. albopictus*	14.01 11.97	52
31.	*Zingiber collinsii*	Zingiberaceae	Rhizome	Water(Hydro-distillation)	*A. albopictus* *C. quinquefasciatus*	25.51 50.11	53

Table 2 Essential oils encapsulated formulation as potential larvicides

S. No	Plant Name	Formulation	Materials used	Droplet size	Target organism	LC_{50} (ppm)	Ref
1.	*Ocimum basilicum L.*	Nano emulsion	Polysorbate 80 /low energy method	-	*C. quinquefasciatus*	96.87% mortality at 100 ppm	54
2.	*Mentha Piperita*	Nano emulsion	Tweem 20, water /low energy spontaneous emulsification method	39.2nm	*An. Stephensi* *An. culicifacies*	123 48	55
3.	*Lippia sidoides*	Nanoparticles	Chitosan, Angico gum	18.7nm	*A. aegypti*	34	56
4.	*Eucalyptus oil*	Micro beads	Chitosan, Tween 80	-	*C. pipiens*	0.419mg/l	57
5.	*Azadirachta indica, Pongamia glabra*	Calcium alginate beads	Tween 80, Sodium alginate	1.83mm	*A. aegypti*	3.1 g/l	58
6.	*Geranium maculatum, Citrus bergamia*	Polymeric nanoparticles	Chitosan, Tween 80/ionic gelation	<535 nm	*C. pipiens*	22.63 38.52	59
7.	*Pterodon emarginatus*	Nano emulsion	Polysorbate 80/sorbitan monooleate/low energy method	151.0 ± 2.25 160.7 ± 1.49	*C. quinquefasciatus*	34.75 7.31-51.86	60
8.	*Trachyspermum ammi* *Illicium verum*	β-cyclodextrin (β-CD) inclusion complexes	β-cyclodextrin, Ethanol	-	*A. aegypti*	23.93	61
9.	*Carica papaya*	Silver nanoparticles	Silver nitrate, Deionized sterilized Water	12 ± 6	*A. aegypti* *C. quinquefasciatus*	<10 <10	62
10.	*Azadirachta indica*	Nano emulsion	Tween 20 / High energy method	-	*C. quinquefasciatus*	11.75	63
11.	*Mentha spicata*	Nano emulsion	Tween 80/ ultrasonic emulsification	97.8 nm	*C. pipiens*	43.57	64
12.	*Cirtus sinensis*	Nano emulsion	Tween 20/ ultrasonic method.	78.8±14.2 nm	*C. pipiens*	27.4	65
13.	*Rosmarinus officinalis*	Nano emulsion	Polysorbate 20/low energy method	<200	*A. aegypti*	250.00	66

*Abbreviations- ppm – parts per million, HD- Hydro distillation, *A. aegypti- Aedes aegypti, An. stephensi-Anopheles stephensi, C. quinquefasciatus- Culex quinquefasciatus, A. albopictus- Aedes albopictus, C. tritaeniorhynchus- Culex tritaeniorhynchus. C. pipiens- Culex pipiens*

Mechanism of action of essential oils as potential larvicides:

Despite the fact that there are several databases accessible that focus on the efficacy of essential oils as possible larvicides, there is little information available on the mechanism of action of these secondary metabolites.

The most of these volatile oils interrupt the central nervous system by inhibiting acetyl cholinesterase (AChE), resulting in the death of mosquito larvae due to intoxication. Essential oils containing monoterpenes, such as *Zingiber officinale* EOs, have been identified as acetyl-cholinesterase inhibitors[53]. Scotti *et al.*[54] concluded that the lipophillicity of volatile oils has a significant impact in larvicidal action and is linked closely with independent factors with a hydrophobic profile.

Double bonds play an important role in the larvicidal efficacy of natural biomolecules because hydrogenation of these bonds lowers the lipophilic nature of such components, limiting their entry via the larval cuticle[55]. Various essential oil constituents interfere with the endocrinologic process of insects, inhibiting morphogenesis. These essential oils have neurotoxic or insecticidal effects[56].

In insects, octopmaine serves as a neurotransmitter, neuromodulator, as well as essential oil target site. The components of essential oil inhibited the octopamine receptors, resulting in acute and sub lethal behavioural consequences[56]. As a result, it's known that the bio constituents of EOs have a variety of modes of action, as well as different levels of ability to pierce the insect cuticle and occupy their bodies, which is closely connected to their ability to offer a pesticidal impact.

Future prospect of essential oils as larvicides:

EOs are recognised to be attractive plant compounds that can be utilised in a wide range of possibilities, including plant protection, human and animal health protection, and vector control. In terms of mosquito control, EOs are now employed mostly as sources of active ingredients for different repellents[57]. Simultaneously, appropriate EOs have been explored as possible active ingredients in non-toxic botanical pesticides for use against adult mosquitoes and their larvae[58, 59].

Researchers explored and published numerous literature work on the efficacy of essential oils as potent larvicides and developed multiple formulations. These formulations developed to observe the efficacy of essential oils on multiple genera of mosquitoes. Although there is no commercial product available based on the essential oils as active components in the larvicidal product.

It may be possible due to various consequences with essential oil as highly volatile in nature, degraded rapidly by environmental factors, highly expensive due to minimum yield with maximum plant extract. Essential oils easily evaporate in nature if not stored with precaution and declines their biological property; major limitation with essential oil use as larvicides[60]. Having all these limitations, essential oils arise as promising alternative approach to synthetic larvicides products. However, scientists overcome these problems via suitable formulation development by encapsulation methods or essential oils stabilization techniques[61]. Nano-emulsion, micro-emulsion, silver nanoparticles and polymeric beads are developed more frequently as compare to other formulation as mentioned in table 2.

Silver nanoparticles (AgNPs) have been reported to be an appealing option to direct plant based extracts, as silver metal has antibacterial effects, and when combined with certain plants, it boosts larvicidal action[62].

Nanoemulsions are widely preferred by researchers as they enhance the solubility of poorly water soluble drugs. Nano-emulsion formulated by various scientists incorporating multiple essential oils with surfactant and co-surfactant. It proven to be an efficient method for preserving the biological attributes of essential oils while increasing their potency[63].

Based on the literature review, it has been determined that both nano-emulsions and silver nanoparticles of selected essential oil exhibit substantial effectiveness against selected mosquito strains[64]. Polymeric beads have emerged as a new choice for larvicidal products since they encapsulate a large number of essential oils and release them in a regulated manner, providing a longer effect[65].

It is crucial to monitor the detrimental impacts of essential oils in non-target organisms in order to continue using them commercially. Only a few studies focused into the non-target effects of essential oils as larvicidal agents. Although essential oils are non-toxic, safe to use, eco-friendly, sometimes become little toxic against small crustaceans[66, 56].

Based on particular studies, toxic effects are frequent as a result of a hypothesized mode of action or the use of a large amount of essential oils. Few essential oils have been reported to have an anaesthetic or sedative effect on fish in some experiments[67].

However, when all factors were considered, the use of essential oils as larvicides resulted in the lowest toxicity and highest efficacy if compared to synthetic larvicides.

Conclusion:

From this study, we can conclude that essentials oils emerge as promising approach to natural eco-friendly larvicidal agents. These proved safe, easy to use and developed as botanical larvicides products. Developing larvicides product by using essential oils minimizes the toxicity and resistance developed by synthetic chemical insecticides. However, in order to develop a more sustainable product, there is a need to focus on field studies of the larvicidal properties of these essential oils alone or in combination.

Conflict of interest:

There is no conflict of interest between the authors.

References:

1. Pavela R. Essential oils for the development of eco-friendly mosquito larvicides: a review. Ind Crops Prod, 2015; 15(76):174-87. DOI: https://doi.org/10.1016/j.indcrop.2015.06.050.

2. Tandina F, Doumbo O, Traoré SF, Parola P, Robert V. Mosquitoes (Diptera: Culicidae) and mosquito-borne diseases in Mali, West Africa. Parasites & vectors. 2018; 11(1):1-2. DOI: https://doi.org/10.1186/s13071-018-3045-8 .

3. Hari I, Mathew N. Larvicidal activity of selected plant extracts and their combination against the mosquito vectors Culex quinquefasciatus and Aedes aegypti. Environ. Sci. Pollut. Res, 2018; 5(9):9176-9185. DOI: https://doi.org/10.1007/s11356-018-1515-3

4. Luz TR, de Mesquita LS, do Amaral FM, Coutinho DF. Essential oils and their chemical constituents against Aedes aegypti L. (Diptera: Culicidae) larvae. Acta Tropica, 2020; 1(212):105705. Doi: https://doi.org/10.1016/j.actatropica.2020.105705

5. Monath T.P, Vasconcelos P.F, Yellow fever. J. Clin. Virol. 2018;64:106-13. Doi. https://doi.org/10.1590/1806-9282.64.02.106

6. Tolle M.A, Mosquito-borne diseases. Curr. Probl. Pediatr. Adolesc. Health Care, 2009; 39(4):97-140. Doi: https://doi.org/10.1016/j.cppeds.2009.01.001

7. da Silva MR, Ricci-Júnior E, An approach to natural insect repellent formulations: From basic research to technological development. Acta tropica, 2020; 1(212):105419. Doi: https://doi.org/10.1016/j.actatropica.2020.105419

8. Ashwini U, Asha S, Larvicidal activity of natural products against mosquito species. Int J Chemtech Res, 2017; 10(5):875-878.

9. Walshe DP, Garner P, Adeel AA, Pyke GH, Burkot TR. Larvivorous fish for preventing malaria transmission. Cochrane Database Syst. Rev, 2017; 12. Doi: https://doi.org/10.1002/14651858.CD008090

10. Chung HN, Rodriguez SD, Gonzales KK, Vulcan J, Cordova JJ, Mitra S, *et al.,* Toward Implementation of Mosquito Sterile Insect Technique: The Effect of Storage Conditions on Survival of Male Aedes aegypti Mosquitoes (Diptera: Culicidae) During Transport. J. Insect Sci, 2018; 18(6). Doi: https://doi.org/10.1093/jisesa/iey103

11. Bourtzis K, Lees RS, Hendrichs J, Vreysen MJ. More than one rabbit out of the hat: radiation, transgenic and symbiont- based approaches for sustainable management of mosquito and tsetse fly populations. Acta Tropica 2016; 157:115-130. Doi: https://doi.org/10.1016/j.actatropica.2016.01.009

12. Bravo A, Gill SS, Soberon M, Mode of action of Bacillus thuringiensis Cry and Cyt toxins and their potential for insect control. Toxicon, 2007; 49:423-435. Doi: https://doi.org/10.1016/j.toxicon.2006.11.022

13. Bonin A, Paris M, Frérot H, Bianco E, Tetreau G, Després L, The genetic architecture of a complex trait: Resistance to multiple toxins produced by Bacillus thuringiensis israelensis in the dengue and yellow fever vector, the mosquito Aedes aegypti. Infect. Genet. Evol, 2015; 35:204-213.Doi: https://doi.org/10.1016/j.meegid.2015.07.034

14. Tikar SN, Mendki MJ, Chandel K, Parashar BD, Prakash S. Susceptibility of immature stages of Aedes (Stegomyia) aegypti ; vector of dengue and chikungunya to insecticides from India. Parasitol. Res. 2008. Doi: https://doi.org/10.1007/s00436-007-0848-5

15. Geetha RV, Roy A, Essential oil repellents-a short review. Int. J. Drug Dev. Res, 2014; 6(2):20-27.

16. Bakkali F, Averbeck S, Averbeck D, Idaomar M, Biological effects of essential oils–a review.Food Chem. Toxicol, 2008; 46(2):446-75. https://doi.org/10.1016/j.fct.2007.09.106

17. El Asbahani A, Miladi K, Badri W, Sala M, Addi EA, Casabianca H, *et al*. Essential oils: from extraction to encapsulation. Int. J. Pharm. Doi: https://doi.org/10.1016/j.ijpharm.2014.12.069

18. Pichersky E, Noel JP, Dudareva N. Biosynthesis of plant volatiles: nature's diversity and ingenuity. Science, 2006; 311(5762):808–811. DOI: 10.1126/science.1118510

19. CFR- Code of Federal Regulations Title 21. Website. http://www.accessdata.fda.gov/ (9 December 2014).

20. Ait-Ouazzou A, Cherrat L, Espina L, Lorán S, Rota C, Pagán R. The antimicrobial activity of hydrophobic essential oil constituents acting alone or in combined processes of food preservation. IFSET, 2011; 12:320–329.Doi: https://doi.org/10.1016/j.ifset.2011.04.004

21. Burt S, Essential oils: their antibacterial properties and potential applications in foods—a review. Int. J. Food Microbiol, 2004;94(3):223-53.Doi: https://doi.org/10.1016/j.ijfoodmicro.2004.03.022

22. Ghosh A, Chowdhury N, Chandra G, Plant extracts as potential mosquito larvicides. Indian J. Med. Res, 2012; 135(5):581–598.

23. Mathew N, Anitha MG, Bala TS, Sivakumar SM, Narmadha R, Kalyanasundaram M. Larvicidal activity of Saraca indica, Nyctanthes arbor-tristis, and Clitoria ternatea extracts against three mosquito vector species. Parasitol. Res. 2009; 104(5):1017-25 Doi: https://doi.org/10.1007/s00436-008-1284

24. Babu M, Ashok K, Larvicidal activity of onion (Allium cepa) peel extracts against Anopheles stephensi. Int J Zool Invest 2021; 7(2). DOI:10.33745/ijzi.2021.v07i02.042

25. Rahuman AA, Venkatesan P, Larvicidal efficacy of five cucurbitaceous plant leaf extracts against mosquito species. Parasitol. Res, 2008; 103(1):133-9 https://doi.org/10.1007/s00436-008-0940-5

26. Manh HD, Hue DT, Hieu NT, Tuyen DT, Tuyet OT, The Mosquito larvicidal activity of essential oils from Cymbopogon and Eucalyptus Species in Vietnam. Insects. 2020; 11(2):128. Doi: https://doi.org/10.3390/insects11020128

27. Muturi EJ, Ramirez JL, Zilkowski B, Flor-Weiler LB, Rooney AP, Ovicidal and larvicidal effects of garlic and asafoetida essential oils against West Nile virus vectors. J. Insect Sci, 2018;18(2):43.Doi: https://doi.org/10.1093/jisesa/iey036

28. Kumar G, Karthik L, Rao KB, Kirthi AV, Rahuman AA, Larvicidal, repellent and ovicidal activity of Calotropis gigantea against Culex gelidus, Culex tritaeniorhynchus (Diptera: Culicidae). Int. J. Agric. Technol. 2012; 8(3):869-80. Doi:

29. Firooziyan S, Amani A, Osanloo M, Moosa-Kazemi SH, Basseri HR, Hajipirloo HM, *et al.*, Preparation of nanoemulsion of Cinnamomum zeylanicum oil and evaluation of its larvicidal activity against a main malaria vector Anopheles stephensi. J. Environ. Health Sci. Eng. 2021; 29:1.Doi: https://doi.org/10.1007/s40201-021-00667-0

30. Rojas-Olivos A, Solano-Gómez R, Granados-Echegoyen C, Santiago-Santiago LA, García-Dávila J, Pérez-Pacheco R, Lagunez-Rivera L, Larvicidal effect of Clinopodium macrostemum essential oil extracted by microwave-assisted hydrodistillation against Culex quinquefasciatus (Diptera: Culicidae). Revista da Sociedade Brasileira de Medicina Tropical. 2018; 51:291-6. Doi: https://doi.org/10.1590/0037-8682-0284-2017

31. 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.Doi: https://doi.org/10.1016/j.exppara.2013.01.018

32. Kovendan K, Murugan K, Kumar AN, Vincent S, Hwang JS, Bioefficacy of larvicdial and pupicidal properties of Carica papaya (Caricaceae) leaf extract and bacterial insecticide, spinosad, against chikungunya vector, Aedes aegypti (Diptera: Culicidae). Parasitol Res. 2012; 110(2):669-78. Doi: https://doi.org/10.1007/s00436-011-2540-z

33. Pavela R, Maggi F, Cianfaglione K, Bruno M, Benelli G, Larvicidal activity of essential oils of five apiaceae taxa and some of their main constituents against Culex quinquefasciatus. Chem. Biodivers. 2018; 15(1). Doi: https://doi.org/10.1002/cbdv.201800148

34. Dharmagadda VSS, Naik SN, Mittal PK, Vasudevan P, Larvicidal activity of Tagetes patula essential oil against three mosquito species. Bioresour. Technol. 2005; 96(11), 1235–1240. Doi: https://doi.org/10.1016/j.biortech.2004.10.020

35. Pavela R, Vrchotová N, Tříska J, Larvicidal activity of extracts from Ammi visnaga Linn.(Apiaceae) seeds against Culex quinquefasciatus Say.(Diptera: Culicidae). Exp. Parasitol, 2016; 1(165):51-7. Doi: https://doi.org/10.1016/j.exppara.2016.03.016

36. Granados-Echegoyen CA, Chan-Bacab MJ, Ortega-Morales BO, Vásquez-López A, Lagunez-Rivera L, Diego-Nava F, *et al.*, Argemone mexicana (Papaverales: Papavaraceae) as an alternative for mosquito control: First report of larvicidal activity of flower extract. J. Med. Entomol. 2019; 56(1):261-7. Doi: https://doi.org/10.1093/jme/tjy159

37. Kim SI, Ahn YJ. Larvicidal activity of lignans and alkaloid identified in Zanthoxylum piperitum bark toward insecticide-susceptible and wild Culex pipiens pallens and Aedes aegypti. Parasites Vectors, 2017; 10(1).Doi: https://doi.org/10.1186/s13071-017-2154-0

38. 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. Doi: https://doi.org/10.1007/s00436-011-2731-7

39. Vatandoost H, Rustaie A, Talaeian Z, Abai MR, Moradkhani F, Vazirian M, *et al.,* Larvicidal Activity of Bunium persicum essential oil and extract against Malaria Vector, Anopheles stephensi. J Arthropod Borne Dis, 2018; 12(1):85. Doi:

40. Balasubramani S, Sabapathi G, Moola AK, Solomon RV, Venuvanalingam P, Bollipo Diana RK. Evaluation of the Leaf Essential Oil from Artemisia vulgaris and Its Larvicidal and Repellent Activity against Dengue Fever Vector Aedes aegypti—An Experimental and Molecular Docking Investigation. ACS Omega, 2018; 3(11):15657-65. Doi:https://doi.org/10.1021/acsomega.8b01597

41. Gomes DR, Dos Santos DL, Alencar LJ, Dos Santos CL, Pereira LJ, Dos Santos LA, Evaluation of larvicidal, adulticidal, and anticholinesterase activities of essential oils of Illicium verum Hook. f., Pimenta dioica (L.) Merr., and Myristica fragrans Houtt. against Zika virus vectors. Environ. Sci. Pollut. Res. 2018; 25(23):22541. Doi: https://doi.org/10.1007/s11356-018-2362-y

42. Zoubiri S, Baaliouamer A, Seba N, Chamouni N. Chemical composition and larvicidal activity of Algerian Foeniculum vulgare seed essential oil. Arab. J. Chem. 2014; 7(4):480-5.Doi: https://doi.org/10.1016/j.arabjc.2010.11.006

43. Anees AM, Larvicidal activity of Ocimum sanctum Linn. (Labiatae) against Aedes aegypti (L.) and Culex quinquefasciatus (Say). Parasitol. Res., 2008; 103(6):1451-3. Doi: https://doi.org/10.1007/s00436-008-0991-7

44. Govindarajan M, Jebanesan A, Pushpanathan T, Larvicidal and ovicidal activity of Cassia fistula Linn. leaf extract against filarial and malarial vector mosquitoes. Parasitol. Res, 2008; 102(2):289-92. Doi: https://doi.org/10.1007/s00436-007-0761-y

45. Singh RK, Dhiman RC, Mittal PK. Mosquito larvicidal properties of Momordica charantia Linn (family: Cucurbitaceae). J. Vector Borne Dis. 2006; 43(2):88.

46. Senthilkumar N, Varma P, Gurusubramanian G. Larvicidal and adulticidal activities of some medicinal plants against the malarial vector, Anopheles stephensi (Liston). Parasitol. Res. 2009; 104(2):237-44. Doi: https://doi.org/10.1007/s00436-008-1180-4

47. Moon HI, Cho SB, Kim SK, Composition and immunotoxicity activity ofessential oils from leaves of Zingiber officinale Roscoe against Aedes aegypti L. Immunopharmacol. Immunotoxicol. 2011; 33:201–204. Doi: https://doi.org/10.3109/08923973.2010.495393

48. Arriaga AMC, Rodrigues FEA, Lemos TLG, Oliveira MCF, Lima JQ, Santiago GMP. Composition and larvicidal activity ofessential oil from Stemodia maritima L. Nat. Prod. Commun, 2007; 2:1237–1239. Doi: https://doi.org/10.1177/1934578X0700201209

49. Jiraungkoorskul W. Efficiency of Tinospora crispa against Culex quinquefasciatus larva. Environ. Sci. Pollut. Res., 2019; 26(15):14712-6. Doi: https://doi.org/10.1007/s11356-018-2429-9

50. Srinivasan PV, Thanigaivel A, Edwin ES, Ponsankar A, Nathan SS, Rani SS, *et al.,* Toxicological effects of chemical constituents from Piper against the environmental burden Aedes aegypti Liston and their impact on non-target toxicity evaluation against biomonitoring aquatic insects. Environ. Sci. Pollut. Res., 2018; 25(11):10434-46. Doi: https://doi.org/10.1007/s11356-017-9714-x

51. 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. Doi: https://doi.org/10.1016/j.exppara.2013.01.018

52. Huong LT, Huong TT, Huong NT, Hung NH, Dat PT, Luong NX. Mosquito larvicidal activity of the essential oil of Zingiber collinsii against Aedes albopictus and Culex quinquefasciatus.J. Oleo Sci. 2020; 69(2):153-60.Doi: https://doi.org/10.5650/jos.ess19175

53. Moyes CL, Vontas J, Martins AJ, Ng LC, Koou SY, Dusfour I, Contemporary status of insecticide resistance in the major Aedes vectors of arboviruses infecting humans. PLoS Negl Trop Dis. 2017; 11(7):1-20. Doi: https://doi.org/10.1590/0037-8682-0489-2019

54. Scotti L, Scotti MT, Silva VB, Santos SRL, Cavalcanti SCH, Mendonc JB. Chemometric studies on potential larvicidal compounds against Aedes aegypti. Med. Chem., 2014; 10(2):201-10.

55. Lomonaco D, Santiago GMP, Ferreira YS, Arriaga AMC, Mazzetto SE, Melec G. *et al.,* Study of technical CNSL and its main components as new green larvicides. Curr. Green Chem, 2009; 11(1):31-3. Doi: https://doi.org/10.1039/B811504D

56. Rattan RS, Mechanism of action of insecticidal secondary metabolites of plant origin. Crop Prot. 2010; 29:913–920. Doi: https://doi.org/10.1016/j.cropro.2010.05.008

57. Miresmailli S, Isman MB, Botanical insecticides inspired by plant–herbivore chemical interactions.Trends Plant Sci, 2014; 19(1):29-35. Doi: https://doi.org/10.1016/j.tplants.2013.10.002

58. Walker K, Lynch M, Contributions of Anopheles larval control to malaria suppression in tropical Africa: review of achievements and potential. Medical and veterinary entomology. 2007; 21(1):2-1.Doi: https://doi.org/10.1111/j.1365-2915.2007.00674.x

59. Dias CN, Moraes DF, Essential oils and their compounds as Aedes aegypti L.(Diptera: Culicidae)larvicides. Parasitol. Res. 2014; 113(2):565-92. Doi: https://doi.org/10.1007/s00436-013-3687-6

60. Isman MB, Grieneisen ML. Botanical insecticide research: many publications, limited useful data. Trends Plant Sci, 2014; 19(3):140-5. Doi: https://doi.org/10.1016/j.tplants.2013.11.005

61. Turek C, Stintzing FC. Stability of essential oils: a review. Compr. Rev. Food Sci. Food Saf. 2013; 12(1):40-53. Doi: https://doi.org/10.1111/1541-4337.12006

62. Ahmed S, Ahmad M, Swami BL, Ikram S. A review on plants extract mediated synthesis of silver nanoparticles for antimicrobial applications: a green expertise. J. Adv. Res, 2016; 17(1):17-28. Doi: https://doi.org/10.1016/j.jare.2015.02.007

63. Li Y, Zheng J, Xiao H., McClements DJ, Nanoemulsion-based delivery systems for poorly water-soluble bioactive compounds: Influence of formulation parameters on polymethoxyflavone crystallization. Food Hydrocoll, 2012; 27(2):517-28. Doi: https://doi.org/10.1016/j.foodhyd.2011.08.017

64. Oliveira AE, Duarte JL, Cruz RA, Souto RN, Ferreira RM, Peniche T, et al., Pterodon emarginatus oleoresin-based nanoemulsion as a promising tool for Culex quinquefasciatus (Diptera: Culicidae) control. J. Nanobiotechnology. 2017; 15(1):1-1.Doi: https://doi.org/10.1186/s12951-016-0234-5

65. Pant M, Dubey S, Raza SK, Patanjali PK, Encapsulation of neem and karanja oil mixture for synergistic as well as larvicidal activity for mosquito control. J Sci Ind Res. 2012. http://hdl.handle.net/123456789/13992

66. 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., 2018; 25(11):10218-27. Doi: https://doi.org/10.1007/s11356-016-8146-3

67. Silva LL, Garlet QI, Koakoski G, Oliveira TA, Barcellos LJ, Baldisserotto B. Effects of anesthesia with the essential oil of Ocimum gratissimum L. in parameters of fish stress. Rev. Bras. de Plantas Medicinais, 2015; 17:215-23.

68. Sundararajan B, Moola AK, Vivek K, Kumari BDR, Formulation of nanoemulsion from leaves essential oil of Ocimum basilicum L. and its antibacterial, antioxidant and larvicidal activities (Culex quinquefasciatus), Microb. Pathog. 2018; 125:475-85. Doi: https://doi.org/10.1016/j.micpath.2018.10.017

69. Ghosh V, Ranjha R, Gupta AK, Formulation of anti-larval nanoemulsion: Impact of droplet size on larvicidal activity against

malaria vectors in Chhattisgarh, India. Indian J. Biochem. Biophys. 2021; 58(2):178-86.

70. Paula HC, Sombra FM, Abreu FO, Paul R. Lippia sidoides essential oil encapsulation by angico gum/chitosan nanoparticles. J. Braz. Chem. Soc, 2010; 21:2359-66.

71. Essa EE, Mo'men SA, Rady MH, Ma'moun SA, Barakat EM, Salama MS. Eucalyptus oil nano-emulsion encapsulated in chitosan beads as a new approach in control of Culex pipiens larvae. Int. J. Mosq. Res., 2019; 6(5):63-9.

72. González JO, Jesser EN, Yeguerman CA, Ferrero AA, Band BF. Polymer nanoparticles containing essential oils: new options for mosquito control. Environ. Sci. Pollut. Res. 2017; 24(20):17006-15. Doi: https://doi.org/10.1007/s11356-017-9327-4

73. Pandiyan GN, Mathew N, Munusamy S. Larvicidal activity of selected essential oil in synergized combinations against Aedes aegypti. Ecotoxicol. Environ. Saf. 2019; 15(174):549-56. Doi: https://doi.org/10.1016/j.ecoenv.2019.03.019

74. Chandrasekaran R, Seetharaman P, Krishnan M, Gnanasekar S, Sivaperumal S. Carica papaya (Papaya) latex: a new paradigm to combat against dengue and filariasis vectors Aedes aegypti and Culex quinquefasciatus (Diptera: Culicidae). Biotechnol. 2018; 8(2):1. . Doi: https://doi.org/10.1007/s13205-018-1105-6

75. Anjali CH, Sharma Y, Mukherjee A, Chandrasekaran N. Neem oil (Azadirachta indica) nanoemulsion—a potent larvicidal agent against Culex quinquefasciatus. Pest Manag. Sci., 2012; 68(2):158-63. Doi: https://doi.org/10.1002/ps.2233

76. Mohafrash SM, Fallatah SA, Farag SM, Mossa AT. Mentha spicata essential oil nanoformulation and its larvicidal application against Culex pipiens and Musca domestica. Ind Crops Prod, 2020; 1:157. Doi: https://doi.org/10.1016/j.indcrop.2020.112944

77. Azmy MR, Gohary EG, Mahmoud M, Salem AM, Abdou AM, Salama S. Assessment of larvicidal activity of nanoemulsion from Citrus sinensis essential oil on Culex pipiens L. (Diptera: Culicidae). Egypt. J. Aquat. Biol. Fish. 2019; 23(3):61-7. Doi:10.21608/ejabf.2019.35100

78. Duarte JL, Amado JR, Oliveira AE, Cruz RA, Ferreira AM, Souto RN, *et al.,* Evaluation of larvicidal activity of a nanoemulsion of Rosmarinus officinalis essential oil. Rev. bras. farmacogn. 2015; 25:189-92.Doi: https://doi.org/10.1016/j.bjp.2015