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ORIGINAL RESEARCH ARTICLE

Plant oils in the fight against the West Nile Vector, *Culex pipiens*

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Abstract

Controlling mosquitoes naturally and safely to avoid mosquito-borne diseases is an urgent need. Plant oils are a promising source for mosquito control. The larvicidal effects of 18 oils were evaluated against the early 4th larvae, *Culex pipiens*. All oils showed larvicidal activity (55 to 100%, 24 h post-treatment with 2000 ppm for 24 h). The efficacy of oils was classified as the highly effective group (H group) inducing 95-100% mortalities, including six oils: *Azadirachta indica, Cyperus alternifolius, Lupinus luteus*, *Lactuca sativa, M. alternifolia,* and *Persea americana* (MO% = 98.33, 100, 98.33, 98.33, 100, and 95%, respectively). Their LC_{50} values were 588.31, 496.96, 677.45, 611.60, 445.28, and 646.34 ppm, respectively; whereas their LC_{99} values were 1601.14, 1331.06, 1953.29, 1667.27, 1342.56, and 1725.94 ppm, respectively. The moderately effective group (83-93% mortalities) included *Syzygium aromaticum, Capsicum annuum, Aloe vera, Nigella sativa, Phyllanthus emblica, Citrullus colocynthis, Daucus carota, Carthamus glaucus*, *Ocimum basilicum*, and *Triticum aestivum*. Their LC_{50} values ranged from 762.39 (*S. aromaticum*) to 1043.59 ppm (*T. aestivum*). The least effective group included *P. armeniaca* (55%) and *Allium cepa* (78%). The novel larvicidal activity of seven oils (*C. glaucus, C. alternifolius, D. carota, L. sativa, M. alternifolia, P. armeniaca* and *T. aestivum*) against larvae of *Cx. pipiens* was reported for the first time in this investigation. Our findings demonstrate the potential of *M. alternifolia,* and *C. alternifolius* followed by *A. indica, L. luteus,* or *L. sativa* as the most potent larvicides that could be used for integrated mosquito control programs.

Keywords *Cyperus* · Neem · Lupine · Avocado · Lettuce · *Culex pipiens*

Introduction

Mosquitoes transmit dangerous parasites and viruses that infect millions of people and animals mainly in the subtropical and tropical areas (Korgaonkar et al. 2012; Shaukat et al. 2019; Anoopkumar and Aneesh 2021); expanding the geographic distribution of mosquitoes resulted in the emergence of pathogens and diseases in new regions adversely affecting health security and socioeconomic levels all over the globe (Anoopkumar and Aneesh 2021).

Culex pipiens (Diptera: Culicidae) is the most common mosquito in rural and urban areas (Zahran et al. 2017). It is the main vector of filariasis and transmits many viral diseases including Japanese encephalitis, Saint Louis encephalitis, and West Nile fever (Chancey et al. 2015).

Mosquitoes are controlled via repellents (Khater et al. 2019) and synthetic chemical pesticides such as pyrethroids, organophosphates, etc. (Benelli 2015; Baz et al. 2021), which are still used in large quantities until the present time resulting in insecticide resistance in mosquito vectors (Smith et al. 2016) along with adverse effects on non-target species, including humans (Koureas et al. 2012; Pavela 2015).

Searching for safe and eco-friendly alternatives is essential for public health. Botanicals possess parasiticidal (Seddiek et al. 2014; Abbas et al. 2020; Khater et al. 2020) and insecticidal effects as ovicidal, adulticidal (Khater et al. 2014; Khater and Geden 2019); larvicidal (Khater 2014; Murugan et al. 2016; Alkenani et al. 2021; Rudayni et al.

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2021; de Oliveira et al. 2022), deterrents and repellents (Khater et al. 2018, 2019; Khater and Geden 2018, 2019).

Essential oils (EOs) were used science ancient civilizations (Khater 2017) are potential alternatives to synthetic insecticides, have no or little effects on non-target organisms, and are available in many parts of the world (Khater, 2013; Roni et al. 2015; Govindarajan et al. 2016a, b; Ahmed et al. 2021; Iqbal et al. 2021). Their popularity among organic farmers, as well as environmentally aware consumers, has considerably increased the interest in plant-based insecticides (Ahmed et al. 2021; Iqbal et al. 2021).

It was noted that mosquito populations may be less resistant to plant oils that include combinations of active components because they act on insects at various target locations or with diverse mechanisms of action (Khater 2012, 2013; Benelli 2015; Ahmed et al. 2021; Iqbal et al. 2021). Currently, plant-based insecticides make up <1% of the world's pesticide market and they are highly demanded eco-friendly control of mosquito-borne diseases (Senthil-Nathan 2020). In the present work, 18 commercial plant oils were evaluated as eco-friendly insecticides against *Cx. pipiens* larvae and determining their lethal concentration values and relative toxicities.

Materials and methods

Plant oils

Eighteen oils were purchased from two companies as follows, 11 oils from EL CAPTAIN Company for extracting natural oils, plants, and cosmetics "Cap Pharm" El Obor, Cairo, Egypt, and seven oils from Harraz for Food Industry & Natural products, Cairo, Egypt (Table 1).

Culex pipiens

Mosquito larvae, *Cx. pipiens* were provided from the insecurity of Medical, and Molecular Entomology Section, Entomology Department, Faculty of Science, Benha University, Egypt and maintained at 27 + 2°C, 75-85% RH and 4: 10 h (L/D) photoperiod (Baz 2013).

Larvicidal efficacy

Eighteen oils were screened for their larvicidal efficacy (WHO 2017) against the early fourth instar larvae, *Cx. pipiens*. Oils were added to a solvent consisting of dechlorinated water plus 5% tween 20. Twenty larvae were placed in a 500 mL glass beaker containing 250 mL of each oil concentration (125, 250, 500, 1000, and 2000 ppm) for each oil. The control group was treated with the solvent only. The experiment was replicated three times. Larval mortality (MO) for each oil concentration was recorded 24 h post-treatment (PT).

Table 1 Plants oils used as larvicides against 4th larval mosquito, *Culex pipiens*

Latin Name	Order	Family Name	Common Name
*Allium cepa**	Asparagales	Amaryllidaceae	Onion
*Aloe vera***	Asparagales	Asphodeloideae	Aloe vera
*Azadirachta indica**	Sapindales	Meliaceae	Neem
*Carthamus glaucus***	Asterales	Asteraceae	Cactus
*Capsicum annuum***	Solanales	Solanaceae	Chilli
*Citrullus colocynthis**	Cucurbitales	Cucurbitaceae	Bitter apple
*Cyperus alternifolius***	Poales	Cyperaceae	Cyperus
*Daucus carota**	Apiales	Apiaceae	Red Carrot
*Lactuca sativa**	Asterales	Asteraceae	Lettuce
*Lupinus luteus***	Fabales	Fabaceae	Lupine
*Ocimum basilicum**	Lamiales	Lamiaceae	Basil
*Nigella sativa**	Ranunculales	Ranunculaceae	Black cumin
*Melaleuca alternifolia**	Myrtales	Myrtaceae	Tree tea
*Persea americana***	Laurales	Lauraceae	Avocado
*Phyllanthus emblica***	Malpighiales	Phyllanthaceae	Myrobalan
*Prunus armeniaca**	Rosales	Rosaceae	Apricot
*Syzygium aromaticum**	Myrtales	Myrtaceae	Cloves
*Triticum aestivum***	Poales	Poaceae	Common wheat

*Plant oils purchased from El Captain Company for extracting natural oils, plants, and cosmetics "Cap Pharm"; **Plant oils purchased from Harraz Company for Food Industry & Natural products

Statistical analysis

Analyses of data were done using the one-way analysis of variance (ANOVA), Duncan's multiple range tests, as well as the Probit analysis, to calculate the lethal concentration (LC) values via the computer program PASW Statistics 2009 (SPSS version 22). The relative efficacies (RE) were calculated (Khater and Geden 2018) according to this formula: RE= LC_{50} (LC_{90}, LC_{95}, or LC_{99}) for *Prunus armeniaca*, the reference oil/ LC_{50} (LC_{90}, LC_{95}, or LC_{99}) for Essential oil.

Results

The larvicidal effect of 18 oils was evaluated against the early 4th larvae of *Cx. pipiens*. PT with 2000 ppm for 24 h, all plant oils had larvicidal activity (55 to 100%) (Table 2), and their lethal concentration 50 (LC_{50}) values ranged from 445.28 (*Melaleuca alternifolia*) to 1657.40 ppm (*P. armeniaca*) (Table 3).

The efficacy of oils could be classified as the highly effective group (H group) inducing 95-100% mortalities, including six oils: *Azadirachta indica, Cyperus alternifolius, Lupinus luteus*, *Lactuca sativa, M. alternifolia,* and *Persea americana* (MO% = 98.33, 100, 98.33, 98.33, 100, and 95%, respectively) (Table 2). Their LC_{50} values were 588.31, 496.96, 677.45, 611.60, 445.28, and 646.34 ppm, respectively; whereas their LC99 values were 1601.14, 1331.06, 1953.29, 1667.27, 1342.56, and 1725.94 ppm, respectively. *P. armeniaca* was the least effective oil and was considered as the reference oil. The RE of such oils according to LC_{50} values were 2.8, 3.3, 2.4, 2.7, 3.7, and 2.6 times, respectively, then *P. armeniaca*; whereas the those according to LC99 were 2.6, 3.2, 2.2, 2.5, 3.1, and 2.4 times, respectively, than *P. armeniaca* (Table 3).

The moderately effective group (M group) contained ten oils resulted in 83-93% mortalities including *Aloe vera, Capsicum annuum, Carthamus glaucus*, *Citrullus colocynthis, Daucus carota, Nigella sativa, Ocimum basilicum*, *Phyllanthus emblica, Syzygium aromaticum,* and *Triticum aestivum* and their mortality %, PT with 2000 ppm, were 90.00, 88.30, 90.00, 90.00, 90.00, 86.67, 90.00, 90.00, 93.33, and 83.33%, respectively (Table 2). Their LC_{50} values ranged from 762.39 (*S. aromaticum*) to 1043.59 ppm (*T. aestivum*) and their LC_{99} values ranged from 1897.90 to 2791.73, respectively (Table 3).

The RE of the M group according to their LC_{50} values were 1.9, 2.0, 1.8, 1.9, 1.9, 2.0, 1.8, 1.9, 2.2, and 1.6 times than *P. armeniaca*, respectively, whereas those of LC_{99} values were 1.8, 2.0, 1.6, 1.8, 1.7, 1.9, 1.6, 1.7, 2.2, and 1.5 times than *P. armeniaca*, respectively. The least effective group (L group) included only two oils, *P. armeniaca* and *Allium cepa* inducing 78.33 and 55.00 % mortalities, respectively (Tables 3).

Table 2 Larval mortality (%) of plant oils used against 4th larval mosquito, *Culex pipiens* after 24 h

Oil	Concentration (ppm)						Grouping
	0	125	250	500	1000	2000	
*Allium cepa**	00±00aF	8.33±1.67deE	16.67±1.67fD	30.00±2.89hC	53.33±7.26fB	78.33±4.41hA	L
*Aloe vera***	1.67±1.67aF	11.67±1.67cdE	20.00±2.89defD	38.33±1.67gC	70.00±2.89cB	90.00±2.89deA	M
*Azadirachta indica**	00±00aF	16.67±1.67abE	35.00±2.89abD	60.00±7.64bC	85.00±2.89aB	98.33±1.67abA	H
*Carthamus glaucus***	00±00aF	8.33±1.67deE	23.33±1.67cdD	40.00±2.89fgC	63.33±4.41eB	88.33±3.33efA	M
*Capsicum annuum***	00±00aF	8.33±1.67deE	16.67±3.33fD	48.33±7.26dC	75.00±2.89bB	90.00±5.77deA	M
*Citrullus colocynthis**	00±00aF	13.33±1.67bcE	25.00±2.89cD	46.67±1.67deC	66.67±6.01deB	90.00±2.89deA	M
*Cyperus alternifolius***	1.67±1.67aF	16.67±1.67abE	31.67±4.41bD	55.00±2.89cC	83.33±3.33aB	100.00±0.00aA	H
*Daucus carota**	1.67±1.67aF	11.67±1.67cdE	23.33±4.41cdD	43.33±4.41efC	65.00±5.77deB	90.00±2.89deA	M
*Lactuca sativa**	00±00aF	10.00±2.89cdE	21.67±1.67deD	55.00±2.89cC	75.00±2.89bB	98.33±1.67abA	H
*Lupinus luteus***	00±00aF	10.00±0.00cdE	25.00±0.00cD	43.33±3.33efC	78.33±1.67bB	98.33±1.67abA	H
*Ocimum basilicum**	1.67±1.67aF	10.00±2.89cdE	20.00±2.89defD	38.33±4.41gC	65.00±7.64deB	86.67±4.41fgA	M
*M. alternifolia**	00±00aF	20.00±2.89aE	36.67±4.41aD	65.00±5.77aC	85.00±2.89aB	98.33±1.67abA	H
*Nigella sativa**	00±00aF	10.00±2.89cdE	21.67±1.67deD	43.33±3.33efC	68.33±1.67cdB	90.00±2.89deA	M
*Persea americana***	00±00aF	16.67±1.67abE	31.67±4.41bD	58.33±6.01bcC	85.00±5.77aB	95.00±2.89bcA	H
*Phyllanthus emblica***	00±00aF	10.00±2.89cdE	18.33±3.33efD	38.33±4.41gC	68.33±6.01cdB	90.00±2.89deA	M
*Prunus armeniaca**	00±00aF	5.00±0.00eE	8.33±1.67gD	25.00±2.89iC	36.67±1.67gB	55.00±2.89iA	L
*Syzygium aromaticum**	1.67±1.67aF	11.67±1.67cE	25.00±2.89cD	40.00±2.89fgC	76.67±4.41bB	93.33±4.41cdA	M
*Triticum aestivum***	0±0aF	6.67±1.67eE	16.67±4.41fD	33.33±1.67hC	58.33±3.33fB	83.33±1.67gA	M

a, b & c: There is no significant difference (P>0.05) between any two means, within the same column that has the same superscript letter, while A, B & C: There is no significant difference (P>0.05) between any two means for the same attribute, within the same row have the same superscript letter (Numbers of the same column followed by the same small letter are not significantly different (one-way ANOVA, Duncan's MRT, P>0.05); H: The highly effective (95-100% mortalities), 6 oils; M: The moderately effective group (81-92% mortalities), 10 oils; L.: The moderately effective group, includes the rest of the oils, 2 oils

[a]Mean value of three replicates

Table 3 Lethal time values of applied oils against *Culex pipiens* larvae

Oil name	LC_{50} (LCL–UCL)	RE	LC_{90} (LCL–UCL)	RE	LC_{95} (LCL–UCL)	RE	X^2 (Sig)	Equation (R^2)
Allium cepa	1142.63 (810.60- 1739.67)	1.5	2160.34 (1301.96-3328.68)	1.4	2516.82 (1866.40-4332.54)	1.4	12.99 (0.011)[a]	Y=1.24 +1.09 E-3x (0.937)
Aloe vera	851.50 (474.40-1423.82)	1.9	1724.81 (1217.24- 3508.39)	1.8	1941.83 (1391.97- 4135.21)	1.8	19.53 (0.001)[a]	Y=0.95 + 1.19 E-3x (0.935)
Azadirachta indica	588.31 (37.94-2624.39)	2.8	1189.95 (746.57-10394.35)	2.4	1488.86 (909.46-13328.12)	2.3	42.90 (.000)[a]	Y= -0.73+1.32 E-3x (0.887)
Capsicum annuum	809.85 (390.79- 1742.06)	2.0	1615.60 (1079.42- 4476.75)	1.9	1844.02 (1229.06-5297.58)	1.9	31.55 (0.000)[a]	Y=-1.13 + 1.35 E-3x (0.864)
Carthamus glaucus	902.81 (570.35-1491.00)	1.8	1813.09 (1307.07-3418.82)	1.7	2071.14 1485.47-3995.75)	1.7	18.05 (0.001)[a]	Y=1.13 + 1.24E-3x (0.918)
Citrullus colocynthis	908.26 (547.32-1374.67)	1.9	1705.30 (1241.48- 3093.55)	1.8	1976.55 (1410.36- 3608.73)	1.8	17.20 (0.002)[a]	Y=1.1 + 1.28 E-3x (0.940)
Cyperus alternifolius	496.96 (374.28-678.21)	3.3	956.45 (750.27-1452.24)	3.2	1086.71 (845.05-1683.47)	3.2	10.27 (.036)[a]	Y=-1.17 +2.37 E-3x (0.973)
Daucus carota	873.56 (570.70- 1387.52)	1.9	1714.52 (1255.66- 3055.89)	1.8	1992.92 (1423.35- 3555.33)	1.7	16.92 (.002)[a]	Y=0.1.17 +1.32 E-3x (0.938)
Lactuca sativa	677.45 (142.73- 1638.14)	2.4	1344.36 (852.80-5649.91)	2.3	1556.10 (986.03-6855.260	2.2	33.75 (0.000)[a]	Y=0.71 + 1.28 E-3x (0.906)
Lupinus luteus	611.60 (397.97-1020.80)	2.7	1165.61 (843.33- 2321.07)	2.6	1322.66 (949.61-2709.66)	2.6	17.21 (0.002)[a]	Y= -1.26+ 2.06 E-3x (0.855)
Melaleuca alternifolia	445.28 (262.68-731.38)	3.7	939.58 (678.97-1936.50)	3.3	1079.71 (772.59- 2302.53)	3.2	18.43 (0.001)[a]	Y=0.86 +2.03E-3x (0.928)
Nigella sativa	843.32 (509.75- 1438.14)	2.0	1704.32 (1213.72- 3362.86)	1.8	1928.41 (1381.14-3940.64)	1.8	19.82 (.001)[a]	Y=1.08 +1.28 E-3x (0.922)
Ocimum basilicum	932.50 (607.21- 1493.82)	1.8	1858.81 (1356.16- 3356.57)	1.6	2121.41 (1539.70- 3913.40)	1.6	16.74 (.002)[a]	Y=1.13 +1.21 E-3x (0.931)
Persea Americana	646.34 (388.65-1178.38)	2.6	1241.08 (872.55- 2774.22)	2.5	1409.68 (984.77-3251.58)	2.5	21.51 (.000)[a]	Y=1.15 + 1.71 E-3x (0.953)
Phyllanthus emblic	850.97 (532.28- 1397.19)	1.9	1744.52 (1258.97- 3260.86)	1.8	1997.83 (1434.53- 3819.63)	1.7	17.32 (0.002)[a]	Y=1.04 +1.23 E-3x (0.942)
Prunus armeniaca	1657.40 (1153.55- 3289.95)	1.0	3061.11 (2124.26- 7134.42)	1.0	3459.04 (2377.51-8246.20)	1.0	14.34 (.006)[a]	Y= -1.47+ 8.85 E-3x (0.853)
Reference oil: *Prunus armeniaca*								
Syzygium aromaticum	762.39 (673.75-870.65)	2.2	1387.93 (1226.01-1619.35)	2.2	1565.26 (1377.30-1836.87)	2.2	6.75 (0.150)[a]	Y=1.38 + 1.78 E-3x (0.994)
Triticum aestivum	1043.59 (714.14-1624.23)	1.6	2006.68 (1484.17-3490.14)	1.5	2279.73 (1676.47- 4045.08)	1.5	15.55 (0.004)[a]	Y=1.29 +1.22 E-3x (0.919)

Control:0% mortality rate. Significant at P<0.05 level; LC_{50} lethal concentration that kills 50% of the exposed larvae, LC_{90} lethal concentration that kills 90% of the exposed larvae, Upper Confidence Limit (UCL), Lower Confidence Limits (LCL), RE: Relative efficacy, χ^2: chi-square

Discussion

Mosquitoes are carriers of several diseases that cause significant health problems and the development of resistance to chemical pesticides has led to a search for alternative control methods. The data of the present work indicated that all oils had varying toxicity levels against mosquito larvae, with mortalities increasing as the concentrations increased, with no larval death in the control group.

This study highlighted the lethal potential of 18 plant oils, including seven novel oils; *Carthamus glaucus, C. alternifolius, D. carota, L. sativa, M. alternifolia, P. armeniaca*, and *T. aestivum* against *Cx. pipiens* 4th instar larvae. Oils were classified into three groups based on their mortality % PT with oils (2000 ppm) and discussed accordingly.

C. alternifolius and *M. alternifolia* were the most effective oils (H group) in the present work, recording 100% MO, followed by *A. indica, L. luteus*, *L. sativa*, and *P. Americana,* and their LC_{50} values were 496.96, 445.28588.31, 611.60, 677.45, and 646.34 ppm, respectively. *C. alternifolius* oil was a novel and highly effective oil in the present study. Essential oils originating from the Myrtaceae family, could be used as "green" mosquito repellents and/or complementing antimicrobials (An et al.

2020). Cyperus species were reported to have a long ancient history in folkloric medicine (Boulos 1983). This genus is famous for having various biological activities such as antimicrobial, anti-inflammatory, anti-allergy, gastroprotective, anti-malarial, and anti-diabetic (Sccftwartz et al. 1998; Raut and Gaikwad 2006), and this is attributed to the presence of a variety of chemical compounds such as quinones (Alves et al. 1992), flavonoids (Chau et al. 2013), and sesquiterpenes (Xu et al. 2008).

Similar to our finding, *Melaleuca spp.* was highly effective against *Aedes aegypti* larvae (Park et al. 2011). Tea tree oil, *M. alternifolia* oil has been shown to cause the loss of viability and impairment of glucose-dependent respiration of *Aedes albopictus* (Carson et al. 2006). *M. alternifolia* and its monoterpene components effectively treated parasites (Lam et al. 2020). Terpinen-4-ol was found to be the most abundant bioactive chemical element in the tea tree oil, *M. alternifolia* (Volpato et al. 2016).

The product was formulated based on *A. indica, M. alternifolia,* and *C. guianensis* oils at 12.5 % and 25 % concentrations controlled of the 3rd larvae stage of *Aedes aegypti* by causing lethal injuries and avoiding larval development (Torres et al. 2020). Tea tree leaves, *M. alternifolia* are used to control and expel many insect species (Williamson et al. 2007; Maguranyi et al. 2009; Callander and James 2012; Volpato et al. 2016; Dris et al. 2017).

Azadirachta indica is among the most effective plant oils in this study; different chemical extracts of *A. indica* were found to have a similar effect on *Cx. pipiens* larvae (Alouani et al. 2009; Anjali et al. 2012; Hasaballah and El-Naggar 2017).

In this study, *L. luteus* and *L. sativa* were classified as group H, and these oils are used for the first time against *Cx pipiens* larvae. Our finding agrees with a similar study indicated the larvicidal effect of alkaloids extracted from bitter lupin seeds, not oil, against *Musca domestica*, *Cx. pipiens*, and fleas, *Xenopsylla cheopis* under laboratory conditions and found that methanol extract of alkaloids was more efficient against *Cx. pipiens* larvae than aqueous extract of alkaloids, with LC_{50} and LC_{90} values of 0.79 and 1.17 mg/ml, respectively (HASSAN et al. 2019). The seeds of the bitter lupin (*Lupinus luteus*) are used as potential natural pesticide sources (Bermúdez-Torres et al. 2009) Although some gramine alkaloids are identified in *L. luteus*, the main alkaloids found in lupin are from the quinolizidine family (Prusinski 2015).

Our results indicated that *S. aromaticum, C. annuum, A. vera, N. sativa, P. emblica, C. colocynthis, D. carota, C. glaucus, O. basilicum*, and *T. aestivum* were classified as M-grouped oils (83.3 - 93.3% MO). While *P. armeniaca*, and *Allium cepa* was the least effective group.

O. basilicum induced 86.67 % MO (LC50 =932.50) in this study. A similar finding was reported as the ethanol extract of *O. basilicum* leaves had larvicidal effect against mosquito larvae of *Anopheles. arabiensis* and *Culex. quinquefasciatus* (LC50 =17.78 and 16.98 ppm, respectively). In addition, flowers' ethanol extract had a similar effect (LC50= 15.48 ppm and 15,84 ppm, respectively). *O. basilicum* leaf extract had flavonoids, glycosides, tannins, and steroids whereas the flowers showed the presence of only tannins, terpenoids, steroids, and flavonoids (Rudayni et al. 2021).

Alike our findings, some other plants were effectivly controlled mosquito larvae. Plant oils, *Citrus aurantifolia* (LC_{50} = 13.49 mg/L) and *Cupressus macrocarpa* oils (LC_{50} = 22.93 mg/L) were highly effective, causing 73.3 and 52.0 % mortalities, respectively. The oils also caused pupal and adult mortality rates against *Cx. pipiens* (from 3.33 to 25%), respectively (El-Sabrout et al. 2020). Oil-resins as *Commiphora molmol*, *Araucaria heterophylla*, *Eucalyptus camaldulensis*, *Pistacia lentiscus*, and *Boswellia induced larvicidal effect against Cx pipiens* in Egypt. After treatment with 1500 ppm acetone extracts 24 and 48 h, the highest larval mortalities were recorded for *C. molmol* (83.3% and 100% and LC_{50}= 623.52 and 300.63 ppm) and *A. heterophylla* (75% and 95% and LC_{50}= 826.03 and 384.71 ppm), respectively (Baz et al. 2021).

Extracts of rosemary leaves, *Rosmarinus officinalis* (Shalaby and Khater 2005) and oils of fenugreek (*Trigonella foenum-grecum*), earth almond (*Cyperus esculentus*), mustard (*Brassica compestris*), olibanum (*Boswellia serrata*), rocket (*Eruca sativa*), and parsley (*Carum ptroselinum*), respectively, controlled larvae of *Cx. pipiens* in Egypt (Khater and Shalaby 2008). *Piper purusanum* oil adversely affected malaria and dengue vectors via egg hatchability (7.6 ± 1.5 to 95.6 ± 4.5%), larval survival (LC_{50} from 49.84 to 51.60 ppm), and the action of acetylcholinesterase (IC_{50} of 2.29 μg/mL), which can be associated to its mechanisms of action. *P. purusanum* oil induced no lethal effect on non-target organisms as *Toxorhynchites splendens, Anisops bouvieri,* and *Gambusia affinis* (LC_{50} from 2098.80 to 7707.13 ppm) (de Oliveira et al. 2022).

The potency of plant extracts was normally associated with the type of solvent used in the extraction of bioactive compounds against mosquito species (Thongwat et al. 2017; Mostafa et al. 2019; Baz et al. 2021).

Botanicals including essential oils are relatively safe, readily available, and biodegradable, they may be a viable alternative to synthetic insecticides (Khater 2013; Abd El Meguid et al. 2019). Furthermore, plant oils containing mixtures of active components (terpenoids, pesticide fatty acid, and phenols) (Senthil-Nathan 2020; Baz et al. 2021) act on insects at different target sites or with a different mode of action that might reduce resistance in mosquito populations (Khater 2013; Senthil-Nathan 2020; Ahmed et al. 2021; Iqbal et al. 2021).

Conclusion

M. alternifolia and *C. alternifolius* were the most potent oils tested in the study and are recommended for field applications, followed by *A. indica, L. luteus,* or *L. sativa*. The novel larvicidal activity of seven oils (*C. glaucus, C. alternifolius, D. carota, L. sativa, M. alternifolia, P. armeniaca,* and *T. aestivum*) against larvae of *Cx. pipiens* was reported for the first time in this investigation. Overall, in local, regional, and rural communities with few alternative options, the application of these eco-friendly oils for low-cost and safe phytochemical pesticides for mosquito control is critical. More studies are needed for revealing the composition and safety and improving nanoformulations of the highly efficient oils (Govindarajan et al. 2016a, b) against mosquitoes the management of vector-borne diseases.

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Declarations

Ethics approval Not abdicable.

Conflict of interest The authors declare that there is no conflict of interest.

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