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Original article

Larvicidal effects of some essential oils against *Aedes aegypti* (L.), the vector of dengue fever in Saudi Arabia

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ABSTRACT

Essential oils are very popular among organic growers because they are ecologically safe, do not have mammalian toxicity, and cannot be resistant to a variety of contaminants. Four essential oils, Lemon, Lavender, Peppermint, and Neem, were tested for larvicide efficacy against the dengue fever vector *Aedes aegypti* larvae under laboratory conditions using dipping bioassay techniques. Among the essential oils tested, lemon, peppermint, and lavender oils showed high larvicidal activity against larvae of *Ae. aegypti*. Lemon oil showed the highest effects (LC_{50} 10.676 ppm), while Peppermint, Lavender and Neem oil showed the lowest effects (LC_{50} 21.380, 29.818 and 38.058 ppm, respectively). As a result, the mixture of lemon oil (LC_{50}) with Peppermint oil (LC_{25}) showed the highest co-toxicity factor, whereas the mixture of Lemon oil (LC_{50}) with Diesel oil (LC_{25}) showed the lowest co-toxicity factor. Based on the results of this study, it appears that essential oils may be useful as larvicides against *Ae. aegypti* larvae. In search of new natural larvicides, these compounds may provide an alternative to Synthetic insecticides as these are environmentally safe insecticides.

1. Introduction

Various tropical and subtropical countries are home to Aedes aegypti *(Ae. aegypti)*, a vector of dengue fever. Nearly half of the world's population is now at risk from dengue fever, which has increased fourfold since 1970. Dengue transmission rates had been estimated by Hale et al. to be greater than 50 % in 1988 (Hales et al., 2002). Female mosquitoes are the main vector of diseases that cause serious health problems, especially in developing countries located in tropical and subtropical regions (Dharmagadda et al., 2005). Currently, there is no dengue vaccine available, and vector control will stay the primary method of control. The reduction of resources for mosquito production is considered the main method to treat several major vector diseases in the world (Alyaha et al., 2018). When effective methods have been implemented to target mosquitoes properly, it helped in saving lives and protecting the lives of millions. Nevertheless, vector control in general and mosquitoes, in particular, are still presenting a challenge. This is in addition to the challenges represented by old and emerging diseases (Al-Hakimi et al., 2022; WHO, 2000). Larvicidal activity largely depends on the use of synthetic insecticides such as organophosphates, pyrethroids, and insect growth regulators (Algamdi and Mahyoub, 2022). By using these insecticides we can effectively control the pest but their frequent use has become a danger to the biological ecosystems and thus the widespread development of resistance (Al-Hakimi et al., 2022; Hedin et al., 1997). In Jeddah, a campaign was organized to reduce mosquito breeding sources through health awareness from house to house carried out by supervisors. However, cases of dengue are continuing, and this confirms that awareness-raising work alone is not sufficient to control the disease. This must include periodic spraying of pesticides essential for vector and disease control. In the past few years, the need has become urgent to use environmentally friendly natural products in the management of vector mosquitoes as a biological control agent by physical and chemical methods (Barnawi et al., 2019; Mahyoub, 2018; Mahyoub et al., 2018). Using natural products avoids further deleterious effects on humans and resources (Al-Zahrani Mohamd et al., 2019; Mahyoub, 2019). Moreover, the economic benefits of using, manufacturing and applying any of local wild plants as pesticidal agents is inexpensive compared to the harmful effects of chemicals, pollution and radiation (Al-Hakimi et al., 2022; Mahyoub Jazem, 2021). Recent

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studies have proven the pesticidal effect of medicinal plants on the vector of Dengue Fever viruses derived from *Ae. aegypti* mosquitoes (Al-Rashidi et al., 2022). However, previously published works have not attempted to study the effects of essential oils on *Ae. aegypti* larvae. Therefore, this study aims to evaluate the susceptibility of the *Ae. aegypti* larvae against essential oils such as Lemon, Peppermint, Lavender and Neem (natural oils from plants) and compare to diesel oil (natural oil from the ground) under laboratory conditions using the WHO larvicide bioassay technique (WHO, 1999), this study may be helpful in future to manage mosquito population.

2. Materials and methods

2.1. Mass rearing of the Ae. aegypti mosquito larvae

The larvae of mosquitoes were originally collected from the different breeding sites from the different municipalities of Jeddah and colonized in the laboratory without exposure to pathogens or insecticides for some generations to get the susceptible strain. Adults were raised in a laboratory at 25 ± 2 °C and 60 - 70% relative humidity (Adebayo et al., 1999; Alyaha et al., 2018), The photoperiod was 14:10 h (light/dark). For obtaining proteins for egg maturation, adult females were frequently fed on the blood of restrained rats to supplement 10 % sucrose. Fish food was used as a food source for the larvae. These mosquitos take 3–4 weeks to grow from an egg to an adult under these conditions. Larvae of the late 3rd and early 4th instars were used to conduct these experiments.

2.2. Larval bioassays

According to the standard WHO larvicide bioassay method (WHO, 1999), essential oils and other compounds were evaluated and sensitively tested for their larvicidal effects against *Ae. aegypti* larvae. Analyze the sensitivity of *Ae. aegypti* larvae on their late 3rd and early 4th instars to these compounds. Five replicates of each oil concentration were prepared, each containing 100 ml of water and 20 larvae of late 3rd or early 4th instar, and the mortality rate was observed for each replicate after 24 h of treatment. It was decided to count dead larvae by using needles that were pricked in the neck or siphon and larvae remained motionless.

Using distilled water, 20 larvae of *Ae. aegypti* of the late 3rd instar or early 4th instar were transferred to a 500 ml enamel bowl containing 100 ml of distilled water and 1.0 ml of a serial dilution of each extract. For each concentration, five replicates were conducted simultaneously, with a total of 100 larvae. Distilled water was used to maintain the larval population of the 3rd or 4th instars. Each compound's toxicity was evaluated at five different concentrations, with mortality ranges ranging from 0 to 100 %. In addition to observing and recording symptoms, no food was offered to the larvae after treatment. A larva was considered dead if, after 24 h, it showed no swimming movements, even when gently touched with a glass rod, as described in the World Health Organization's technical report series (WHO, 1999). Each concentration's mortality rate was calculated by combining the dead larvae in five replicates. These bioassays tests were performed at 25 ± 5 °C and 60 - 70% relative humidity on laboratory strains of mosquito larvae and mortality was observed after 24 h of pesticide treatment (Adebayo et al., 1999; Mahyoub, 2019; WHO, 1999).

2.3. Sample preparation

The larvae of *Ae. aegypti* were treated with commercially available lemon, peppermint, lavender, neem, and diesel oils. In *n*-hexane, a 1000 ml/l stock solution of essential oils was prepared.

2.4. Mixtures toxicity (joint action)

Lemon oil (LC_{50}) was combined with other oils such as Peppermint, Lavender, Neem, and Diesel (LC_{25}) and used as a control. To distinguish between potentiation, antagonism, and additive, the combined effect of the different mixtures was expressed in terms of a Co-toxicity factor according to (Sun and Johnson, 1960) using the following formula:

$$\text{Co} - \text{toxicity factor (CF)} = \frac{(O - E)}{E} \times 100$$

where:

O: is observed mortality (OM) expressed as % and E: is expected mortality (EM) expressed as %.

The joint action of different mixtures against mosquito larvae was expressed as the co-effective factor (C.F.) as follows:

Potentiation effect:.$(CF) \leq +20$
Antagonism effect:.$(CF) \leq -20$
Additive effect: C.F values range between positive 20 and negative 20.

2.5. Statistical analysis

Mortality percentages were calculated for natural mortalities according to (Abbott, 1925). The tested oils were compared for their efficiency according to their LC_{50}, LC_{90} and slopes of the toxicity lines and statistical parameters (Finney, 1971; Mahyoub, 2019).

3. Results

This study, tested four essential oils; Lemon, Peppermint, Lavender and Neem (natural oils from plants) compared with Diesel oil (natural oil from the ground) against *Ae. aegypti* larvae with series concentrations under laboratory conditions using dipping application bioassay technique. The evaluations of compound actions were compared as follows:

3.1. Comparison on basis of percent larval mortality

The results are presented in Tables 1–5 and Figs. 1–5, exhibited the toxicity of Lemon oil, Peppermint oil, Lavender oil, Neem oil and Diesel oil using the WHO larval bioassay technique against *Ae. aegypti* larvae with series concentrations; of 2–40, 10–50, 15–55, 10–100 and 20–180 ppm, respectively. The percent mortality ranged between 17 and 90 % when treated larvae with Lemon oil according to the previous concentrations, while ranged between 14 and 94 when treated with Peppermint oil, on the other hand, percent mortality ranged between 13 and 88 % when treated with Lavender oil, whereas, reached to 14–89 % when treated with Neem oil. Finally, percent mortality ranged between 12 and 87 % when treated with Diesel oil with the above concentrations.

3.2. Comparison on basis of LC_{50} and LC_{90} and relative toxicity

The required values, i.e., LC_{50} and LC_{90} are presented in Tables 1–6 and Figs. 1–6. Data given summarized the susceptibility of *Ae. aegypti* larvae to the tested essential oils; Lemon, Peppermint, Lavender and Neem compared to Diesel oil.

The results according to LC_{50s}, LC_{90s} and relative toxicity clearly showed that Lemon oil gave the highest effect against *Ae. aegypti* larvae (LC_{50} 10.676 ppm); while Peppermint oil, Lavender oil and

Table 1
Susceptibility of *Ae. aegypti* larvae to Lemon oil after 24 h exposure time.

Conc. (ppm)	Larval mortality (%)[a]	Statistical parameters				
		LC_{25} (LCL-UCL)	LC_{50} (LCL-UCL)	LC_{90} (LCL-UCL)	Slope	$(Chi)^2$
2	17	3.599	10.676	62.38	1.572	6.69
5	32	(2.648–4.559)	(8.021–11.549)	(46.618–95.408)		
15	54					
25	72					
40	90					

LCL: Lower confidence limit, UCL: Upper confidence limit.
[a] : Five replicates, a total of 20 larvae each; control mortalities ranged between 0.0 and 3.0%.

Table 2
Susceptibility of *Ae. aegypti* larvae to Peppermint oil after 24 h exposure time.

Conc. (ppm)	Larval mortality (%)[a]	Statistical parameters				
		LC_{25} (LCL-UCL)	LC_{50} (LCL-UCL)	LC_{90} (LCL-UCL)	Slope	$(Chi)^2$
10	14	14.172	21.380	50.23	3.455	3.071
20	46	(11.705–15.354)	(19.433–23.292)	(44.426–58.921)		
30	66					
40	80					
50	94					

LCL: Lower confidence limit, UCL: Upper confidence limit.
[a] : Five replicates, a total of 20 larvae each; control mortalities ranged between 0.0 and 3.0%.

Table 3
Susceptibility of *Ae. aegypti* larvae to Lavender oil after 24 h exposure time.

Conc. (ppm)	Larval mortality (%)[a]	Statistical parameters				
		LC_{25} (LCL-UCL)	LC_{50} (LCL-UCL)	LC_{90} (LCL-UCL)	Slope	$(Chi)^2$
15	13	20.005	29.818	63.655	3.891	1.956
20	27	(17.922–21.839)	(27.718–32.107)	(55.880–75.850)		
30	46					
40	67					
55	88					

LCL: Lower confidence limit, UCL: Upper confidence limit.
[a] : Five replicates, a total of 20 larvae each; control mortalities ranged between 0.0 and 3.0%.

Table 4
Susceptibility of *Ae. aegypti* larvae to Neem oil after 24 h exposure time.

Conc. (ppm)	Larval mortality (%)[a]	Statistical parameters				
		LC_{25} (LCL-UCL)	LC_{50} (LCL-UCL)	LC_{90} (LCL-UCL)	Slope	$(Chi)^2$
10	14	19.686	38.058	133.177	2.356	13.399
30	30	(6.736–23.475)	(20.927–58.956)	(121.640–502.966)		
50	54					
70	78					
100	89					

LCL: Lower confidence limit, UCL: Upper confidence limit.
[a] : Five replicates, a total of 20 larvae each; control mortalities ranged between 0.0 and 3.0%.

Table 5
Susceptibility of *Ae. aegypti* larvae to Diesel oil after 24 h exposure time.

Conc. (ppm)	Larval mortality (%)[a]	Statistical parameters				
		LC_{25} (LCL-UCL)	LC_{50} (LCL-UCL)	LC_{90} (LCL-UCL)	Slope	$(Chi)^2$
20	**12**	40.265	82.329	301.24	2.226	9.317
50	**31**	(18.579–51.231)	(53.790–124.963)	(256.847–1073.575)		
80	**44**					
120	**58**					
180	**87**					

LCL: Lower confidence limit, UCL: Upper confidence limit.
[a] : Five replicates, a total of 20 larvae each; control mortalities ranged between 0.0 and 3.0%.

Table 6
Relative toxicity of some essential oils on *Ae. aegypti* larvae after continuous exposure for 24 h.

Oil name	LC_{25}	LC_{50}	LC_{90}	Slope	Relative toxicity*	Order of toxicity
Lemon oil	3.599	10.676	62.38	1.572	8.4	1
Peppermint oil	14.172	21.380	50.23	3.455	3.8	2
Lavender oil	20.005	29.818	63.65	3.891	2.7	3
Neem oil	19.686	38.058	133.177	2.356	2.1	4
Diesel oil	40.265	82.329	301.24	2.226	1.0	5

Neem oil gave medium effects (LC_{50s} 21.380, 29.818 and 38.058 ppm), whereas Diesel oil gave the least effect (LC_{50} 82.329 ppm), and obtained the same trend in LC_{90s} (Tables 1–6) and Figs. 1–6.

3.3. The slope of toxicity lines

Data in Tables 1–6 show that the slope of *Ae. aegypti* larvae when using tested essential oils; Lemon, Peppermint, Lavender and Neem compared with Diesel oil were (1.572, 3.455, 3.891, 2.356 and 2.226).

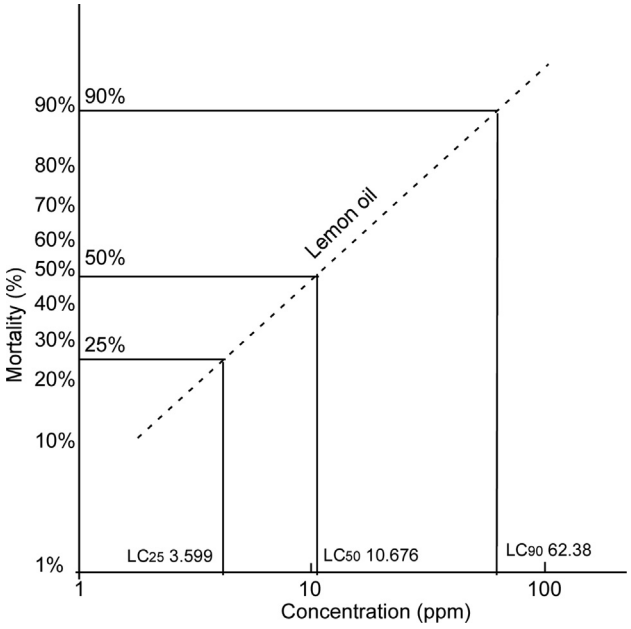

Fig. 1. LC-P line of Lemon oil against *Ae. aegypti* larvae.

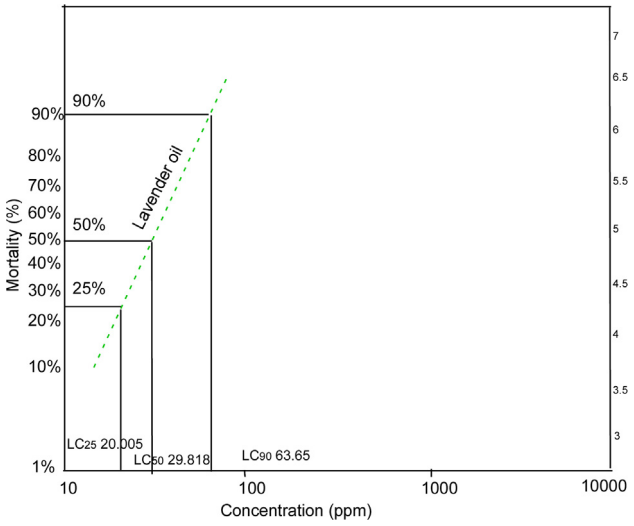

Fig. 3. LC-P line of Lavender oil against *Ae. aegypti* larvae.

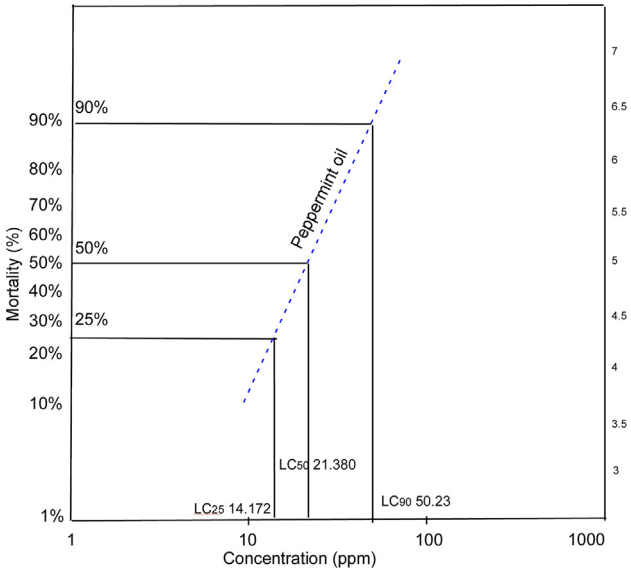

Fig. 2. LC-P line of Peppermint oil against *Ae. aegypti* larvae.

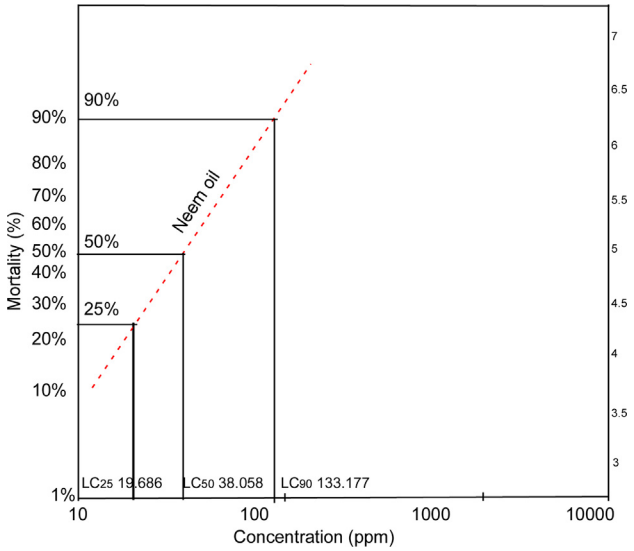

Fig. 4. LC-P line of Neem oil against *Ae. aegypti* larvae.

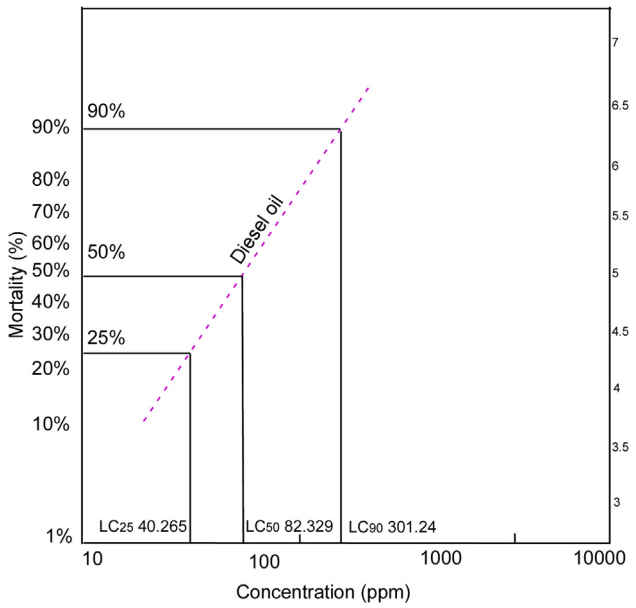

Fig. 5. LC-P line of Diesel oil against *Ae. aegypti* larvae.

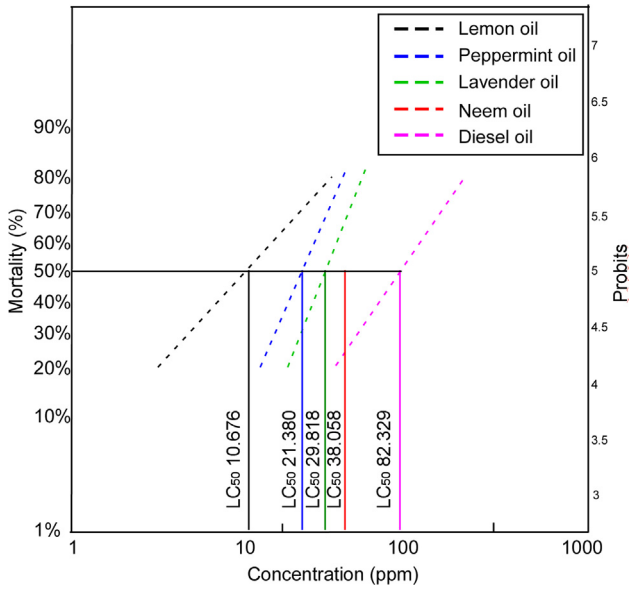

Fig. 6. LC-P lines of some essential oils on *Ae. aegypti* larvae.

3.3.1. X^2 $(Chi)^2$ value

Generally, when tabulated X^2 $(Chi)^2$ is greater than calculated at 0.05 level of significance indicating the homogeneity of results.

Results in Tables 1–5 indicated that the calculated X^2 $(Chi)^2$ reached 6.69, 3.071, 1.956, 13.399 and 9.317 when using Lemon, Lavender, Peppermint, Neem and Diesel oil on *Ae. aegypti* larvae.

$$\text{Relative toxicity}* = \frac{LC_{50}\ of\ least\ toxic\ compound}{LC_{50}\ of\ most\ toxic\ compound}$$

According to our results, Lemon, Peppermint and Lavender essential oils show homogeneity, [tabulated X^2 $(Chi)^2$ greater than calculated $(Chi)^2$ at 0.05 level of significance], whereas in the case of neem and diesel oil show heterogeneity [tabulated X^2 $(Chi)^2$ less than calculated $(Chi)^2$], respectively.

3.4. Joint action studies of some essential oils against Ae. aegypti larvae using dipping application technique under laboratory conditions

Results in Table 6 show that the preliminary toxicity screening of four essential oils; Lemon, Peppermint, Lavender and Neem (natural oils from plants) compared with Diesel oil (natural oil from the ground) against *Ae. aegypti* larvae with series concentrations under laboratory conditions using dipping application bioassay technique. For the tested essential oils, the $LC_{25,50}$ values were 3.599, 10.676 ppm for Lemon oil, 14.172, 21.380 ppm for Peppermint oil, 20.005, 29.818 ppm for Lavender oil and 19.686, 38.058 ppm for Neem oil and finally 40.686, 82.329 ppm for Diesel oil, respectively.

Results in Table 7 show the expected percentage observation of the 4th instar field larvae of *Ae. aegypti* mosquito through mixing Lemon oil with Peppermint oil, Lavender oil, Neem oil and Diesel oil as shown in table C.F. value and the type of combined effect produced by mixing the tested compounds. Lemon oil was used in this study at a concentration that kills 50 % (LC_{50}) of the larvae with corresponding concentrations for the LC_{25} values for Peppermint oil, Lavender oil, Neem oil and Diesel oil. The values of the effective factor assistant C.F obtained from mixing lemon oil with N Peppermint oil, Lavender oil, Neem oil confirmed the existence of different levels of Potentiation where mixing LC_{50} of Lemon oil with LC_{25} of Peppermint resulted in giving the highest level of reinforcement (C.F. = + 26.3). Mixing LC_{50} of Lemon oil with LC_{25} Lavender oil (C.F. = + 24.7) came the second. Then mixing LC_{50} of Lemon oil with LC_{25} Neem oil (C.F. = + 20.5), while mixing LC_{50} of Lemon oil with LC_{25} Diesel oil gave additive effects, where the C.F. values were equal to (C.F. = + 12.5) (Table. 7 and Fig. 7).

$$\text{Co}-\text{toxicity factor} = \frac{Observed\ \%\ mortality - Expected\ \%\ mortality}{Expected\ \%\ mortality} \times 100$$

Table 7
The joint action of some essential oils on *Ae. aegypti* larvae after continuous exposure for 24 h.

Essential oil	Cumulative mortality (%)		C.F.*	Joint action
	Expected	Observed		
Lemon oil (LC_{50}) + Peppermint oil (LC_{25})	75	95	26.3	Potentiation
Lemon oil (LC_{50}) + Lavender oil (LC_{25})	75	93	24.7	potentiation
Lemon oil (LC_{50}) + Neem oil (LC_{25})	75	88	20.5	potentiation
Lemon oil (LC_{50}) + Diesel oil (LC_{25})	75	80	12.5	additive effect

EM (%) = summation of mortality (%) from insects exposed to several LC values of each essential oil in a paired combination as tested individually.
OM (%) mortality indicates that of the mixture tested in the same experimental container at the LC values level of each.
* Coeffective factor (Mansour et al., 1966).

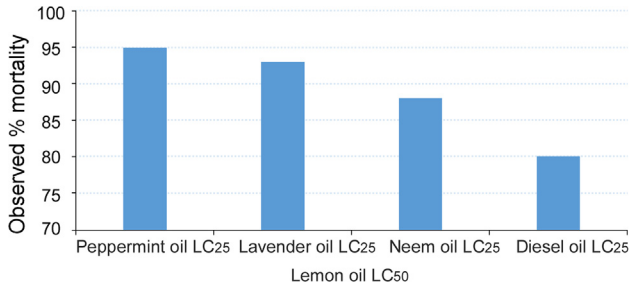

Fig. 7. Joint action of binary mixtures of some essential oils on *Ae. aegypti* larvae after continuous exposure for 24 h. under laboratory conditions.

A positive factor of ≥ 20 refers to potentiation, a negative factor of ≤ -20 refers to antagonism, and the intermediate values of >-20 to <20 refer to an additive effect.

4. Discussion

Insecticides are a critical component of the *Ae. aegypti* control program. Dengue fever epidemics are mainly controlled by killing both adult mosquitoes and larvae with insecticides. However, these pesticides have serious negative repercussions on the environment because they cause pollution of soil and surface water, soil and living organisms (Zhang et al., 2015). Moreover, prolonged use of pesticides renders mosquitoes resistant and thus presents the biggest obstacle to the control of medically significant arthropod pests and will directly contribute to the re-emergence and outbreak of vector-borne diseases over a wide geographic scale of the world (Georghiou and Taylor, 1986; Smith et al., 2016; WHO, 1976). In contrast, some herbs have insecticidal properties that have enabled them to be used as environmentally friendly control alternatives in the past few years to replace dangerous chemical pesticides (Al-Rashidi et al., 2022; Hazarika et al., 2018). Essential oils from natural plants are one of the most important alternatives for their ease of obtaining and low cost compared to synthetic chemical products. Moreover, they do not leave residues in the environment because they are extracted from renewable sources and decompose quickly (Al-Rashidi et al., 2022; Hazarika et al., 2018) and they do not develop insect resistance (Kusuma and Mahfud, 2017; Mashlawi et al., 2022). Thus, using essential oils for mosquito control is an environmentally safe option compared to harmful synthetic insecticides. There are several techniques for using essential oils to control mosquitoes. One study suggested that essential oils can be used to kill mosquitoes by inhalation (Lee et al., 2001). In this study, however, the dipping technique was used in an aqueous solution of plant extracts for a specified period at different concentrations according to (WHO, 2006). Our results showed that the mortality rate ranged from 17 to 90 % when the larvae were treated with Lemon oil, while it ranged between 14 and 94 when treated with Peppermint oil, and between 13 and 88 % when treated with Lavender oil, and between 14 and 89 % when treated with Neem oil, and final rangedged between 12 and 87 % when treated with diesel oil. Lemon oil is among the eight essential oils tested against *Cx. quinquefasciatus* filarial vectors that showed 100 % larvicidal activity at 1000 ppm (Manimaran et al., 2012). Amer and Mehlhorn (2006) documented that lemon oil and some other oils used in the study showed larvicidal activity against *Ae. aegypti*. They also reported that these oils could protect the skin of human volunteers for a maximum of 8 h and were 100 % repellent against the three species used in the study, *Ae. aegypti, Cx. quinquefasciatus* and *An. stephens* (Amer and Mehlhorn, 2006).

In the present study, Lemon oil recorded the highest effect on *Ae. aegypti* larvae (LC_{50} 10.676 ppm), while Peppermint, Lavender, and Neem oils recorded medium effects (LC_{50s} 21.380, 29.818 and 38.058 ppm, respectively), whereas Diesel oil recorded the least effective among all (LC_{50} 82.329 ppm). On the other hand, Peppermint oil recorded the highest effect on *Ae. aegypti* larvae (LC_{90} 50.23 ppm), Lemon Lavender and Neem oils recorded medium effects (LC_{90s} 62.38, 63.65 and 133.177 ppm, respectively), whereas Diesel oil recorded the least effective among all the oils used (LC_{90} 301.24 ppm). Our result for the LC_{50} for lemon oil was significantly better than those reported by (Amer and Mehlhorn, 2006; Manimaran et al., 2012) with LC_{50} values of 50.2 and 43.79 ppm against *Cx. quinquefasciatus* after 24 h post-treated, respectively. The results obtained by Manimaran et al. (2012) for the LC_{50s} of lemon oil against the other two mosquitoes *Ae. aegypti* and *An. stephensi* were 61.69 and 62.78 ppm, respectively. The LC_{90} value of lemon oil in our study was 62.38 ppm against *Ae. aegypti* after 24 h of treatment. Manimaran et al. (2012) reported that LC_{90} values for the same oil against *Ae. aegypti, An. stephensi* and *Cx. quinquefasciatus* were 367.67, 274.38 and 146.94 ppm, respectively.

Peppermint oil in this study recorded the LC_{50} and LC_{90} values of 21.380 and 50.23 ppm against the larvae of *Ae. aegypti,* respectively. A similar observation was reported by Manimaran et al. (2012) with Peppermint oil; LC50 values of 46.23, 42.25 and 39.74 ppm against *Ae. Aegypti, Cx. quinquefasciatus* and *An. stephensi,* respectively. However, our results for LC_{90} were more effective compared to those reported by (Manimaran et al., 2012) of 165.36, 132.41 and 115.67 ppm against *Ae. aegypti, Cx. quinquefasciatus* and *An. stephensi*, respectively. Other similar studies documented that LC_{50} values of four different Peppermint species varied from 47.88 to 74.28 ppm, while LC_{90} values varied from 64.34 to 107.45 ppm against *Cx. pipiens* after 48 h post-treatment (Koliopoulos et al., 2010). In our study, lavender oil showed a relatively high efficacy that ranged from 13 to 88 % mortality after 24 h of treatment, while the LC_{50} and LC_{90} values were 29.818 and 63.65 ppm, respectively. These values were much lower than LC_{50} and LC_{90} values of 301.11 and 1437.63 ppm, respectively which were reported in the same oil against *Cx. pipiens* after 24 h of treatment (Bosly, 2022). Manimaran et al. (2012) reported that lavender and peppermint essential oils at a concentration of 1000 ppm against *Cx. quinquefasciatus* led to 68 and 100 % larval mortality, respectively, indicating the strong larvicide effect of peppermint oil. Another author reported that lavender essential oil recorded a LC_{50} of 140 ppm against *Cx. pipiens* larvae at a concentration of 800 ppm and caused larval mortality of 100 % (El-Akhal et al., 2021).

Neem oils in the present study showed the LC_{50} and LC_{90} values of 38.058 and 133.177 ppm, while Diesel oil showed the LC_{50} and LC_{90} values of 82.329 and 301.24 ppm, respectively against *Ae. aegypti* after 24 h of exposure. In a similar study by (Kaura et al., 2019), neem oil was less effective against *Ae. aegypti* and *Ae. albopictus* at higher concentrations compared to the results of neem oil in this study. The authors observed that the LC_{50s} of larvae and pupae of the two mosquito species tested (*Ae. aegypti* and *Ae. albopictus*) were 7852 and 19054 ppm, while the LC_{90s} were 10,092 and 19952 ppm, respectively.

The present results clearly showed that lemon oil was more effective than other essential oils used, while Peppermint oil, neem oil and lavender oil showed medium effectiveness against *Ae. aegypti* larvae, while diesel oil was less effective among the previous essential oils. In general, however, all of these oils are considered highly effective compared to the oils used in some studies conducted in other areas of the world.

5. Conclusion

Finally, essential oils such as Lemon, Lavender, Peppermint, and Neem offer the strongest larvicidal properties. As a result of the

current study's findings, essential oils should be created as potential natural pesticides for *Ae. aegypti* larvae integrated pest control, although oil mixes must be further assessed for human safety and activity.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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