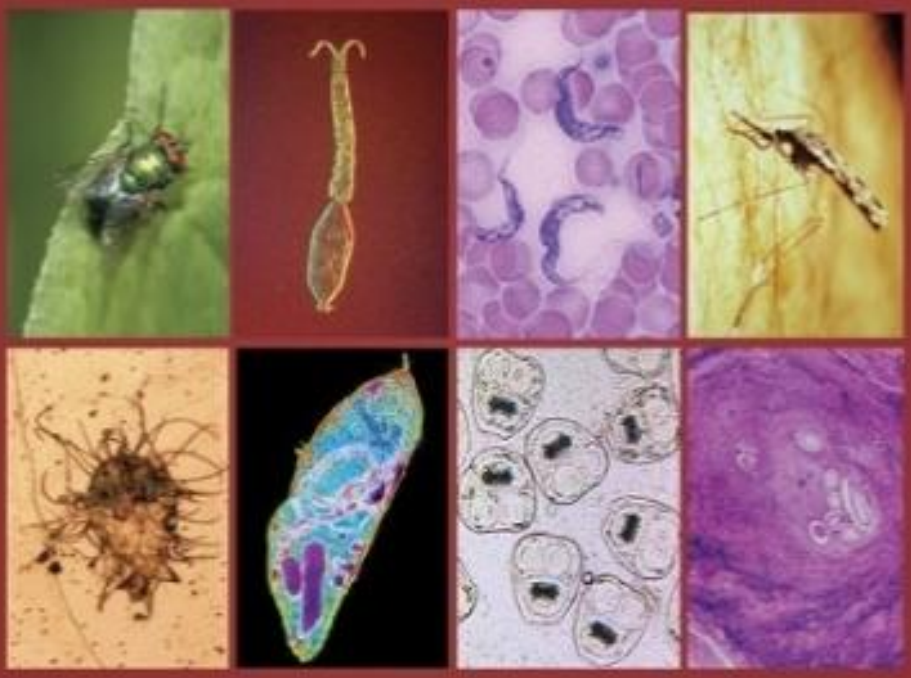
EGYPTIAN ACADEMIC JOURNAL OF

BIOLOGICAL SCIENCES

E

MEDICAL ENTOMOLOGY & PARASITOLOGY



ISSN
2090-0783

WWW.EAJBS.EG.NET

Vol. 17 No. 2 (2025)

Citation: *Egypt. Acad. J. Biolog. Sci. (E-Medical Entom. & Parasitology Vol.17(2) pp **33-48**(2025)*
DOI: **10.21608/EAJBSE.2025.451071**

Egypt. Acad. J. Biology. Sci., 17 (2):33– 48 (2025)

Egyptian Academic Journal of Biological Sciences
E. Medical Entomology & Parasitology

ISSN: 2090–0783
www.eajbse.journals.ekb.eg

Chemical Characterization, Insecticidal and Antimicrobial Activity of Pelargonium, Lemongrass, Eucalyptus and Castor Bean Essential Oils against *Culex pipiens*

Heba M. Aboelela[1], Heba Y. Mady[2], Mohamed M. Baz[3], Gehad A. Basuony[4] and Amira T. Ali[1]

[1]Medical Parasitology Department, Faculty of Medicine, Benha University, Egypt.
[2]Zoology Department, Women College, Ain Shams University, Cairo, Egypt.
[3]Entomology Department, Faculty of Science, Benha University, Benha 13518, Egypt.
[4]Department of Medical Parasitology, Faculty of Medicine, Cairo University, Egypt.
***E-mail: Mohamed.albaz@fsc.bu.edu.eg**

ARTICLE INFO

Article History
Received:30/7/2024
Accepted:4/9/2025
Available:8/9/2025

Keywords:
Culex pipiens, Larvicidal, Antimicrobial, Essential oils, Insecticide.

ABSTRACT

Mosquitoes, among the most lethal creatures on Earth, are responsible for millions of deaths annually through the transmission of various human diseases. The widespread application of pesticides resulted in significant health issues for humans, environmental degradation, and mosquito resistance to synthetic insecticides. This study sought to evaluate four essential oils and their phytochemical profiles against larvae and adult *Culex pipiens*. The oils were tested at different concentrations ranging from 25 to 1000 ppm for larvae. Mortality was evaluated after 24 and 48 h, while concentrations from 0.1% to 1% were tested against female mosquito adults after 60 min of exposure. All the tested essential oils demonstrated larvicidal activity, with mortality rates after 24 hours ranging from 90% to 100% at a concentration of 1000 ppm. *Eucalyptus camaldulensis* oil showed the highest efficacy, achieving 100% larval mortality at 1000 ppm (LC_{50} = 305.3 ppm), followed by castor bean (*Ricinus communis*) oil (LC_{50} = 388.3 ppm) and pelargonium (*Pelargonium graveolens*) oil that induced 98% mortality (LC_{50} = 446.2 ppm). Lemongrass (*Cymbopogon citratus*) oil exhibited the lowest larvicidal activity at 1000 ppm with 90% mortality (LC_{50} = 491.5 ppm). Pelargonium, lemongrass, and eucalyptus oils showed high adulticidal activity against female *Cx. pipiens*, achieving 100% mortality at 1% concentration after 60 min. Eucalyptus and pelargonium oils also demonstrated significant antibacterial efficacy among which eucalyptus oil demonstrated the highest overall activity, with inhibition zones reaching 25 mm against *Bacillus subtilis* and *Candida albicans* while *Klebsiella pneumoniae* and *Salmonella typhi* showed moderate sensitivity, with inhibition zones reaching up to 14 mm and 19 mm. GC-MS analysis of oils revealed various bioactive phytochemicals, including sesquiterpenes, aliphatic alcohols, and fatty acids, which may account for the reported effects.

INTRODUCTION

Mosquito-borne illnesses continue to pose a significant worldwide health threat, particularly in tropical and subtropical areas. The primary vectors, *Culex pipiens* transmit diseases including West Nile virus, Japanese encephalitis, filariasis (Madhav *et al.,* 2024).

Increasing apprehensions over pesticide resistance and environmental safety have propelled research into plant-derived bioinsecticides as alternate remedies. Consequently, numerous initiatives concentrate on reducing mosquito populations by targeting people at various life stages, including larvae and adults, and restricting their capacity for dissemination. These strategies are crucial for disrupting the transmission cycle and ultimately avoiding the dissemination of these diseases (Baz *et al.,* 2024).

Medicinal plants and essential oils have long been known to contain many beneficial substances that can help treat illnesses and serve as natural pesticides, which can help deal with pesticide resistance and pollution while being safe for other living things. Essential oils (EOs) are secondary metabolites produced by aromatic plants and utilized in the control of certain insect pests and mites. Over 3000 essential oils are documented in the literature, with around 300 in commercial application, including those derived from several *Eucalyptus* species (Gilles *et al.,* 2010; Stefanakis *et al.,* 2013). The *Eucalyptus* genus has 900 species and subspecies. In 1998, Hill and Johnson classed *Eucalyptus* based on its morphological and molecular properties. According to these scientists, Corymbia, hitherto categorized as a subgenus of *Eucalyptus*, has been upgraded to the status of a distinct genus with 113 recognized species; among which *Corymbia citriodora, C. maculata, C. ficifolia, C. ptychocarpa, and C. torelliana* are the most recognized species (Barbosa *et al.,* 2016). Notwithstanding this reclassification, the names initially identified in the references were employed for the compilation of this study to enhance the discourse. *Eucalyptus* is a primary genus of the Myrtaceae family, indigenous to Australia and cultivated globally. *Eucalyptus* trees possess perpetual leaves that emit a fragrance due to the essential oils produced and stored in secretory cells. These essential oils are aromatic, spicy, and either colorless or pale yellow, but some investigations have indicated a brownish or greenish hue. Essential oils derived from eucalyptus are often abundant in monoterpenes and, in certain instances, sesquiterpenes. Numerous essential oils are utilized for medicinal applications and in the fragrance industry. The eucalyptus essential oils used for medicine have a lot of 1,8-cineole, while those used in perfumes contain more citronellal, citral, and geranyl acetate (Barbosa *et al.,* 2016).

The genus *Pelargonium* (Geraniaceae) includes more than 280 species of evergreen perennial flowering plants. *Pelargonium roseum* (PRO) is cultivated for its smell and aesthetic appeal as an ornamental plant, serving as a vital ingredient in the food, beverage, and perfume industries (Szutt *et al.,* 2020). Research shows that essential oils and main ingredients from can repel mosquitoes in laboratory tests on malaria-carrying insects (Yohana *et al.,* 2022). The rose-scented geranium, a plant of the Geraniaceae family, belongs to the *Pelargonium* genus. The insecticidal capabilities of geranium oil and its components, chiefly citronellol and geraniol, are well-documented (Wazir *et al*., 2025). The essential oil of *P. roseum* has been investigated for its antibacterial, antifungal, and anti-inflammatory properties (Galea *et al.,* 2024).

The insecticidal efficacy of lemongrass essential oil is attributed to its diverse secondary metabolites, including bioactive cyclic and acyclic terpenes, which interfere with neurotransmission in insects (Eden *et al.,* 2020). Additionally, various secondary metabolites, including alkaloids, flavonoids, and carotenoids, have been identified in lemongrass extracts, suggesting its potential as a bio-insecticide. Tannin molecules may serve as inhibitors of enzymatic activity in insect digestion (Rahayu & Mairawita, 2018). Citral, a combination of geranial and neral, is

recognized for the insecticidal properties of lemongrass essential oil, attributed to its interaction with oxidative stress and intracellular oxygen radicals (Sanches *et al.,* 2018).

The ancient Egyptians, from the time of the Pharaohs, were acquainted with fragrant herbs, utilizing them in religious practices, cosmetics, embalming, and therapeutic applications. The initial documentation of essential oil distillation originated in Egypt (Sobhy *et al.,* 2023). Four essential oils, such as pelargonium, lemongrass, eucalyptus, and castor, were chosen for this study because they are easy to procure in local markets, inexpensive, and commonly used in traditional medicine (Baz *et al.,* 2024). The present work aims to evaluate the larvicidal and adulticidal activity of these essential oils against the larvae and females of the *Cx. pipiens* mosquito, which is the primary vector for several diseases. The research also seeks to study the chemical composition of these oils using GC/MS analysis techniques to identify the active components responsible for their insecticidal activity, in addition to evaluating the antimicrobial activity of some of these oils against a selected group of pathogenic bacteria and fungi. This work provides an alternative opportunity to provide safe and effective natural alternatives that can be used to enhance mosquito control strategies and avoid reliance on synthetic chemical pesticides.

MATERIALS AND METHODS

Essential Oils:

The high-purity essential oils used in this study were sourced from Nefertari Company, Egypt, specializing in the extraction of natural oils, plants, and cosmetics (Table 1). Essential oils stored in their original containers (brown glass) at 4 °C and away from direct exposure to light and moisture to maintain the stability of their chemical composition and prevent the decomposition of active compounds.

Table 1. List of essential oils tested against *Culex pipiens.*

No.	Common name	Botanical name	Family
1	Pelargonium	*Pelargonium graveolens*	Geraniaceae
2	Lemongrass	*Cymbopogon citratus*	Poaceae
3	Eucalyptus	*Eucalyptus camaldulensis*	Myrtaceae
4	Castor bean	*Ricinus communis*	Euphorbiaceae

Rearing of *Cx. pipiens*:

Cx. pipiens larvae were reared in an insectary under controlled environmental conditions of 27 ± 2 °C temperature and 75 ± 5% relative humidity, with a 12 h light and 12 h dark cycle. They were nourished with a mixture of Tetramine fish food and finely ground bread in a 1:3 ratio. Once pupation occurred, these were transferred from enamel trays into cups containing dechlorinated water and placed in mesh cages measuring 35 × 35 × 40 cm, allowing for adult emergence. Female mosquitoes were routinely provided blood meals from a hamster, while all adults had continuous access to a 10% sugar solution. Both larval and pupal stages were consistently maintained in the same laboratory setting to ensure a steady supply for experimental purposes (Baz *et al.,* 2025).

Larvicidal Activity:

The effectiveness of pelargonium, lemongrass, eucalyptus and castor bean oils in killing larvae was tested on third-stage larvae of *Cx. pipiens* following the guidelines set by the World Health Organization (WHO, 2005). The solution of each oil was prepared as a stock by combining 1 mL of oil with 100 mL of distilled water and 0.1 mL of Tween-20. The larvae were exposed to five distinct concentrations that were formulated (25, 50, 125, 250, 500, and 1000 ppm). Twenty *Cx. pipiens* larvae were treated with each

oil in 250 mL glass beakers containing 150 mL of water under the specified controlled conditions. Three replicates were performed for each concentration of oil and control. After 24 and 48 h, mosquito larvae were checked to see how many larvae died to determine the larval lethal concentration (LC_{50}) using probit analysis.

Adulticidal Activity:

The adulticidal efficacy of the oils was evaluated using the modified CDC bottle methodology (WHO, 2016). Four distinct concentrations of each oil were prepared by dissolving in ethanol (0.1%, 0.25%, 0.5%, and 1.0%). Each prepared concentration of oil was utilized to coat the CDC bottles (250 mL Wheaton bottles with screw caps) in the same manner as the control bottle, which was coated solely with ethanol. The solvent was evaporated from the bottles for one hour at 27 ± 2 °C. Three replicates were performed for each concentration of oil and control. Ten adult female mosquitoes, aged 3 to 4 days and glucose-fed were picked using an aspirator and carefully placed into each bottle, which was then sealed with its lid. A mosquito was deemed dead if it was incapacitated or unable to move or stand within 60 min of exposure. The number of knocked-down mosquitoes was documented from each bottle at 5, 10, 20, 30, and 60 min to ascertain the median knockdown time (KT_{50} and KT_{90}) values for each concentration *via* probit analysis. Live mosquitoes were subsequently extracted from the bottles after one hour and transferred to individual paper cups containing a 10% sucrose solution.

Antimicrobial Assay:

The agar diffusion method is commonly employed to assess the antibacterial efficacy of two essential oils. This approach involves uniformly distributing a microbial suspension over the surface of an agar plate to inoculate it with bacteria or fungi, akin to the disk diffusion technique. Subsequently, a 6 mm diameter well is created in the agar utilizing a sterile cork borer or pipette tip. Each well is then filled with 100 µL of the oil or antimicrobial agent prepared at the specified concentration. The plates are incubated at conditions appropriate for the specific bacteria under examination. Throughout incubation, the antimicrobial agent permeates the agar and suppresses microbial proliferation (Magaldi *et al.,* 2004). Following an incubation period of 16 to 24 h for bacteria and up to 48 h for fungus, the inhibition zones defined as the clear regions surrounding the wells where microbial proliferation has ceased are measured in millimeters. Gentamicin (1 mg/mL) functioned as a positive control for bacterial strains, while fluconazole (1 mg/mL) was employed for fungal strains. Fifty milligrams of oil were dissolved in one milliliter of distilled water to prepare the essential oil.

GC/MS Analysis:

The essential oils were analyzed for their chemical makeup using GC–MS with a Trace GC-TSQ mass spectrometer from Thermo Fisher Scientific, which had a special capillary column called TG–5MS that is 30 meters long and 0.25 mm wide with a film thickness of 0.25 µm. The gas chromatograph's working parameters included an initial column oven temperature of 50 °C, which was subsequently increased at a rate of 5 °C/min to 250 °C, held for 2 min, and then raised at a rate of 30 °C/min to 300 °C. The MS transfer line and injector were calibrated at 270 °C and 260 °C, respectively, with helium as the carrier gas at a flow rate of 1 mL/min. The solvent retention duration was 4 min, and 1 µL of the diluted samples was automatically injected using an AS1300 autosampler in GC split mode. In comprehensive scanning mode, mass spectra were collected using electrospray ionization (EI) across a range of 50–650 m/z at a voltage of 70 V. The ion source temperature was set at 200 °C. The mass spectra of the components were matched with those in the NIST 14 and WILEY 09 mass spectral libraries, and the

identified substances were obtained using the Total Ion Chromatogram (TIC) (Mostafa *et al.,* 2024).

Statistical Analysis:

Statistical analysis was conducted using SPSS version 23 (IBM, USA), applying Probit analysis to determine lethal concentration (LC) values. A one-way analysis of variance (ANOVA) (Post Hoc/Turkey's HSD test) was also performed. A significance threshold of $P<0.05$ was used for all tests. Principal component analysis (PCA) was conducted using Unscrambler X 10.3 (CAMO SA, Oslo, Norway).

RESULTS

Mosquito Larvicidal Activity:

The larvicidal effects of the four essential oils were evaluated against 3rd instar larvae of *Cx. pipiens*. The results demonstrated that all tested essential oils exhibited larvicidal activity. Table 2 showed that the mortality rates after 24 h ranged from 90% to 100% at a concentration of 1000 ppm. Among the tested oils at 1000 ppm, *Eucalyptus* (*E. camaldulensis*) essential oil showed the highest efficacy, achieving 100% larval mortality (LC_{50} = 305.3 ppm; LC_{90} = 1088.4 ppm), followed by castor bean (*R. communis*) oil that induced 100% mortality (LC_{50} = 388.3 ppm; LC_{90} = 1515.4 ppm), pelargonium (*P. graveolens*) induced 98.33% mortality (LC_{50} = 446.2 ppm; LC_{90} = 1770.0 ppm), whereas lemongrass (*C. citratus*) oil exhibited the lowest larvicidal activity with 90.0% mortality (LC_{50} = 491.5 ppm; LC_{90} = 1849.5 ppm) (Table 3). These results indicated that all oils caused 100% larval mortality after 48 h, demonstrating latent effects; eucalyptus oil exhibited greater effectiveness against *Cx. pipiens* larvae than the other oils at both 24 and 48 h after treatment (Fig. 1).

Table 2. Efficacy of essential oils on *Culex pipiens* larval mortality, 24, and 48 h post-treatment.

Time (h)	Sample	Concentration (ppm)						
		0	25	50	125	250	500	1000
24	*C. citratus*	0 ± 0^{aG}	3.33 ± 3.3^{bF}	10.00 ± 2.8^{cE}	18.33 ± 1.6^{dD}	36.67 ± 1.6^{dC}	68.33 ± 1.6^{dB}	90.0 ± 0.0^{bA}
	E. camaldulensis	0 ± 0^{aG}	6.67 ± 1.6^{aF}	16.67 ± 1.6^{aE}	30.00 ± 2.8^{aD}	58.33 ± 1.6^{aC}	95.00 ± 2.8^{aB}	100.0 ± 0.0^{aA}
	R. communis	0 ± 0^{aG}	3.33 ± 3.3^{bF}	13.33 ± 1.6^{bE}	26.67 ± 3.3^{bD}	50.00 ± 2.8^{bC}	86.67 ± 3.3^{bB}	100.0 ± 0.0^{aA}
	P. graveolens	0 ± 0^{aG}	3.33 ± 1.6^{bF}	13.33 ± 1.6^{bE}	23.33 ± 3.3^{bD}	46.67 ± 3.3^{cC}	75.00 ± 2.8^{cB}	98.33 ± 1.6^{aA}
48	*C. citratus*	1.67 ± 1.3^{aG}	6.67 ± 3.3^{cF}	15.00 ± 0.0^{E}	23.33 ± 4.4^{dD}	51.67 ± 1.6^{dC}	90.00 ± 2.8^{bB}	100.0 ± 0.0^{aA}
	E. camaldulensis	1.67 ± 1.3^{aF}	15.00 ± 5.0^{aE}	23.33 ± 1.6^{aD}	48.33 ± 4.4^{aC}	81.67 ± 4.4^{aB}	100.0 ± 0.0^{aA}	100.0 ± 0.0^{aA}
	R. communis	1.67 ± 33^{aF}	8.33 ± 4.4^{cE}	20.00 ± 2.89^{bD}	36.67 ± 3.3^{bC}	70.00 ± 5.0^{bB}	100.0 ± 0.0^{aA}	100.0 ± 0.0^{aA}
	P. graveolens	1.67 ± 1.3^{aF}	11.67 ± 4.4^{bE}	20.00 ± 2.8^{bD}	30.00 ± 2.8^{cC}	65.00 ± 2.8^{cB}	98.33 ± 1.6^{aA}	100.0 ± 0.0^{aA}

a, b & c: There is no significant difference ($P>0.05$) between any two means for each time, within the same column have the same superscript letter. a, b & c There is no significant difference ($P>0.05$) between any two means, within the same row have the same superscript letter.

Table 3. Lethal concentrations (ppm) of essential oils against *Culex pipiens* larvae, 24 and 48 h. post-treatment

Time (h)	Treatment	LC_{50} (Low-Up.)	LC_{90} (Low-Up.)	LC_{95} (Low-Up.)	Slope±SE	X^2 (sign.)
24	*C. citratus*	491.5 (301.6-827.1)	1849.5 (1462.7-4909.8)	2692.7 (2229.7-8349.3)	2.226±0.153	23.181 (0.00)
	E. camaldulensis	305.3 (185.0-484.1)	1088.4 (838.8-4109.7)	1572.5 (1249.9-4109.7)	2.331±0.152	22.883 (0.00)
	R. communis	388.3 (281.3-536.8)	1515.4 (1140.0-2718.1)	2252.9 (1652.2-4433.9)	2.189±0.154	9.946 (0.04)
	P. graveolens	446.2 (305.6-660.6)	1770.0 (1340.3-3608.2)	2644.4 (1984.6-5995.0)	2.128±0.145	14.168 (0.01)
48	*C. citratus*	404.2 (257.7-643.4)	1651.7 (1258.7-3932.9)	2461.6 (1917.3-6761.5)	2.096±0.147	17.983 (0.01)
	E. camaldulensis	210.5 (148.7-300.1)	917.9 (975.9-1744.1)	1380.6 (997.8-2954.7)	2.049±0.153	10.113 (0.03)
	R. communis	260.0 (163.4-399.5)	839.8 (641.0-1769.4)	1170.9 (924.1-2756.8)	2.517±0.164	21.646 (0.00)
	P. graveolens	276.9 (144.0-500.7)	1005.4 (797.6-3188.3)	1449.1 (1263.6-5525.3)	2.288±0.150	33.381 (0.00)

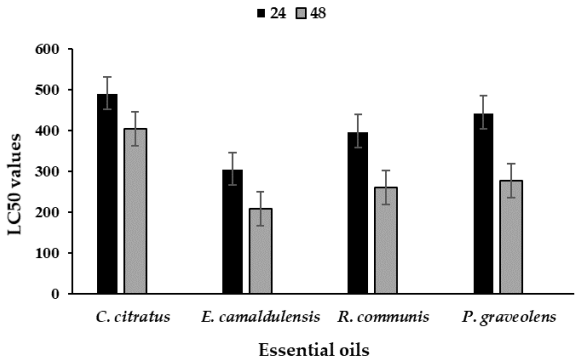


Fig. 1: The LC_{50} values of lemongrass, eucalyptus, castor bean, and geranium oils against 3rd larval instar of *Culex pipiens*, 24 and 48 h post-treatments

Adulticidal Activity:

The impact of the test concentrations of the four essential oils on *Cx. pipiens* females was assessed after 60 min of exposure, as shown in Table 4, and illustrated in Figure 2. The results showed that pelargonium oil had the best effect, knocking down all the *Cx. pipiens* females (100%), followed by lemongrass oil (96.67%), eucalyptus (93.33%), and castor bean oil (73.33%), all at a concentration of 0.5%. The assay revealed that at a higher concentration (1%), pelargonium and rest of the oils could knock the *Cx. pipiens* females fastest, and all of them were dead after 60 min: 100% with pelargonium, 100% with lemongrass, 100% with eucalyptus, and 96.67% with castor bean. The KT_{50} and KT_{90} values of the pelargonium oil was 12.14 and 25.90 min, lemongrass oil was 15.62 and 32.63 min, and eucalyptus had 18.63- and 36.40-min values, respectively. Data showed that castor bean oil exhibited the lowest adulticidal efficacy, with a 50 and 90% knockdown rate of 26.23 and 57.48 min, respectively, after 60 min at a concentration of 1.0% (Table 5). The pelargonium, lemongrass, and eucalyptus essential oils showed high adulticidal effects against female adults of *Cx. pipiens* after 60 min exposure at 1% concentration, with the mortality rate reaching 100%. The LC_{50} values were calculated for pelargonium oil (0.09%), lemongrass (0.11%), eucalyptus oil (0.15%), and castor bean (0.23%) (Table 6).

Table 4. Knockdown rate (mortality %) of essential oils against *Culex pipiens* female adults.

EOs	Conc. (%)	Time (min)						
		5	10	15	20	25	30	60
C. citratus	0.1	0.0 ± 0.0^{cF}	0.0 ± 0.0^{dF}	3.33 ± 3.3^{dE}	6.67 ± 3.3^{dD}	20.00 ± 0.0^{dC}	33.33 ± 3.3^{dB}	46.67 ± 3.3^{dA}
	0.25	0.0 ± 0.0^{cF}	3.33 ± 3.3^{cF}	6.67 ± 3.3^{cE}	16.67 ± 8.8^{cD}	36.67 ± 3.3^{cC}	56.67 ± 3.3^{cB}	76.67 ± 3.3^{cA}
	0.5	6.67 ± 3.3^{bG}	10.00 ± 0.0^{bF}	23.33 ± 3.3^{bE}	33.33 ± 3.3^{bD}	60.00 ± 5.7^{bC}	86.67 ± 3.3^{bB}	96.67 ± 0.0^{bA}
	1.0	10.0 ± 5.7^{aF}	16.67 ± 3.3^{aE}	30.00 ± 0.0^{aD}	50.00 ± 0.0^{aC}	86.67 ± 6.6^{aB}	100.0 ± 0.0^{aA}	100.0 ± 0.0^{aA}
E. camaldulensis	0.1	0.0 ± 0.0^{cE}	0.0 ± 0.0^{cE}	0.0 ± 0.0^{dE}	3.33 ± 3.3^{dD}	16.67 ± 3.3^{dC}	23.33 ± 3.3^{dB}	36.67 ± 3.3^{dA}
	0.25	0.0 ± 0.0^{cF}	0.0 ± 0.0^{cF}	3.33 ± 3.3^{cE}	13.33 ± 3.3^{cD}	23.33 ± 3.3^{cC}	46.67 ± 3.3^{cB}	60.00 ± 0.0^{cA}
	0.5	3.33 ± 3.3^{bG}	6.67 ± 3.3^{bF}	13.33 ± 3.3^{bE}	20.00 ± 5.7^{bD}	43.33 ± 3.3^{bC}	70.00 ± 10.0^{bB}	93.33 ± 3.3^{bA}
	1.0	6.67 ± 3.3^{aF}	10.00 ± 0.0^{aE}	23.33 ± 3.3^{aD}	33.33 ± 3.3^{aC}	73.33 ± 6.6^{aB}	100.0 ± 0.0^{aA}	100.0 ± 0.0^{aA}
P. graveolens	0.1	0.0 ± 0.0^{dF}	0.0 ± 0.0^{dF}	6.67 ± 3.3^{dE}	13.33 ± 3.3^{dD}	23.33 ± 3.3^{dC}	36.67 ± 3.3^{cB}	50.0 ± 5.7^{cA}
	0.25	3.33 ± 3.3^{cG}	6.67 ± 3.3^{cF}	13.33 ± 8.8^{cE}	30.00 ± 5.7^{cD}	50.00 ± 5.7^{cC}	66.67 ± 6.6^{bB}	90.0 ± 10.0^{bA}
	0.5	13.33 ± 3.3^{bF}	20.00 ± 5.7^{bE}	36.67 ± 6.6^{bD}	53.33 ± 3.3^{bC}	76.67 ± 8.8^{bB}	100.0 ± 0.0^{aA}	100.0 ± 0.0^{aA}
	1.0	16.67 ± 3.3^{aF}	23.33 ± 3.3^{aE}	43.33 ± 3.3^{aD}	73.33 ± 3.3^{aC}	96.67 ± 3.3^{aB}	100.0 ± 0.0^{aA}	100.0 ± 0.0^{aA}
R. communis	0.1	0.0 ± 0.0^{bD}	0.0 ± 0.0^{cD}	0.0 ± 0.0^{dD}	0.0 ± 0.0^{dD}	10.00 ± 0.0^{dC}	13.33 ± 3.3^{dB}	26.67 ± 3.3^{dA}
	0.25	0.0 ± 0.0^{bF}	0.0 ± 0.0^{cF}	3.33 ± 3.3^{cE}	6.67 ± 3.3^{cD}	16.67 ± 3.3^{cC}	33.33 ± 6.6^{cB}	46.67 ± 6.6^{cA}
	0.5	0.0 ± 0.0^{bG}	6.67 ± 3.3^{bF}	10.00 ± 0.0^{bE}	20.00 ± 0.0^{bD}	30.00 ± 5.7^{bC}	46.67 ± 8.8^{bB}	73.33 ± 6.6^{bA}
	1.0	3.33 ± 3.3^{G}	6.67 ± 3.3^{aF}	13.33 ± 3.3^{aE}	26.67 ± 3.3^{aD}	43.33 ± 6.6^{aC}	60.00 ± 5.7^{aB}	96.67 ± 3.3^{aA}

a, b & c: There is no significant difference (P>0.05) between any two means for each plant, within the same column have the same superscript letter. A, B & C: There is no significant difference (P>0.05) between any two means, within the same row have the same superscript letter.

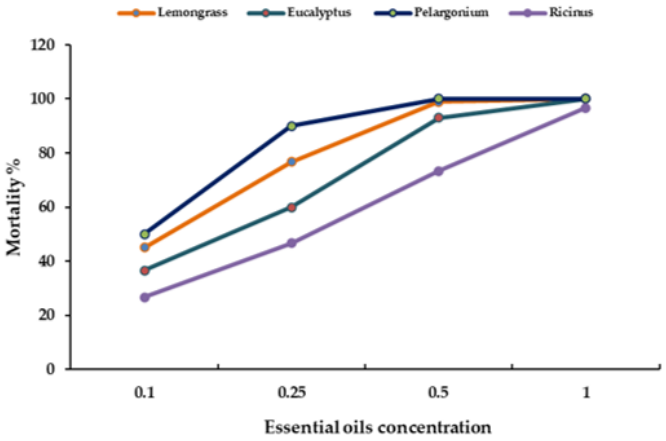


Fig. 2. Knockdown rate (mortality %) of essential oils against *Culex pipiens* female adults.

Table 5. Probit analysis of knockdown time and mortality rates of *Culex pipiens* females after oil exposure for 60 min

EOs	Conc. (%)	KT_{50}	KT_{90}	KT_{95}	R_2	Slope±SE	Chi (Sig)
C. citratus	0.1	55.15	152.92	204.18	0.9498	2.893±0.285	14.070 (0.015)
	0.25	29.24	54.04	64.32	0.9704	4.804±0.554	5.765 (0.123)
	0.5	21.28	52.13	67.20	0.9470	3.293±0.258	45.748 (0.000)
	1.0	15.62	32.63	40.06	0.8953	4.081±0.280	73.864 (0.000)
E. camaldulensis	0.1	68.73	194.88	261.86	0.8921	2.831±0.314	15.816 (0.007)
	0.25	42.50	104.06	134.13	0.9496	3.295±0.283	19.123 (0.001)
	0.5	26.34	57.93	72.43	0.9505	3.744±0.278	41.669 (0.000)
	1.0	18.63	36.40	44.01	0.8760	4.405±0.317	111.761 (0.000)
P. graveolens	0.1	50.73	150.74	205.25	0.9434	2.709±0.260	11.042 (0.050)
	0.25	25.77	60.10	76.40	0.9699	3.485±0.259	18.194 (0.002)
	0.5	15.27	35.22	44.63	08834	3.532±0.246	53.711 (0.000)
	1.0	12.14	25.90	33.46	0.9150	3.889±0.266	57.624 (0.000)
R. communis	0.1	91.94	266.99	361.20	0.8254	2.768±0.368	11.253 (0.046)
	0.25	55.87	152.93	203.44	0.8520	2.930±0.290	13.151 (0.022)
	0.5	35.97	95.27	125.55	0.9869	3.030±0.251	3.887 (0.565)
	1.0	26.23	57.48	71.79	0.9533	3.762±0.279	34.558 (0.000)

Table 6. The adulticidal effects of essential oils against female adults of *Culex pipiens* after 60 min exposure.

EOs	Conc. (%)	Mortality (%)	LC_{50} (Low-Up.)	LC_{90} (Low-Up.)	LC_{95} (Low-Up.)	X^2 (Sig)
C. citratus	0.1	46.67 ± 3.33^{d}	0.11 (0.09-0.13)	0.38 (0.32-0.46)	0.53 (0.43-0.68)	1.125 (0.569)
	0.25	$76.67\pm3.33^{c\,us}$				
	0.5	96.67 ± 0.00^{b}				
	1.0	100.0 ± 0.00^{a}				
E. camaldulensis	0.1	36.67 ± 3.33^{d}	0.15 (0.11-0.18)	0.48 (0.31-0.54)	0.65 (0.51-0.73)	9.397 (0.009)
	0.25	60.00 ± 0.00^{c}				
	0.5	93.33 ± 3.33^{b}				
	1.0	100.0 ± 0.00^{a}				
P. graveolens	0.1	50.0 ± 5.77^{c}	0.09 (0.05-0.11)	0.23 (0.18-0.27)	0.30 (0.21-0.38)	1.074 (0.584)
	0.25	90.0 ± 10.00^{b}				
	0.5	100.0 ± 0.00^{a}				
	1.0	100.0±0.00a				
R. communis	0.1	26.67 ± 3.33^{d}	0.23 (0.19-0.26)	0.87 (0.71-0.99)	1.28 (1.08-1.32)	7.223 (0.022)
	0.25	46.67 ± 6.67^{c}				
	0.5	73.33 ± 6.67^{b}				
	1.0	96.67 ± 3.33^{a}				

a, b & c: There is no significant difference (P>0.05) between any two means for each plant, within the same column have the same superscript letter.

Antimicrobial Activity of Pelargonium and Eucalyptus Oils:

The antimicrobial activity of pelargonium and eucalyptus oils was evaluated by incubating bacterial cultures (*Bacillus subtilis, Staphylococcus aureus, Klebsiella pneumoniae, Salmonella typhi*) for 16 to 24 h and fungal cultures (*Candida albicans* and *Aspergillus niger*) for up to 48 h, before assessing microbial killing. Both oils exhibited varying degrees of inhibition against the tested organisms. *Eucalyptus* oil demonstrated the highest activity overall, with inhibition zones reaching 25 mm against *B. subtilis* and *C. albicans*. *K. pneumoniae* and *S. typhi* showed moderate sensitivity, with inhibition zones reaching 19 and 18 mm, respectively. Pelargonium EO had significant effects against *B. subtilis* and *C. albicans* showing a 24 mm and 17 mm inhibition zones, respectively. The smallest area where growth was stopped was seen with *Aspergillus niger*, which only responded to *Eucalyptus* oil, creating a 17 mm zone, while pelargonium oil had no effect on it at all (Table 7, Fig. 3).

Table 7. Antimicrobial activities of pelargonium and eucalyptus oils against six pathogenic microorganisms.

	Treated*		Control**
	Pelargonium	Eucalyptus	
Bacillus subtilis (ATCC 6633)	24.0±0.4	25.0±1.1	21.0±0.2
Staphylococcus aureus (ATCC 6538)	14.0±1.0	23.0±0.5	22.0±0.1
Klebsiella pneumoniae (ATCC 13883)	14.0±0.5	19.0±0.8	25.0±0.6
Salmonella typhi (ATCC 6539)	15.0±0.1	18.0±0.9	24.0±0.8
Candida albicans (ATCC 10221)	17.0±0.8	25.0±1.0	21.0±10
Aspergillus niger (ATCC16888)	NA	17.0±0.7	37.0±0.8

* Inhibition zone (mm); ** Control for Bacteria was Gentamycin and for fungi was fluconazole at concentration 1.0 mg/ml; 50 mg of the samples were dissolved in 1.0 ml DW; NA: No activity

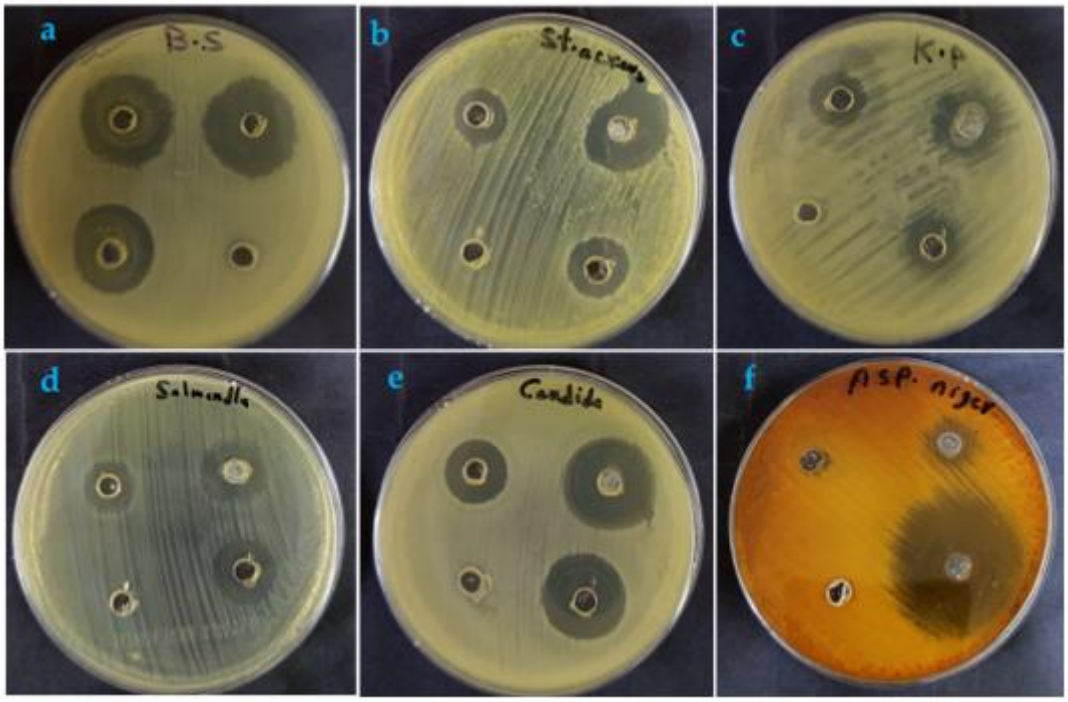


Fig. 3. Antimicrobial activities of pelargonium and eucalyptus oils against (a) *Bacillus subtilis* (ATCC 6633), (b) *Staphylococcus aureus* (ATCC 6538), (c) *Klebsiella pneumoniae* (ATCC 13883), (d) *Salmonella typhi* (ATCC 6539), (e) *Candida albicans* (ATCC 10221), and (f) *Aspergillus niger*(ATCC 16888) microorganisms.

GC/MS Identified Components from Pelargonium, Lemongrass, Eucalyptus and Castor Bean Oils:

GC–MS analysis was employed to facilitate the metabolic examination of the four essential oils. Employing methanol as a solvent, the findings from our study's GC–MS analysis facilitated the identification of various compounds in the oil of pelargonium, lemongrass, and eucalyptus, and castor bean, encompassing terpenes, phenols, esters, fatty acids, alkanes, and aliphatic amines (Tables 8-11). The extract of pelargonium comprised 26 components (Table 8), with notable concentrations of 1,6-Octadien-3-ol, 3,7-dimethyl- (19.50%), 6-Octen-1-ol, 3,7-dimethyl- (17.91%), 6-Octen-1-ol, 3,7-dimethyl-, acetate (11.10%), 10-Epi-ç-eudesmol (10.98%) and Ç-Muurolene (9.35%). The extract of lemongrass contained nine compounds, with the highest concentrations being 2,6-Octadienal, 3,7-dimethyl-, E- (50.33%) and 2,6-Octadienal, 3,7-dimethyl- (34.71%) (Table 9). The extract of eucalyptus had 13 compounds, with the most abundant being Bicyclo [2.2.1] heptan-2-one,1,7,7-trimethyl- (28.72%), Eucalyptol (25.69%), and Bicyclo[2.2.1] heptane, 2,2-dimethyl-3-methylene (20.86%), as shown in Table 10. In the extract of castor bean, 16 substances were identified: 13-Hexyloxacyclotridec-10-en-2-one (54.0%), 8,11,14-Eicosatrienoic acid, (z,z,z)- (13.27%), 10-Heptadecen-8-ynoic acid, methyl ester, E- (9.01%), and 9-Octadecenoic acid (z)- (6.22%) (Table 11).

Table 8. The major chemical constituents of *Pelargonium graveolens* oil.

No	RT	Area %	Compound Name	M. F.	Nature
1	4.72	0.73	(1R)-2,6,6-Trimethylbicyclo [3.1.1] hept-2-ene	$C_{10}H_{16}$	Monoterpene
2	5.43	0.08	2H-Pyran, 2-ethenyltetrahydro-2,6,6-trimethyl-	$C_{10}H_{18}$	Monoterpene
3	6.58	0.08	Benzene, 1-methyl-3-(1-methylethyl)-	$C^{10}H^{14}$	Monoterpene
4	6.69	0.11	Isopinocarveol	$C^{10}H^{16}$	Monoterpene
5	8.55	**19.50**	1,6-Octadien-3-ol, 3,7-dimethyl-	$C_{10}H_{18}O$	Monoterpene
6	10.73	0.24	Levomenthol	$C_{10}H_{20}O$	MAM
7	10.89	0.88	3-Cyclohexene-1-methanol, à,à,4-trimethyl-, (s)-	$C_{10}H_{18}O$	Monoterpene
8	12.20	**17.91**	6-Octen-1-ol, 3,7-dimethyl-	$C_{10}H_{20}O$	MAM
9	12.84	9.16	Geraniol	$C_{10}H_{18}O$	Monoterpene
10	13.33	**11.10**	6-Octen-1-ol, 3,7-dimethyl-, acetate	$C_{12}H_{22}O_2$	ME
11	13.96	3.82	Geranylformate	$C_{11}H_{18}O_2$	Monoterpenes
12	16.19	1.54	alfa. -Copaene	$C_{15}H_{24}$	Sesquiterpene
13	16.36	2.53	(-)-á-Bourbonene	$C_{15}H_{24}$	Sesquiterpene
14	16.53	0.29	2,6,10-Dodecatrien-1-ol, 3,7,11-trimethyl-	$C_{15}H_{26}$	SA
15	17.44	1.25	Á-copaene	$C_{15}H_{24}$	Sesquiterpene
16	17.68	0.87	6-Octen-1-ol, 3,7-dimethyl-, propanoate	$C_{13}H_{24}O_2$	ME
17	18.57	**9.35**	Ç-Muurolene	$C_{15}H_{24}$	Sesquiterpene
18	19.75	1.25	Citronellyl butyrate	$C_{14}H_{26}O_2$	MA
19	19.99	4.15	2,6-Di-t-butyl-4-methylphenol Ionol	$C_{15}H_{24}O$	Sesquiterpene
20	20.41	1.24	Butanoic acid, 3,7-dimethyl-2,6-octadienyl ester, (e)-	$C_{14}H_{24}O_2$	ME
21	21.77	**10.98**	10-Epi-ç-eudesmol	$C_{15}H_{26}O$	SA
22	22.85	0.59	Cholestan-3-ol, 2-methylene-, (3á,5à)-	$C_{28}H_{48}O$	CAC
23	23.33	0.20	Pentanoic acid, 4-methyl-, 3,7-dimethyl-6-octenyl ester	$C_{16}H_{30}O_2$	esters
24	23.52	1.30	Geranylangelate	$C_{15}H_{24}O_2$	Sesquiterpene
25	26.17	0.57	4,8-Decadienal, 5,9-dimethyl-	$C_{12}H_{20}O$	Monoterpenes
26	30.50	0.24	17-Octadecynoic acid	$C_{18}H_{32}O_2$	Alkynoic acids

RT: Retention Time; M. F.: Molecular Formula; MAM: monoterpene alcohol menthol; MA: monoterpenoid alcohol; ME: Monoterpene ester; SA: sesquiterpene alcohol; CAC: cyclic alcohol compound

Table 9. The major chemical constituents of *Cymbopogon citratus* oil

No	RT	Area %	Compound Name	M. F.	Nature
1	8.58	1.13	1,6-Octadien-3-ol, 3,7-dimethyl-	$C_{10}H_{18}O$	Monoterpene
2	1056	3.80	Trans-verbenol	$C_{10}H_{16}O$	Monoterpene
3	12.12	**34.71**	2,6-Octadienal, 3,7-dimethyl-	$C_{10}H_{16}O$	Monoterpene
4	12.35	3.45	Geraniol acetate	$C_{12}H_{20}O_2$	Monoterpenes
5	12.93	**50.33**	2,6-Octadienal, 3,7-dimethyl-, E-	$C_{10}H_{16}O$	Monoterpene
6	16.07	4.82	2,6-Octadien-1-ol, 3,7-dimethyl-, acetate	$C_{12}H_{20}O_2$	Monoterpenes
7	16.68	0.87	Cyclopropanemethanol, 2-methyl-2-(4-methyl-3-pentenyl)-	$C_{11}H_{20}O$	Aliphatic Alcohol
8	17.69	0.26	Trans-à-bergamotene	$C_{15}H_{24}$	Sesquiterpene
9	31.85	0.45	4-(2,2-Dimethyl-6-methylenecyclohexyl) butanal	$C_{13}H_{22}O$	Terpenes

RT: Retention Time; M. F.: Molecular Formula

Table 10. The major chemical constituents of *Eucalyptus camaldulensis* oil

No	RT	Area %	Compound Name	M. F.	Nature
1	4.53	1.37	Tricyclo [2.2.1.0(2,6)] heptane, 1,7,7-trimethyl-	$C_{10}H_{16}$	Monoterpene
2	5.01	**20.86**	Bicyclo [2.2.1] heptane, 2,2-dimethyl-3-methylene	$C_{10}H_{16}$	Monoterpene
3	6.39	1.37	(1r)-2,6,6-Trimethylbicyclo [3.1.1] hept-2-ene	$C_{10}H_{16}$	Monoterpene
4	6.61	3.44	O-cymene	$C_{10}H_{14}$	Monoterpene
5	6.76	**25.69**	Eucalyptol	$C_{10}H_{18}O$	Monoterpene
6	8.33	0.86	3-Oxatricyclo [4.1.1.0(2,4)] octane, 2,7,7-trimethyl-	$C_{10}H_{16}O$	Monoterpene
7	8.59	0.57	1,6-Octadien-3-ol, 3,7-dimethyl-	$C_{10}H_{18}O$	Monoterpene
8	8.70	0.46	2-Norbornanol, 1,5,5-trimethyl-	$C_{10}H_{18}O$	Monoterpene
9	9.35	**28.72**	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-	$C_{10}H_{16}O$	Monoterpene
10	9.65	1.23	Cis-verbenol	$C_{10}H_{16}O$	Monoterpene
11	9.95	11.42	Isoborneol	$C_{10}H_{18}O$	Monoterpene
12	10.57	1.71	Terpinen-4-ol	$C_{10}H_{18}O$	Monoterpene
13	10.93	2.30	à-Terpineol	$C_{10}H_{18}O$	Monoterpene

RT: Retention Tim; M. F.: Molecular Formula

Table 11. The major chemical constituents of *Ricinus communis* oil.

No	RT	Area %	Compound Name	M. F.	Nature
1	5.70	2.71	Methyl (1Z)-2-(dimethylamino)-N-(methylcarbamoyloxy)-2-oxoethanimidothioate	$C_7H_{13}N_3O_3S$	Dimethylamino
2	6.36	0.66	Z, z, z-4,6,9-nonadecatriene	$C_{19}H_{34}$	Terpenes
3	6.73	1.09	2-Nitrohept-2-en-1-ol	$C_7H_{13}NO_3$	AA
4	7.53	0.71	Ethanimidothioic acid, 2-(dimethylamino)-n-[[(methylamino)carbonyl] oxy]-2-oxo-, methyl ester	$C_7H_{13}N_3O_3S$	Dimethylamino
5	7.61	0.65	8,11,14-Eicosatrienoic acid, (z, z, z)-	$C_{20}H_{34}O_2$	UFA
6	7.83	2.35	Nickel-1,5,9,13-tetraaza-2,6,10,14tetrabenzo-4,12-dinitro-cyclohexadec-4,8,12,16-tetra-ene	$C_{28}H_{20}N_6NiO_6$	AM
7	10.16	1.91	10-Heptadecen-8-ynoic acid, methyl ester, €-	$C_{18}H_{30}O_2$	Fatty Acid
8	10.25	0.65	Z, z, z-4,6,9-nonadecatriene	$C_{19}H_{34}$	Terpenes
9	10.54	**9.01**	10-Heptadecen-8-ynoic acid, methyl ester, €-	$C_{18}H_{30}O_2$	Fatty Acid
10	10.67	**13.27**	8,11,14-Eicosatrienoic acid, (z, z, z)-	$C_{20}H_{34}O_2$	UFA
11	21.82	0.71	(-)-valerenic acid	$C_{15}H_{22}O_2$	Fatty Acid
12	30.70	**54.0**	13-Hexyloxacyclotridec-10-en-2-one	$C_{18}H_{32}O_2$	ML
13	30.93	3.51	Hi-Oleic safflower oil	$C_{21}H_{22}O_{11}$	Oleic acid
14	32.99	**6.22**	9-Octadecenoic acid (z)-	$C_{18}H_{34}O_2$	Diterpene
15	33.38	0.84	12-Methyl-e, e-2,13-octadecadien-1-ol	$C_{19}H_{36}O$	UFA
16	33.88	1.61	Hexadecadienoic acid, methyl ester	$C_{17}H_{30}O_2$	UFE

RT: Retention Time; M. F.: Molecular Formula; AA: aliphatic alcohol; UFA: unsaturated fatty acid; AM: Aromatic macrocycle; ML: Macrocyclic lactone; UFA: unsaturated fatty alcohol; UFE: unsaturated fatty esters

DISCUSSION

Essential oils are useful substances used in many areas, such as protecting plants and helping to keep humans and animals healthy from different pests (Selvakumaran 2024). Plant extracts or essential oils from plants may be effective in managing mosquito populations, as they include a plethora of bioactive components that can decompose into innocuous substances. They are ideally suited for implementation in integrated management methods for mosquito control (Benelli, 2015; Hassan *et al.,* 2024). Plant extracts have proven beneficial in managing insect pests, including mosquitoes, in comparison to synthetic insecticides (Muturi *et al.,* 2020; Selvakumaran *et al.,* 2024).

The current study indicated that four essential oils were effective at killing mosquito larvae, with mortality rates ranging from 90.0% to 100% after 24 h of exposure to 1000 ppm. These results indicate that all essential oils have a significant ability to kill larvae, but their effectiveness varies significantly. Our data revealed that *Eucalyptus camaldulensis* oil showed the best efficacy amongst the four oils, killing 100% larvae at the highest concentration used (1000 ppm) and having the lowest LC_{50} (305.3 ppm), indicating its larvicidal potential even at lower amounts. This is likely due to its content of active compounds such as 1,8-cineole, which is known for its insecticidal properties. Castor oil (*R. communis*) was the second most effective oil, also killing all the larvae at the highest concentration, but it required higher amounts to do so as compared to eucalyptus oil, showing it was still effective but not as strong. *P. graveolens* oil was also highly effective, killing 98.33% of the pests, but it required a little higher concentration to be as lethal as the more effective oils.

This study confirms that essential oils, particularly *Eucalyptus* oil, can be effective and safe alternatives to chemical pesticides in controlling mosquito larvae, which holds significant importance for public health and vector-borne disease control. However, further studies are recommended to determine the physiological mechanisms behind this effectiveness and to evaluate potential environmental and toxicological effects on non-target organisms.

The findings align with previous research demonstrating the larvicidal properties of certain essential oils against *Cx. pipiens* species (Baz *et al.,* 2024). Furthermore, our study data confirmed the strength and efficiency of all the oils used, with eucalyptus oil being the most efficient in killing mosquito larvae, followed by castor bean, geranium, and lemongrass oils. Manh *et al.* (2020) showed that eucalyptus oil possesses larvicidal properties, meaning it can kill or inhibit the development of mosquito larvae. It has been found to be effective at relatively low concentrations, and its efficacy can depend on the surface area of the water body (Riat & Kocher, 2019;).

Earlier research by Khater *et al.* (2023) showed that fifteen plant oils were tested against fourth-instar larvae of *Cx. pipiens* using concentrations of 125 to 2000 ppm. Among the most effective oils (91–100% mortality at 2000 ppm) were castor oil (*R. communis*), chamomile, garlic, jasmine, cinnamon, and rosemary. The LC_{50} of castor oil was the lowest (454 ppm), making it a promising option as a natural pesticide.

A study looked at lemon oil and eucalyptus oil (*C. citriodora* and *E. camaldulensis*) from Vietnam to see how well they kill *Aedes aegypti* larvae and found that lemon oil had an LC_{50} of about 150.5 ppm and an LC_{90} of about 615.9 ppm. *Eucalyptus* oil (*C. citriodora*)

worked better, with an LC_{50} of about 86.8 ppm and an LC_{90} of about 275.4 ppm after 24 h (Manh *et al.,* 2020). Another study looked at the oils from *E. camaldulensis* and *E. urophylla* to see how they affected *Ae. aegypti* and *Ae. albopictus* larvae: *E. camaldulensis* oil was very effective at killing the larvae because of compounds like α-terpinene, making it a strong choice for natural pesticides (Cheng *et al.,* 2009)

The present results demonstrated the high efficacy of essential oils extracted from pelargonium (*P. graveolens*), lemongrass (*C. citratus*), eucalyptus (*E. camaldulensis*), and castor bean (*R. communis*) as adulticidal against the vector mosquito *Cx. pipiens*. The first three oils achieved nearly 100% mortality at 1% concentration after 60 min, while castor oil showed lower efficacy (96.67% at the highest concentration). Our data agreed with the results of the work of Yohana *et al.* (2022), who put it at a 1% concentration, *P. graveolens* (rose-scented geranium) essential oil kills all adult mosquitoes (100% mortality) within 60 min. This insecticidal activity is attributed to compounds like geraniol and citronellol, which are major components of oil.The significantly low LC_{50} results especially for pelargonium (0.09%) and lemongrass (0.11%) indicate their high efficacy at very low concentrations. Previous research has shown that oils from pelargonium are very effective at killing different types of mosquitoes, like *Anopheles* and *Aedes*, with nearly all of them dying in similar tests (Kabera *et al.,* 2011; Alipour *et al.,* 2015). A study on lemongrass oil also demonstrated its rapid and highly toxic activity against *Culex* and *Aedes*, with toxicity linked to its citral content. Regarding *Eucalyptus*, scientific research also confirms its effectiveness as a repellent and growth inhibitor for insects, in addition to its lethal effect. Castor oil, on the other hand, showed relatively less effectiveness. Other studies have indicated that its active compounds are less capable of causing rapid paralysis and death in insects than some other oils. This difference is likely due to the lower concentration of the main terpenes or their slow absorption and distribution in the insect's body.

Eucalyptus oils have shown superior larvicidal activity, mainly due to the active compound, eucalyptol (1,8-cineole), a monoterpene known for its larvicidal properties and strong mosquito repellent. Pelargonium and lemongrass essential oils are highly effective, particularly thanks to compounds such as geraniol and citronellol, which are monoterpene alcohols known to be effective as repellents against adult mosquitoes (Muturi *et al.,* 2020).

These results highlight that essential oils, especially pelargonium and lemongrass, are appealing as natural insecticides and safer options compared to chemical pesticides, effectively killing disease-carrying insects while being better for the environment (Chellappandian *et al.,* 2018). Some studies suggest that field use of these oils requires studies on optimal formulations and measuring the long-term impact on insect communities and non-target organisms to ensure sustainable application (Giunti *et al.,* 2022).

The interplay between insecticidal efficacy and antimicrobial activity represents one of the important multiple dimensions of essential oils' use. This interaction allows not only the control of disease vectors such as the *Cx. pipiens* mosquito by killing or inhibiting their activity but also the protection of the surrounding environment from harmful microorganisms that may affect public health. This integrated dimension enhances the practical value of essential oils as multifunctional natural alternatives that combine insect control with the fight against microbial infections, enhancing their effectiveness and enhancing their use in environmental

and health prevention strategies. Many studies have indicated that certain phytochemicals such as flavonoids, terpenoids, and alkaloids, tannins, can effectively disrupt insect development, including growth, physical formation, transformation, and reproduction (Chamani *et al.,* 2025). These results match what other studies have found, showing that essential oils contain compounds like geraniol and citronellol in pelargonium, citral in lemongrass, and eucalyptol in camphor, which quickly affect the nervous system of insects (Yahia *et al.,* 2023).

Conclusion

Mosquitoes are major carriers of life-threatening diseases that pose significant risks to human health, and managing these risks goes beyond simply eliminating the insects. However, the rise of insecticide-resistant mosquito populations, along with environmental and health concerns linked to chemical pesticides, has led to the search for safer and more sustainable alternatives. Among these, plant-based compounds are attracting interest due to their natural origin, lower toxicity, affordability, and reduced risk of resistance development. In this context, researchers have investigated certain essential oils to identify potent bioactive substances with insecticidal and antimicrobial properties suitable for pest control in both human and animal health. The phytochemical analysis of the four pelargonium, lemongrass, eucalyptus, and castor oils revealed many bioactive chemical components from different classes, *viz*. flavonoids, phenolic acids, triterpenoids, phenolic acids and others together. The findings of the present study revealed that pelargonium, lemongrass, eucalyptus, and castor oil possess larvicidal and adulticidal activities against vector mosquitoes and medicinal values as it has antimicrobial activity.

Declarations:

Ethical Approval: The study was conducted according to the guidelines of the Declaration of Benha University, and approved by Ethics Committee of Faculty of Science, Benha University (Code: BUFS-REC-2025-432Ent).

Competing interests: The authors have no competing interests to declare that are relevant to the content of this article.

Contributions: I hereby verify that all authors mentioned on the title page have made substantial contributions to the conception and design of the study, have thoroughly reviewed the manuscript, confirm the accuracy and authenticity of the data and its interpretation, and consent to its submission.

Funding: This work has received no external funding.

Availability of Data and Materials: All datasets analyzed and described during the present study are available from the corresponding author upon reasonable request.

Acknowledgements: Not applicable.

REFERENCES

Alipour H, Mahdian SMA, Rami A, Abad MOK, Amin M, Dinparast N, 2015. Excito-repellency effects of *Pelargonium roseum* wild (Geraniaceae) essential oil-treated bed nets on the malaria mosquito, *Anopheles stephensi* Liston, 1901 (Diptera: Culicidae). *Journal Entomology,* 3, 87-91.

Barbosa LCA, Filomeno CA, Teixeira RR, 2016. Chemical variability and biological activities of *Eucalyptus* spp. essential oils. *Molecules,* 21(12), 1671.

Baz MM, Elhawary EA, Abdelhafiz AH, Mostafa RM, Alruhaili MH, Gattan HS, Selim A, Gad ME, Abd-Elkhalek HF, 2025. Efficacy of Hot *Capsicum annuum* extracts against the Biological Activity of *Culex pipiens* and *Musca domestica*

Larvae with their Phytochemical Profiles. *Acta Parasitologica,* 70(3), 129.

Baz MM, Selim AM, Radwan IT, Alkhaibari AM, Gattan HS, Alruhaili MH, Gad M E, 2024. Evaluating larvicidal, ovicidal and growth inhibiting activity of five medicinal plant extracts on *Culex pipiens* (Diptera: Culicidae), the West Nile virus vector. *Scientific Reports,* 14(1), 19660.

Benelli G, 2015. Plant-borne ovicides in the fight against mosquito vectors of medical and veterinary importance: a systematic review. *Parasitology Research,* 114(9), 3201-3212.

Chellappandian M, Vasantha-Srinivasan P, Senthil-Nathan S, Karthi S, Thanigaivel A, Ponsankar A, Hunter WB, 2018. Botanical essential oils and uses as mosquitocides and repellents against dengue. *Environment International,* 113, 214-230.

Cheng SS, Huang CG, Chen YJ, Yu JJ, Chen WJ, Chang ST, 2009. Chemical compositions and larvicidal activities of leaf essential oils from two eucalyptus species. *Bioresource Technology,* 100(1), 452-456.

Chamani, M, Dadpour M, Dehghanian Z, Panahirad S, Chenari Bouket A, Oszako T, Kumar S, 2025. From Digestion to Detoxification: Exploring Plant Metabolite Impacts on Insect Enzyme Systems for Enhanced Pest Control. *Insects,* 16(4),1-27.

Eden WT, Alighiri D, Supardi KI, Cahyono E, 2020. The mosquito repellent activity of the active component of air freshener gel from Java Citronella oil (*Cymbopogon winterianus*). *Journal of Parasitology Research,* 1, 9053741.

Galea C, Cocoș DI, Forna NC, Păcurar M, Kamel E, 2024. Phytochemical study of the essential oil of *Pelargonium roseum* by gas chromatographic method. *Romanian Journal of Oral Rehabilitation,* 16(3), 1-9.

Gilles M, Zhao J, An M, Agboola S, 2010. Chemical composition and antimicrobial properties of EOs of three Australian *Eucalyptus* species. *Food chemistry.* 119, 731–737.

Giunti G, Benelli G, Palmeri V, Laudani F, Ricupero M, Ricciardi R, Campolo O, 2022. Non-target effects of essential oil-based biopesticides for crop protection: Impact on natural enemies, pollinators, and soil invertebrates. *Biological Control,* 176, 105071.

Hassan GM, Aboelfadel MA, El-Aassar MR, El-Damer MH, 2024. Implementation of Eco-Friendly Control Tactics against Infestations of *Aphis craccivora* and *Tetranychus urticae* on Common Bean Plants. *Journal of Plant Protection and Pathology,* 15(5), 135-141.

Hill KD, Johnson LAS, 1998. Systematic studies in the eucalypts. 8. A review of the eudesmioid eucalypts, *Eucalyptus* subgenus Eudesmia (Myrtaceae). *Telopea,* 7(4), 375-414.

Kabera J, Gasogo A, Uwamariya A, Ugirinshuti V, Nyetera P, 2011. Insecticidal effects of essential oils of *Pelargonium graveolens* and *Cymbopogon citratus* on *Sitophilus zeamais* (Motsch.). *African Journal of Food Science*, 5(6), 366-375.

Khater H, E Soliman D, Slim A, Debboun M, Baz MM, 2023. Larvicidal efficacy of fifteen plant essential oils against *Culex pipiens* L. mosquitoes in Egypt. *Egyptian Journal of Veterinary Sciences,* 54(2), 183-192.

Madhav M, Blasdell KR, Trewin B, Paradkar PN, López-Denman AJ, 2024. *Culex*-transmitted diseases: mechanisms, impact, and future

control strategies using Wolbachia. *Viruses*, 16(7), 1134.

Magaldia S, Mata-Essayaga S, Hartung de Caprilesa C, Pereza C, Colella MT, Carolina O, Yudith O, 2004. Well diffusion for antifungal susceptibility testing. *International Journal of Infectious Diseases,* 8, 39-45.

Manh HD, Hue DT, Hieu NTT, Tuyen DTT, Tuyet OT, 2020. The Mosquito larvicidal activity of essential oils from *Cymbopogon* and *Eucalyptus* Species in Vietnam. *Insects,* 11(2), 1-7.

Mostafa RM, Baz MM, Ebeed HT, Essawy HS, Dawwam GE, Darwish AB, Selim A, El-Shourbagy NM, 2024. Biological effects of *Bougainvillea glabra, Delonix regia, Lantana camara, and Platycladus orientalis* extracts and their possible metabolomics therapeutics against the West Nile virus vector, *Culex pipiens* (Diptera: Culicidae). *Microbial Pathogenesis,* 195, 106870.

Muturi EJ, Hay WT, Doll KM, Ramirez JL, Selling G, 2020. Insecticidal activity of *Commiphora erythraea* essential oil and its emulsions against larvae of three mosquito species. *Journal of Medical Entomology,* 57(6), 1835-1842.

Rahayu R, Mairawita J, 2018. Efficacy and residual activity of lemongrass essential oil (*Cymbopogon flexuosus*) against German cockroaches (*Blattella germanica*). *Journal of Entomology*, 15,149–154.

Riat AK, Kocher DK, 2019. Larvicidal potential of *Eucalyptus globulus* oil against *Anopheles stephensi*. *International Journal of Mosquito Research,* 6(2), 24-26.

Sanches LJ, Marinello PC, Panis C, Fagundes TR, Morgado-Díaz JA, de-Freitas-Junior JCM, Cecchini R, Cecchini AL, Luiz RC, 2018. Cytotoxicity of citral against melanoma cells: The involvement of oxidative stress generation and cell growth protein reduction. *Tumor Biology*, 39: 1010428317695914.

Selvakumaran J, Ragavendran K, Ignacimuthu S, Sivanandhan S, Reegan AD, Aremu AO, Thiruvengadam M, 2024. Mosquitocidal susceptibility and non-target effects of essential oil from *Brassica nigra* WDJ Koch seeds on immature stages of *Aedes aegypti* L., *Anopheles stephensi* Liston and *Culex quinquefasciatus* Say. *South African Journal of Botany,* 167, 578-584.

Sobhy HA, Elissawy AE, Eldahshan OA, Singab ANB, 2023. Role of Egyptian Essential Oils in Health Care and Industry. In Pharmacological Aspects of Essential Oils (pp. 107-119). CRC Press.

Stefanakis MK, Touloupakis E, Anastasopoulos E, Ghanotakis D, Katerinopoulos HE, Makridis P, 2013. Antibacterial activity of EOs from plants of the genus *Origanum*. *Food Control,* 34, 539–546

Szutt A, Dołhańczuk-Śródka A, Sporek M, 2020. Evaluation of Chemical Composition of Essential Oils Derived from Different Species Leaves. *Ecological Chemistry and Engineering S*, 26(4), 807-816.

Wazir N, Hussain F, Akhtar T, Nasir U, Zaman MA, Nazish N, Naeem MI, 2025. Larvicidal, Insecticidal and Mosquito repellent activity of Scented Geranium (*Pelargonium* species) essential oil against Malarial Vector; Anopheles stephensi. Complementary and Alternative Medicine: *Essential Oils,* 153-161.

WHO, 2005. Guidelines for laboratory and field testing of mosquito larvicides.

World Health Organization, 1-41.

WHO, 2016. Test procedures for insecticide resistance monitoring in malaria vector mosquitoes, (Second edition) (Updated June 2018),1-48.

Yahia H, Djebbar F, Mahdi D, Soltani N, 2023. Insecticidal activity of *Eucalyptus globulus* (Labill) essential oil against *Culiseta longiareolata* (M., 1838) (Diptera: Culicidae). *Allelopathy Journal,* 59(1), 81-94.

Yohana R, Chisulumi PS, Kidima W, Tahghighi A, Maleki-Ravasan N, Kweka EJ, 2022. Anti-mosquito properties of *Pelargonium roseum* (Geraniaceae) and *Juniperus virginiana* (Cupressaceae) essential oils against dominant malaria vectors in Africa. *Malaria Journal,* 21(1), 219.

ARABIC SUMMARY

التحليل الكيميائي، والفعالية الحشرية والميكروبية لزيوت الجيرانيوم، الليمون العطرى، والأوكالبتوس، وزيت الخروع ضد بعوض الكيوليكس بيبينز

هبة م. أبو العلا[1]، هبة يحيي. ماضي[2]، محمد م. باز[3]، جهاد أ. بسيوني[4]، أميرة ت. علي[1]

1-قسم الطفيليات الطبية، كلية الطب، جامعة بنها، بنها، مصر
2-قسم علم الحيوان، كلية البنات، جامعة عين شمس، القاهرة، مصر
3-قسم علم الحشرات، كلية العلوم، جامعة بنها، بنها ، مصر
4-قسم الطفيليات، كلية طب القاهرة، جامعة القاهرة، القاهرة، مصر

تعتبر البعوض من أكثر المخلوقات فتكًا على وجه الأرض، وهي مسؤولة عن ملايين الوفيات سنويًا من خلال نقل الأمراض البشرية المختلفة. ونتيجةً لذلك، كان استخدام العديد من المبيدات الحشرية الصناعية ضروريًا لمنع انتشار الأمراض، مما أدى إلى زيادة استخدام هذه المواد الكيميائية لحماية الإنسان. وقد أدى الاستخدام الواسع النطاق للمبيدات الحشرية إلى مشاكل صحية كبيرة للبشر، وتدهور بيئي، ومقاومة البعوض للمبيدات الحشرية الصناعية. سعت هذه الدراسة إلى تقييم أربعة زيوت عطرية وخصائصها الكيميائية النباتية ضد يرقات البعوض . أُجريت الاختبارات الحيوية في بيئات معملية، وحُددت التركيزات القاتلة (LC_{50}, LC_{90}) بعد 24 و48 ساعة. أظهرت جميع الزيوت العطرية المختبرة نشاطًا قاتلًا لليرقات، وتراوحت معدلات الوفيات بعد 24 ساعة بين 90 % و100% عند تركيز 1000 جزء في المليون. أظهر زيت الأوكالبتوس العطري (*E. camaldulensis*) أعلى فعالية، محققًا نسبة نفوق 100% لليرقات (LC_{50} = 305.3) جزء في المليون)، يليه زيت الخروع جزء من (LC_{50} = 388.3جزء في المليون)، ثم زيت البلارجونيوم (*P. graveolens*) الذي ساهم في نفوق 98% (LC_{50} = 446.2) % جزء في المليون). أما زيت الليمون (*C. citratus*) فقد أظهر أقل نشاط مبيد لليرقات، حيث بلغت نسبة نفوقه 90% (LC_{50} = 491.5)جزء في المليون). أما زيوت البلارجونيوم والليمون والأوكالبتوس، فقد أظهرت نشاطًا مبيدًا عاليًا ضد أنثى البعوض *Cx. pipiens* حيث حققت نسبة نفوق تقارب 100% عند تركيز 1% بعد 60 دقيقة من التعرض. أظهر زيت الأوكالبتوس والبلارغونيوم فعاليةً مضادةً للبكتيريا بشكلٍ ملحوظ. كما أظهر زيت الأوكالبتوس أعلى فعاليةٍ إجمالية، حيث وصلت مناطق التثبيط إلى 25 مم ضد العصوية الرقيقة والفطريات البيضاء. أظهرت الكلبسيلا الرئوية والسالمونيلا التيفية حساسيةً متوسطة، حيث وصلت مناطق التثبيط إلى 14 مم و19 مم على التوالي. كشف تحليل كروماتوغرافيا الغاز-مطياف الكتلة (GC-MS) عن العديد من المواد الكيميائية الضوئية النشطة بيولوجيًا، بما في ذلك التربينات الاحادية والمتعددة، الاحماض الدهنية، والأحماض الفينولية، والتي قد تُفسر التأثيرات المُبلغ عنها. قد يُسهّل هذا البحث تطوير بدائل اقتصادية للمبيدات الحشرية العضوية باهظة الثمن والمواد الكيميائية الخطرة، وذلك من خلال استخدام نباتاتٍ سهلة المنال وصديقة للبيئة، وعادةً ما تكون آمنةً للإنسان والحيوان والنظام البيئي