PLANT SCIENCE TODAY
Vol x(x): xx–xx
https://doi.org/10.14719/pst.3232

eISSN 2348-1900

RESEARCH ARTICLE

Mosquito larvicidal property of *Citrus* species

Anamika K S, Gomathy M & Manikantan Pappuswamy*

Life science, CHRIST University, Bangalore 560 029, India

*Correspondence email - manikantan.p@christuniversity.in

Received: 29 December 2023; Accepted: 13 February 2025; Available online: Version 1.0: 21 April 2025

Cite this article: Anamika KS, Gomathy M, Manikantan P. Mosquito larvicidal property of *Citrus* species. Plant Science Today (Early Access). https:/doi.org/10.14719/pst.3232

Abstract

Mosquitoes and their larvae have several detrimental effects on humans, animals and the environment. Their bites cause itching, allergic reactions and skin irritation. Mosquito larvae thrive in stagnant water, polluting water sources and creating breeding grounds for further infestations. Large mosquito populations negatively impact agriculture and livestock by transmitting diseases to animals. Additionally, their presence reduces outdoor activities, affecting tourism and economic productivity in affected regions. The review focuses on the Culicidae mosquito genera *Anopheles, Aedes* and *Culex*, including many species in each. The papers show that Clevenger and Soxhlet apparatus methods maintain high-quality and quantity oils because of their unique properties. These methods are cost-effective and environmentally friendly since chloroform, carbon tetrafluoride and other similar pollutants are not used, which causes severe health issues. Future research will examine how oil release from plant parts varies with age and how this relates to mosquito mortality. Different plant parts may yield varying quantities of oil at different stages, which can be considered as a point of discussion. The present findings support the efficiency of certain *Citrus* species in the Rutaceae family to eradicate mosquitoes and its larvae.

Keywords: *Citrus* species; LC_{50}; mosquito larvicide; rutaceae

Introduction

Mosquitoes are the primary carriers of different diseases with high mortality rates. According to recent studies, vector-borne diseases cause an intimidating effect that causes more than 700000 deaths annually (1). Each year, over 0.5 billion and 0.96 billion individuals contract malaria and dengue, respectively, with mortality rates exceeding 4 lakh and 0.25 lakh, while lymphatic filariasis affects 0.1 billion people annually (2). The range and severity caused by mosquitoes continue to grow and thus can be considered a global issue. The insecticides used to eliminate them are causing additional problems, such as heavy metal deposition, which later leads to complications like cancer, reproductive disorders and respiratory and neurological conditions (3). Moreover, insecticide-resistant mosquitoes are an alarming issue that can't be controlled (4).

In this instance, substitutes to control mosquitoes have been developed with an almost 100 % death rate. Essential oils are a class of secondary metabolites produced by plants and can be extracted from their leaves, peels, bark and seeds (5). These aromatic oils are 100 % cost-effective, environmentally friendly and have mosquito larvicidal properties. It is proven that the plants from the rutaceae family have aromatic oils which can be extracted from different parts and act as an efficient mosquito larvicide (5). Due to the strong demand for *Citrus* fruits, which produce a significant amount of essential oils, their waste can be repurposed into valuable products such as insecticides or animal feed (6, 7). In this manner, the least expensive and most efficient insecticide to eradicate mosquitoes can be designed. These essential oils interact with gaba and octopamine receptors, preventing insect resistance development, which is an added advantage (8) (Table 1).

Materials and Methods

Collection and isolation of essential oils

The plant parts were usually collected in the mornings to maximize the oil content, which can be reduced due to stress caused by sunlight, humidity and temperature. These can adversely affect the oil since diurnal variations influence the quality.

This present study found that the Clevenger and Soxhlet apparatus methods were widely used. While both are similar, they differ in the quality of essential oils produced-Soxhlet yields a higher quantity but lower quality, whereas Clevenger provides superior quality with a lower yield. The fresh peels were subjected to hydro-distillation using Clevenger apparatus: 50g (9) or 200g (10) at 70 - 100 °C for 3 hr (6). Anhydrous sodium sulfate was added to absorb the moisture content; thus, it can be stored in cold conditions for further usage (9, 10). Different solvents were also used in the soxhlet extraction method. Other than this, the process remains the same. The plant part was washed and dried in an

Table 1. Plants and their affected mosquito species

S.No	Plant species	Common name	Species
1	*Citrus aurantifolia*	Lime	*An. labranchiae, Cx. quinquefasciatus, A. albopictus, A. aegypti*
2	*Citrus aurantium*	Bitter orange	*An. stephensi, Cx. pipiens*
3	*Citrus hystrix*	Kaffir lime	*A. aegypti*
4	*Citrus limetta*	Musambi/ sweet lemon	*Cx. mimulus, A. albopictus, An. maculates*
5	*Citrus limon*	Lemon	*An. stephensi, Cx. pipiens, A. albopictus*
6	*Citrus paradisi*	Grape fruit	*An. stephensi, A. aegypti, A. albopictus*
7	*Citrus reticulata*	Mandarin orange	*A. albopictus, A. aegypti, Cx. pipiens*
8	*Citrus sinensis*	Sweet orange	*A. albopictus, Cx. tritaeniorhynchus, An. stephensi, An. labranchiae, A. aegypti, An. subpictus, Cx. pipens, Cx. quinquefasciatus*
9	*Citrus sinensis*	Valencia orange	*A. aegypti, Cx. pipiens*
10	*Citrus reticulata*	Mandarine	*A. aegypti, Cx. pipiens*
11	*Clausena excavate*	Pink lime berry	*A. aegypti, A. albopictus*
12	*Feronia limonia*	Wood apple	*A. aegypti, An. stephensi, Cx. quinquefasciatus*
13	*Chloroxylon swietenia*	Ceylon satin wood	*A. aegypti, An. stephensi*
14	*Ruta chalepensis*	Fringed rue	*A. aegypti, An. quadrimaculatus, A. albopictus*
15	*Swinglea glutinosa*	Tabog	*A. aegypti*
16	*Toddalia asiatica*	Wild orange tree	*A. albopictus*
17	*Zanthoxylum armatum*	Prickly ash	*A. aegypti, An. stephensi, Cx. quinquefasciatus*
18	*Zanthoxylum avicennae*	Prickly ash	*A. albopictus*
19	*Zanthoxylum limonella*	Prickly ash	*A. aegypti, An. dirus*
20	*Zanthoxylum oxyphyllum*	Prickly ash	*A. aegypti*

oven at 60 °C for 48 hr and then these dried parts were made to fine powder using an electric blender. This powder was loaded in the thimble of the Soxhlet apparatus for steam distillation using different solvents such as Di-ethyl ether (11, 12), ethanol (5) and methanol (13). The specifications include 4-5 hr cycle time and an extractor ID of 38 mm. The oil can be condensed by keeping it at room temperature (11) or using a rotary vacuum evaporator (13). Another method for oil extraction is the cold press method (8, 12, 14).

Calculation of LC_{50}

LC_{50} is the concentration required to kill 50 % of the test organisms and LD_{50} is the dose at which it kills 50 % of the test organisms. The percentage mortality was calculated using the formula:

(No. of dead larvae * 100)/(No. of larvae used) …(Eqn.1)

The mosquito larvae were collected and used for the test by being introduced to different essential oil concentrations and maintaining control for the cross-check. The number of deaths was noted in 24 hr, i.e., 24 and 48 hr. The larvae were not fed during the study and five replicates were conducted to verify the results (11).

Description

Since 21 components were separated from the leaves, 94.8 % are served by dl-limonene. The peel of *Citrus aurantium* included dl-limonene, β-myrcene and α-piene, while *C. paradisi* displays 35.7 ppm LC50, *C. aurantium* displays 31.2 ppm, *Anopheles stephensi's* LC_{90} readings were 35.71 ppm and 70.23 ppm, respectively (9). (Table 2, 3)

In contrast to *C. bergamia*, which contains 31.9 % of linalyl acetate, *C. limon, C. reticulata* and *C. sinensis* contain 52.8 %, 59.2 % and 88.8 % of limonene. In contrast to *C. sinensis*, which contains 96.1% monoterpene hydrocarbons, *C. bergamia* has 46.7 % monoterpene hydrocarbons and 50.9 % oxygenated chemicals such esters, aldehydes and alcohols. As mentioned earlier, the composition of linalool, c-terpinene, limonene, linalyl acetate and β-pinene varies among the species (8).

The mosquito larvicidal activity by the *Citrus* species is due to the presence of nomilin in varying concentrations; *C. sinensis* has 377 ppm and 21.2 ppm of limonin and nomilin, respectively, whereas *C. reticulata* have 5.3 ppm and 3.9 ppm of the same. Due to the toxicity of nomilin, the LC_{50} value is 121.04 ppm; that of limonin is 382.2 ppm after 72-hr exposure (11). (Table 4-6)

Table 2. Plants with affected mosquito species and their lethal concentration

S. No	Plant species	Mosquito species	Lethal concentration (LC_{50})
1.	*C. aurantium*	*An. stephensi*	31.20 ppm
2.	*C. paradisi*	*An. stephensi*	73.83 ppm
3.	*C. paradisi*	*A. aegypti*	47.3 ppm
4.	*C. paradisi*	*A. albopictus*	85.1 ppm

Table 3. Lethal concentration of *Citrus* extracts affecting *A. albopictus*

S. No	Plant species	Mosquito species	Lethal concentration (LC_{50})	Percentage mortality	Lt50 value
1.	*C. sinensis*	*A. albopictus*	297 ppm	97%	18.5 hr
2.	*C. reticulata*	*A. albopictus*	377.4 ppm	88%	31 hr

Table 4. *Citrus* extracts with solvents affected mosquitoes and lethal concentration

S. No	Plant species peel and extracted solvent	Mosquito species	Lethal concentration
1	*C. sinensis* + chloroform	*An. Stephensi*	LC50 = 58.3 ppm
2	*C. sinensis* + chloroform	*An. Stephensi*	LC90 = 298.3 ppm
3	*C. sinensis* + methanol	*Cx. tritaeniorhynchus*	LC50 = 38.2 ppm
4	*C. sinensis* + methanol	*Cx. tritaeniorhynchus*	LC90 = 184.7 ppm

Table 5. Plants with affected mosquito species and their LC_{50} and LC_{90} values

S. No	Mosquito species	Plant species	Lethal concentration (LC_{90})	Lethal concentration (LC_{50})
1	*An. labranchiae*	*C. aurantium*	83.8 ppm	160 ppm
2	*Cx. quinquefasciatus*	*C. aurantium*	351 ppm	179.8 ppm
3	*A. albopictus*	*C. aurantium*	-	322.4 ppm
4	*A. aegypti*	*C. hystrix*	-	30.1 ppm
5	*An. stephensi*	*C. limon*	138.9 ppm	35.95 ppm
6	*A. aegypti*	*C. reticulata*	-	15.4 ppm
7	*An. labranchiae*	*C. sinensis*	351.4 ppm	640 ppm
8	*An. subpictus*	*C. sinensis*	298.3 ppm	58.3 ppm
9	*An. stephensi*	*C. sinensis*	138.9 ppm	35.95 ppm
10	*A. aegypti*	*C. sinensis*	1371 ppm	85.9 ppm
11	*Cx. pipens*	*C. sinensis*	-	20-160 ppm

Table 6. *A. albopictus* with different citrus plants, specific parts and time of exposure

S. No	Mosquito species	Plant species	Plant part		Time of exposure (hr)
			Seed	Peel	
1	*A. albopictus*	*C. limon*	395.6 ppm	468.7 ppm	24
2	*A. albopictus*	*C. limon*	247.2 ppm	392.2 ppm	48
3	*A. albopictus*	*C. sinensis*	906 ppm	1009.4 ppm	24
4	*A. albopictus*	*C. sinensis*	759.8 ppm	1041.5 ppm	48

The oil from savage citrange has great efficacy against Aedes albopictuseven after 72 hr, while Cassa grande and Fairchild had the lowest efficiency, according to Faizal et al. Nomilin showed more toxicity than limonin. However, Fairchild and Carrizo citrange exhibited reduced efficiency after 48 hrs an Cassa grande and Carrizocitrange exhibited minimal efficiency after 72 hr (5) (Table 7).

Maximum efficacy was achieved in *C. sinensis* when 45 0 ppm of ethanol extract was placed; this provided total prote ction lasting for 150-180 min (14) (Table 8). Compared to *Aedes aegypti, C. aurantifolia* showed LC_{50} values of 128.8 ppm and 106.8 ppm for the peel and 188.6 ppm and 107.4 ppm for the leaf at 24 and 72 hr, respectively. They demonstrated 5.3 ppm and 17.7 ppm for peel and leaf against *A. aegypti* as an ovicidal property. The primary components of the leaf of *C. aurantifolia* were limonene and citral, while the peel included palatinol-1 c and limonene. 26 and 31 compounds were recovered from the peel and leaf, but the peel and leaf were packed with limonene and farnesol (15) (Table 9). At 43.3 %, 51. 5% and 35 % in *C. reticulata, C. reticulata* var *chinese* and *C. sinensis,* respectively, limonene was a vital factor (16). *C. sinensis, C. limon* and *C. paradisi* contain the most dangerous amount of γ-terpinene, LC_{50} 202 ppm. of these three species, *C. sinensis* has the highest larvicidal properties, at 28.7 ppm, followed by *C. limon* and *C. paradisi*, at 25 ppm and 37 ppm, respectively (6). z-β -ocimene, cis-naphthalenedecahydro and β -pinene are the main elements of *C. medica, C. grandis* and *C. sinensis,* respectively; α -pinene, which is found in all three, confers the larvicidal activity. with LC_{50} and LC_{95} values of 137 ppm and 342.5 ppm for larvae and 78.4 ppm and 126.1 ppm for nymph, respectively, *C. sinensis* has great efficacy in these, resulting in a good nymphocide (7). *C. sinensis* (L) *Osbeck* showed 21.5 ppm LC_{50}, or 100 % death (30 ppm), against *A. aegypti* after 24 hr, while r-limonene, one of its main components, showed LC_{50} of 27 ppm, or 100 % mortality (50 ppm). Paste complex made with ethanol and water displayed 23 ppm LC_{50} at 50 ppm, or 93 % (17) (Table 10).

A lethal ester molecule called corynan-17-1,18,19-didehydro-10-methoxy-acelate is accountable for the larvicidal activity in *C. limetta*. The leaf methanolic extracts showed LC_{50} values of 15560 ppm, 13720 ppm and 11450 ppm, respectively. These values demonstrated greater larvicidal properties against *Cx. mimulus, An. maculates* and *A. aegypti* were determined at 79720 ppm, 86490 ppm and 88210 ppm. *A. albopictus, An. maculates* and *Cx. mimulus* had LC_{50}s for newly molted third instars of 15560 ppm, 13720 ppm and 11450 ppm, respectively; the peel hexane extract of *C. limetta* showed the most potent activity against *An. stephensi* (13, 18).

Table 7. Mosquito species with reference to instar stages, their pupicidal and larvicidal values

S. No	Mosquito species & Instar stages	Larvicidal (LC_{50})	Larvicidal (LC_{90})	Pupicidal
1	*An. stephensi*; 1st instar	182.2 ppm	452.4 ppm	LC50 = 490.8 ppm
2	2nd instar	227.9 ppm	544.7 ppm	
3	3rd instar	291.7 ppm	659.3 ppm	LC90= 987.3 ppm
4	4th instar	398 ppm	858.9 ppm	
5	*A. aegypti*; 1st instar	204.9 ppm	509.7 ppm	LC50 = 497.4 ppm
6	2nd instar	264.3 ppm	607 ppm	
7	3rd instar	342.5 ppm	735 ppm	LC90 = 938.1 ppm
8	4th instar	436.9 ppm	891.6 ppm	
9	*Cx. quinquefasciatus*; 1st instar	244.7 ppm	567 ppm	LC50 = 531 ppm
10	2nd instar	324 ppm	729.8 ppm	
11	3rd instar	385.3 ppm	806.6 ppm	LC90 = 967.2 ppm
12	4th instar	452.8 ppm	890.1 ppm	

Table 8. Plant parts, phytochemical composition, mosquitoes affected with lethal concentration

S. No	Plant species	Plant parts	Components	Mosquito species	LC_{50} (ppm)	LC_{90} (ppm)
1	*C. aurantium*	Fruits	Limonene	Cx. pipiens	39	79
2	*C. hystrix*	Peel	terpinene-4-ol, D – limonene, β – pinene	A. aegypti	30	51
3	*C. limon*	Fruits	Limonene	Cx. pipiens	30	78
4	*C. reticulata*	Peel	γ- terpinene, D – limonene	A. aegypti	15	36
5	*C. sinensis*	Aerial parts	Limonene	*A. aegypti*	20	99
6				*Cx. pipiens*	51	73
7	*Clausena excavate*	Leaves	Terpinolene	*A. aegypti*	37	110
8				*A. albopictus*	41	116
9	*Feronia limonia*	Leaves	β – pinene, estragole	*An. stephensi*	15	36
10				*A. aegypti*	11	42
11				*Cx. quinquefasciatus*	22	60
12	*Chloroxylon swietenia*	Leaves	Limonene, geijerene, germacrene D	*A. aegypti*	16	14
13				*An. stephensi*	28	22
14	*Ruta chalepensis*	Aerial parts	2- nonanone, 2- undecanone	*A. aegypti*	22	36
15				*An. quadrimaculatus*	15	42
16				*A. albopictus*	35	67
17	*Swinglea glutinosa*	Aerial parts	Piperitenone, α – pinene, β - pinene	*A. aegypti*	65	151
18	*Toddalia asiatica*	Roots	D- limonene, geraniol, isopimpinellin, 4- vinylguaiacol, α – gurjunene	*A. albopictus*	69	110
19	*Zanthoxylum armatum*	Seeds	Limonene, linalool	*A. aegypti*	54	171
20				*An. stephensi*	58	183
21				*Cx. quinquefasciatus*	49	146
22	*Zanthoxylum avicennae*	Aerial parts	1, 8- cineole	*A. albopictus*	48	141
23	*Zanthoxylum limonella*	Fruits	Terpinene-4-ol, D- limonene	*A. aegypti*	24	55
24				*An. dirus*	57	76
25	*Zanthoxylum oxyphyllum*	Leaves	Methyl nonyl ketone, methyl heptyl ketone	*A. aegypti*	7	Not determined

Table 9. Mosquitoes with different citrus plants, time of exposure and lethal concentration

S. No	Mosquito species	Plant species	Time of exposure (Hours)	Lethal concentration (LC_{50})
1.	*Cx. pipiens*	*C. reticulata*	24	32.8 ppm
2.		*C. reticulata*	48	20.5 ppm
3.		*C. reticulata chinase*	24	16.1 ppm
4.		*C. reticulata chinase*	48	13.2 ppm
5.		*C. sinensis*	24	15.4 ppm
6.		*C. sinensis*	48	12.5 ppm

Table 10. Mosquitoes with different *Citrus* plants, specific parts and lethal concentration

S. No	Plant species	Plant part	Mosquito species	Lethal concentration (LC_{50})
1	*C. hystrix*	Fruit	*A. aegypti*	30.1 ppm
2	*C. reticulata*	Fruit	*A. aegypti*	15.4 ppm
3	*C. sinensis*	Fruit	*A. aegypti*	11.9 ppm
4	*Clausena excavate*	Twig	*A. albopictus*	41.1 ppm
5	*Clausena excavate*	Leaf	*A. albopictus*	41.2 ppm
6	*Ruta chalepensis*	Leaf	*A. albopictus*	33.2 ppm
7	*Toddalia asiatica*	Root	*A. albopictus*	69.1 ppm

Results and Discussion

The *Citrus* family is one of the most important and widely distributed families in Asian countries and it has high mosquito larvicidal activity. It was understood that a high amount of *Citrus* fruit waste is dumped worldwide, since it is highly used for juices, canned drinks, wines and much more. These wastes can be reused in such a way that it can be helpful for human welfare and society. Mosquitoes are an important and devastating problem all over the globe, especially in developing countries. Hence, reusing these waste products is an efficient mechanism to minimize the cost-effectiveness and healthiness of mosquitoes. *Anopheles,* which is a malarial vector, *Aedes,* the dengue vector; and the *Culex,* which is a Japanese encephalitis vector, are included in this review. These three genera fall under the Diptera order and the Culicidae family. *Aedes* mosquito widely spread yellow fever, dengue and chikungunya, but the efficient discovery of the yellow fever vaccine made the scenario less problematic. In this review, 20 *Citrus* species are taken into account.

The literature showed that *C. sinensis* is mostly studied and used because the nomilin, a good larvicide agent, is present in high amounts in this plant. Limonene is another important compound found in almost all *Citrus* species in relatively higher amounts. Corynan-17-1,18,19-didehydro-10-methoxy-acelate is an ester molecule known for its larvicidal activities against *Anopheles, Aedes* and *Culex,* which is found in *C. limetta*. The LC_{50} values of *C. paradisi, C. aurantium, C. sinensis, C. limon, Feronia limonia* (L.) Swingle, *Chloroxylon swietenia* DC, *Ruta chalepensis L, Zanthoxylum armatum DC* and *Zanthoxylum limonella Alston* against *Anopheles* species are 73.8 ppm, 31.2 ppm, 58.3 ppm, 36 ppm, 15 ppm, 28 ppm, 15 ppm, 58 ppm, 57 ppm respectively.

The LC_{50} values of *C. paradisi, C. limon, C. reticulata, C. sinensis, C. aurantium, C. hystrix, C. reticulata Blanco, C. sinensis Osbeck, Clausena excavate Burm, Feronia limonia* (L) Swingle*, Chloroxylon swietenia* DC*, Ruta chalepensis* L*, Swinglea glutinosa* (Blanco) Merr*, Toddalia asiatica* (L) Lam*, Zanthoxylum armatum* DC*, Zanthoxylum avicennae* (Lam.) DC*, Zanthoxylum limonella Alston* and *Zanthoxylum oxyphyllum Edgew* against *Aedes* species are 85 ppm, 145 ppm, 318 ppm, 297 ppm, 322 ppm, 30 ppm, 15 ppm, 20 ppm, 41 ppm, 11 ppm, 16 ppm, 22 ppm, 65 ppm, 69 ppm, 54 ppm, 48 ppm, 24 ppm and 7 ppm respectively.

The LC_{50} values of *C. sinensis, C. aurantium, C. limon, Citrus sinensis* (L.) *Osbeck, Feronia limonia* (L) *Swingle, Zanthoxylum armatum* DC*, C. reticulata and C. reticulata Chinase* against *Culex* species are 38 ppm, 180 ppm, 30 ppm, 51 ppm, 22 ppm, 49 ppm, 33 ppm and 16 ppm respectively. From these values, it is well understood that the *Citrus* species can be used as an efficient mosquito larvicide.

The *A. albopictus* showed 97 % and 88 % mortality against *Citrus sinensis* and *Citrus reticulata,* exhibiting 297 ppm and 377.4 ppm lethal concentrations (LC_{50}). The LT_{50} values calculated were 18.5 hr and 31 hr for *C. sinensis* and *C. reticulata*, respectively. Since Clevenger is used frequently and produces high-quality oils, temperature control is a constraint; however, Soxhlet produces a higher yield with less amount, raising concerns about time consumption. There was no data regarding the age of the plant part collected for the study. Since the age of the plant part is related to the chemicals produced, their concentration and intensity vary depending on the part and the age. Regarding the disparity in mortality between males and females, no data exist. Since males feed on plant sap and females usually spread illness, there may be differences in the likelihood of killing a certain gender.

Conclusion

In conclusion, *Citrus* species (Rutaceae) exhibit significant mosquito larvicidal properties, highlighting their potential as eco-friendly alternatives to synthetic insecticides. Their bioactive compounds effectively target mosquito larvae, reducing vector populations. Further research on formulation, safety and field efficacy is essential to develop sustainable, plant-based larvicides for mosquito control programs.

Compliance with ethical standards

Conflict of interest: No conflict of interest among authors.

Ethical issues: None

References

1. Naik BR, Tyagi BK, Xue R-D. Mosquito-borne diseases in India over the past 50 years and their global public health implications: A systematic review. J Am Mosq Control Assoc. 2023;39(4):258-77. https://doi.org/10.2987/23-7131
2. Manikandan S, Mathivanan A, Bora B, Hemaladkshmi P, Abhisubesh V, Poopathi S. A review on vector borne disease transmission: Current strategies of mosquito vector control. Indian J Entomol. 2023:503-13. https://doi.org/10.55446/IJE.2022.593
3. Rani L, Thapa K, Kanojia N, Sharma N, Singh S, Grewal AS, et al. An extensive review on the consequences of chemical pesticides on human health and environment. J Clean Prod. 2021;283:124657. https://doi.org/10.1016/j.jclepro.2020.124657
4. Pavela R. Essential oils for the development of eco-friendly mosquito larvicides: a review. Ind Crop Prod. 2015;76:174-87. https://doi.org/10.1016/j.indcrop.2015.06.050
5. Hafeez F, Akram W, Shaalan EA-S. Mosquito larvicidal activity of citrus limonoids against *Aedes albopictus*. Parasitol Res. 2011;109:221-9. https://doi.org/10.1007/s00436-010-2228-9
6. Giatropoulos A, Papachristos DP, Kimbaris A, Koliopoulos G, Polissiou MG, Emmanouel N, et al. Evaluation of bioefficacy of three *Citrus* essential oils against the dengue vector Aedes albopictus (Diptera: Culicidae) in correlation to their components enantiomeric distribution. Parasitol Res. 2012;111:2253-63. https://doi.org/10.1007/s00436-012-3074-8
7. Akono PN, Mbida JAM, Dongmo PMJ, Tonga C, Tchamga LAD, Mounbain F, et al. Chemical composition and insecticidal activity of essential oils of *Cinnamomum zeylanicum*, *Citrus grandis*, *Citrus medica* and *Citrus sinensis* leaves from Cameroon on *Anopheles gambiae* Giles, 1902. J Entomol Zool Stud. 2016;4(6):17-23.
8. Campolo O, Romeo FV, Algeri GM, Laudani F, Malacrinò A, Timpanaro N, et al. Larvicidal effects of four citrus peel essential oils against the arbovirus vector *Aedes albopictus* (Diptera: Culicidae). J Econ Entomol. 2016;109(1):360-5. https://doi.org/10.1093/jee/tov270
9. Sanei-Dehkordi A, Sedaghat MM, Vatandoost H, Abai MR. Chemical compositions of the peel essential oil of Citrus aurantium and its natural larvicidal activity against the malaria vector *Anopheles stephensi* (Diptera: Culicidae) in comparison with *Citrus paradisi*. J Arthropod Borne Dis. 2016;10(4):577-585.
10. El-Akhal F, Lalami AEO, Guemmouh R. Larvicidal activity of essential oils of *Citrus sinensis* and *Citrus aurantium* (Rutaceae) cultivated in Morocco against the malaria vector *Anopheles labranchiae* (Diptera: Culicidae). Asian Pac J Trop Dis. 2015;5(6):458-62. https://doi.org/10.1016/S2222-1808(15)60815-5
11. Sarma R, Adhikari K, Mahanta S, Khanikor B. Insecticidal activities of *Citrus aurantifolia* essential oil against *Aedes aegypti* (Diptera: Culicidae). Toxicol Rep. 2019;6:1091-6. https://doi.org/10.1016/j.toxrep.2019.10.009
12. Galvão J, Silva V, Ferreira S, França F, Santos D, Freitas L, et al. β-cyclodextrin inclusion complexes containing *Citrus sinensis* (L.) Osbeck essential oil: An alternative to control *Aedes aegypti* larvae. Thermochim Acta. 2015;608:14-9.
13. Bilal H, Akram W, Ali-Hassan S. Larvicidal activity of *Citrus limonoids* against *Aedes albopictus* larvae. J Arthropod Borne Dis. 2012;6(2):104-111.
14. Sadr-ud-Din, Akram W, Khan HAA, Hussain A, Hafeez F. Citrus waste-derived essential oils: alternative larvicides for dengue fever mosquito, *Aedes albopictus* (Skuse) (Culicidae: Diptera). Pakistan J Zool.2011;43(2):367-372.
15. Baranitharan M, Krishnappa K, Elumalai K, Pandiyan J, Gokulakrishnan J, Kovendan K, et al. *Citrus limetta* (Risso)-borne compound as novel mosquitocides: Effectiveness against medical pest and acute toxicity on non-target fauna. S Afr J Bot. 2020;128:218-24. https://doi.org/10.1016/j.sajb.2019.11.014
16. Murugan K, Mahesh Kumar P, Kovendan K, Amerasan D, Subrmaniam J, Hwang JS. Larvicidal, pupicidal, repellent and adulticidal activity of *Citrus sinensis* orange peel extract against *Anopheles stephensi, Aedes aegypti* and *Culex quinquefasciatus* (Diptera: Culicidae). Parasitol Res. 2012;111:1757-69. https://doi.org/10.1007/s00436-012-3021-8
17. Badawy MEI, Taktak NEM, El-Aswad AF. Chemical composition of the essential oils isolated from peel of three citrus species and their

mosquitocidal activity against *Culex pipiens*. Nat Prod Res. 2018;32 (23):2829-34. https://doi.org/10.1080/14786419.2017.1378216

18. Osanloo M, Sedaghat MM, Sanei-Dehkordi A, Amani A. Plant-derived essential oils; their larvicidal properties and potential application for control of mosquito-borne diseases. Galen Medical Journal. 2019;8:e1532. https://doi.org/10.31661/gmj.v8i0.1532

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.