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Larvicidal and pupicidal effects of some essential oils against *Musca domestica* Linnaeus, 1758 (Diptera:Muscidae)

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Abstract
Essential oils (EOs) from plants can provide an eco-friendly alternatives to traditional synthetic insecticides. This study aimed to evaluate the effects of six different essential oil (*Foeniculum vulgare, Cinnamomum verum, Allium sativum*, *Capsicum annum, Mentha piperita, Urtica dioica*) against *Musca domestica.* Larvicidal and pupicidal, efficacy of six EOs were evaluated by contact toxicity method at four different doses (1%; 2.5%, 5%, and 10%) in 5 replications. The research was performed at 60 ± 1.5% humidity and 27 ± 0.5 ^{0}C temperature at the Animal Physiology Laboratory of Ondokuz Mayıs University. The LC_{50} and LC_{90} values were determined by probit analysis. The effects of treatment and concentrations on different exposure periods, larval and pupal survival and development time were analyzed by a two-way analysis of variance. The larval toxicity of six EOs increased significantly with increased exposed periods. The larval and pupal mortality percent was also increased as the concentration increased for testing all essential oil. The highest larval mortality percent (100.0%) was observed at the (10%) concentration of six essential oils, and all concentrations of *Cinnamomum verum* oil. Besides, the lowest larval mortality percent (46%) was caused by the 1% concentration of *Foeniculum vulgare.* The highest pupicidal effect was shown by 10, 5, 2.5% *Cinnamomum verum* EOs (100% mortality) and 1% *Cinnamomum verum* EOs (97.36%). The present study revealed that tested essential oil had significant potential for affecting biological parameters of *M. domestica*. The *Cinnamomum verum* EOs can be used as an eco- friendly product for the control of housefly larvae and pupae.
Keywords: Essential oil, Control, *Musca domestica,* Toxic effect

INTRODUCTION

The housefly, *Musca domestica* Linnaeus, 1758 (Diptera: Muscidae), is an opportunistic and cosmopolitan species (Gupta et al., 2012) and found in close association with the activities of humans or humans and domestic animals throughout the world (Schou et al., 2013). More than 100 pathogens can cause diseases such as diarrhea, cholera, typhoid, tuberculosis bacillary, dysentery, paratyphoid shigellosis, and myiasis in animals and humans by houseflies (Ogbalu et al., 2014; Förster et al., 2007).

Houseflies develop on various ephemeral food substrates, such as kitchen waste, swine, goat, bovine, sheep and horse dung, wet hay, fermenting organic matter, human excrement cut grass, urine, (Meyer and Petersen, 1983). Dairy farms are ideal places for housefly breeding and, they pose a serious threat to dairy operations all over the world (Neupane et al., 2019). In addition to transmitting diseases, *Musca domestica L.* causes spoiled food, stress, and irritations to livestock and poultry that lead to reduced efficiency in their production (Kumar et al., 2011a). Besides, it causes heavy economic losses, unnecessary staff annoyance, and a significant decrease in animal management quality (Pavela et al., 2008; Chantawee and Soonwera, 2018a). Therefore, considering the stress and disease caused by houseflies in domestic animals, it is paramount to control them (Kumar et al., 2011a). *M. domestica* population is greatly managed using insecticides. Indiscriminate use of conventional insecticides may develop insecticide resistance and also it leads to environmental and toxicological problems for animals and humans (Khan et al., 2013).

The essential oils (EOs) obtained from plants (Chantawee and Soonwera, 2018a) are considered a good alternative to conventional chemical pesticides and produce environment-friendly effects on living organisms (Scott et al., 2000). There are several researches regarding the toxicity of some essential oils against houseflies such as galangal (*Alpinia galanga*), star anise (*Iillicium verum*), garlic (*Allium sativum*), lemongrass (*Cymbopogon citratus*), ylang-ylang (*Canaga odorata*), clove (*Eugenia caryophyllata*), cinnamon (*Cinnamomum verum*), eucalyptus (*Eucalyptus globulus*), peppermint (*Mentha piperita*), sweet orange (*Citrus sinensis*), lavender (*Lavandula angustifolia*), ginger (*Zigiber officinale*) phlai (*Zigiber cassumunar*), and calamondin (*Citrus madurensis*). Several studies have shown the adulticidal, larvicidal, ovicidal, repellence and deterrence effects of essential oils on house fly which may be used for its management (Chantawee and Soonwera, 2018a; Malik et al., 2007; Pavela, 2008; Kumar et al., 2014).The larval and pupal stages might constitute the majority of the development period of the housefly population (Kumar et al., 2014) and pupiciding and larviciding approaches are effective methods for decreasing the fly population (Chantawee and Soonwera, 2018a).

This present study was conducted to evaluate the efficacy and toxicity of six EOs from *Foeniculum vulgare* Mill (Umbelliferae), *Cinnamomum verum* (Lauraceae), *Allium sativum* L. (Amaryllidaceae), *Capsicum annum* (Solanaceae), *Mentha piperita* (Lamiaceae), and *Urtica dioica* (Urticaceae) against the larvae, and pupae of *M. domestica*

MATERIALS AND METHODS

Collection and rearing of Musca domestica L.

This study was conducted in the Animal Physiology Laboratory, Ondokuz Mayıs University, Samsun, Turkey. Adult houseflies were caught from dairy farms on the campus of Ondokuz Mayıs University using a sweep net and immediately transferred to the laboratory. Adults were kept at a temperature of 27 ± 0.5 °C, 60 ± 1.5% relative humidity (RH) and 12L : 12D light cycle in the cage (40 × 30 × 40 cm), enclosed with cheesecloth. Water and sugar were provided to the housefly adults. A cotton soaked in milk was offered as an oviposition substrate. The newly hatched larvae were transferred to jars containing mixture of wheat and milk. Pupae were kept in another glass jar (1000 ml) for adult emergence. All experimental studies were done under the same conditions (60 ± 1.5% relative humidity = RH and 27 ± 0.5 °C). Pupae and larvae acquired though experimets procedure were used in the pupicidal and larvicidal bioassays.

Larvicidal bioassays

All essential oils (Sigma–Aldrich) used in the study were 98 - 99% pure. From the stock solution, concentrations of 1, 2.5, 5, 10% were prepared. Larvicidal bioassays were performed with 10 larvae (third instar) in plastic cups (200 ml) which had different concentrations of esential oil along with ten grams of larval rearing diet on a filter paper. Control filter paper was sprayed with distile water. Five replicate for each concentration of different essential oil were conducted. Larvae were monitored for any change in mobility and appearance for 1, 5, 10, 15, 20 days, post treatment. Larval mortality was determined by the formation of a brownish appearance and wilting (Kumar et al., 2011b). The two lethal (LC_{50} and LC_{90}) concentrations were determined.

Pupicidal bioassays

Pupicidal bioassays were carried out by following the protocol described by Kumar et al., 2011a; Kumar et al., 2013), with a few modifications. For each pupicidal bioassay, different concentrations of each essential oil were sprayed onto filter paper, using a micropipette in different treatments. Initially, the treated petri dishes with filter paper were air-dried for 6 minutes to allow solvent evaporation, before the introduction of pupae. 10 pupae (aged 2-3 days) were placed in a Petri plate (dia., 90 mm). The Control Petri plate was treated with distilled water alone. Five replicates per treatment were performed. The percentage of pupicidal activity, was determined by the inhibition rate %. Inhibition rate (%IR or PIR) = Cn – Tn / Cn × 100 where Cn depicts the number of newly emerged insects in the control and Tn represents the number of insects in the treated Petri plates. All the treated pupae were recorded for adult emergence for 6 days.

Statistical analysis

Lethal concentrations (LC_{50}, LC_{90}) were computed using Probit analysis. Pupicidal effectivity was calculated in terms of percentage inhibition rate. The effect of treatment and concentrations on different exposure periods, larval and pupal survival and development time were analyzed using a two-way Analysis of Variance (ANOVA using SPSS 20.0). Hence A one-way analysis of variance (ANOVA) was performed to analyze the impacts of exposure period devepment time for each tested dose. In the event of a significant *F*-test ($P < 0.05$), the Tukey's HSD test was used to compare means.

RESULTS

Larvacidal bioassays

All essential oils caused prolongation of larval and pupal durations at all concentrations as compared to the control group (Table 1). The longest larval development time (16.2 days) was recorded at 5% concentration of *U. diocia* essential oil, while the shortest larval development time was found at 1% concentrations of *A. sativum* (7 days). Larval development time differed significantly among essential oils ($F = 1465.631$, $p < 0.001$) and concentrations ($F = 321.103$, $p < 0.0001$). There was significant interaction ($F = 72.242$, $p < 0.001$) among the effects of essential oil and concentraions on larval development time. The longest pupal development time (14.2 days) was recorded at 2.5% and 1% concentrations of *F. vulgare*, and *A. sativum* oil, while the shortest pupal development time (10 days) was recorded at 1% concentrations of *C. annum*, *M. piperita*, and *U. dioica* essential oil (Table 1). The results of the larvicidal activity of essential oil against the larvae of *M. domestica* are presented in Table 1. Pupal development time differed significantly among essential oils ($F = 897.990$; $p < 0.001$) and concentrations ($F = 66.982$, $p < 0.0001$). There was a significant interaction ($F = 42.338$, $p < 0.001$) between the effects of essential oil and concentraions on pupal development time. In the present study the essential oils observed a larvicidal effect which was time-and concentration-dependent. The larval and pupal mortality rates increased as the concentration increased for each of the tested essential oil (Table 1). The highest larval mortality (100.0%) was caused by all concentration of *C. verum* and the lowest mortality rate was caused by all concentration of *F.vulgare* (Table 1).The larval mortality of *M. domestica* differed significantly between essential oil ($F = 102.9$, $p < 0.001$), and concentrations ($F = 823.5$, $p < 0.001$). There was a significant interaction ($F = 39.007$, $p < 0.001$) between concentrations and essential oils. The larval and pupal survival of *M. domestica* (L) at various concentrations of various essential oil are presented in Figure 1. The highest pupal mortality (100.0%) was observed at the highest concentration (10%) of six essential oil, and 5% concentration of six essential oil (except of *M. piperita*) (Figure 1). The percent pupal mortality of *M. domestica* differed significantly between essential oil ($F = 47049.600$, $p < 0.001$), and concentrations ($F = 29382.800$, $p < 0.000$). There was a significant interaction ($F = 29683.860$, $p < 0.001$) between concentrations and essential oils. The larval toxicity of EOs increased significantly with increased exposure periods and concentrations. C. *verum* was the most effective at all concentration (100 %, 100 %, 76%, 46%) after 24 h. of exposure. After 24 hours of exposure, no mortality was observed in *Mentha piperita*, and *Capsicum annum* at 5, 2.5, and 1% concentrations and *Urtica dioica* at 1% concentrations (Table 2). The $LC_{50,}$ LC_{90} values of the essential oils against the house fly are presented in Table 3. In the current study, the LC_{50} and LC_{90} values showed that *Cinnamomum verum* oil was the most toxic ($LC_{50} = 0.021$; LC_{90} 1.688) to house fly larvae. The LC_{50} and LC_{90} values indicated that *Foeniculum vulgare* oil was the least toxic ($LC_{50} = 1.327$; $LC_{90} = 3.312$) to house fly larvae (Table 3).

Pupicidal bioassays

Pupicidal bioassays of *M. domestica* with six essential oils at different concentrations observed diverse efficacy (Table 4).The percentage inhibition rate (PIR), calculated after 6 days, at different concentrations of six essential oils, varied between 52.63 and 100% and the increase in the concentration of all essential oil caused an increased PIR. All EOs at 10% concentration impacted high PIR value, ranging from 86.84% to 100.0%. In pupicidal bioassays at the highest concentration (10%) of *Allium sativum, Cinnamomum verum, Urtica dioica* suppressed the emergence of adult flies by 100%. Cinnamomum verum EOs was the highest performer, with a PIR value of between 100 and 97.36%, for different concentrations of oil tested (10, 5, 2.5, and 1% concentrations) but *Foeniculum vulgare* oil was the poorest performer, with a PIR value of between 52.63 and 86.84%, for different concentrations of tested oil.

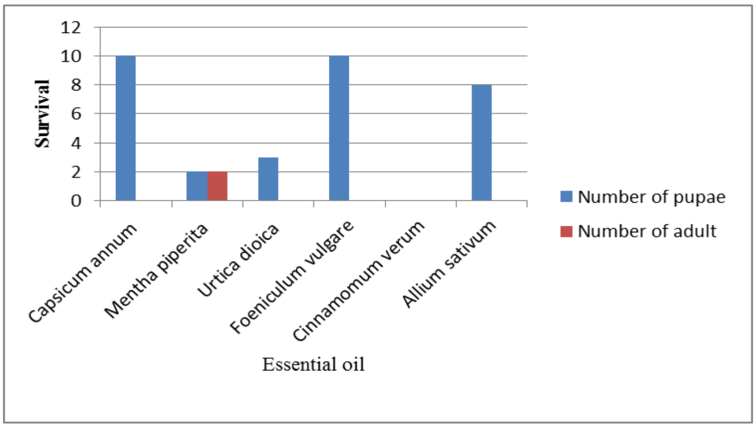
DISCUSSION

The control of *Musca domestica* (L.), relies on the use of chemical pesticides. Indiscriminate use of insecticides, has led to the development of insecticide resistance and tolerance, which have adverse effects on consumers and the environment (Vasantha - Srinivasan et al., 2016). Plant-derived products (essential oils) contain bioactive compounds that may be used for the management of pests of animals, crops, and human beings (Pavela, 2011; Khater and Geden, 2018). Essential oils provide an alternative to synthetic insecticides (Khan et al., 2019). This study tested the activity of six essential oils against the pupae and larvae of *M. domestica*. Our findings suggest that the six EOs exhibited higher mortality rates than the controls against the larvae of house fly. The insecticidal potential of essential oils that are derived from plants has been investigated by different researchers for the control of houseflies (Malik et al., 2007; Kumar et al., 2011a; 2012a,b, 2013, 2014; Zahoor et al., 2020; Pavela, 2008). The present results demonstrated that the mortality percent of *Musca domestica* larvae increased by increasing the exposure period and oil concentration for all botanical extracts tested (Fig. 1). In the current study, the effects of all tested essential oils at the 10% concentration had more toxicity against the larvae of housefly compared to other tested concentrations (5, 2.5, and 1%). Similar results have been observed for the extracts of *Origanum onites* L. (Lamiales: Lamiaceae), *Satureja thymbra* L. (Lamiales: Lamiaceae), and *Myrtus communis* L. (Rosales: Myrtaceae) to the adults of three stored-product insects (Ayvaz et al., 2010). The *Cinnamomum verum* oil had the highest larvicidal activity. The least larvicidal activity

Table 1. Growth and development impact of essential oil on larvae of *M. domestica* (L.).

Essential oil	Concentrations (%)	Mortality (%)	Larval development (day)	Pupal development (day)
Capsicum annum	10	100.0 ± 0.0c*	-	-
	5	80.0 ± 5.4a	14.2 ± 0.5b	-
	2.5	76.0 ± 4.0a	13.2 ± 0.4b	10.2 ± 0.4b
	1	74.0 ± 5.1a	13.2 ± 0.4b	10.0 ± 0.4b
	Control	6.0 ± 0.0b	5.2 ± 0.4a	4.2 ± 0.4a
		F = 9.40 ± 0.0, p < 0.000	F = 1231.500, p < 0.000	F= 1090.500, p < 0.000
Mentha piperita	10	100.0 ± 0.0c	-	-
	5	96.0 ± 2.4bc	14.2 ± 0.5c	10.2 ± 0.4b
	2.5	86.0 ± 2.4b	12.2 ± 0.4b	10.2 ± 0.4b
	1	70.0 ± 2.4a	12.2 ± 0.4b	10.0 ± 0.4b
	Control	6.0 ± 0.0c	5.2 ± 0.4a	4.2 ± 0.4a
		F=18.157, p <0.000	F = 1114.625,p < 0.000	F= 684.000, p < 0.000
Urtica dioica	10	100.0 ± 0.0d	-	-
	5	94.0 ± 5.4c	16.2 ± 0.2d	-
	2.5	82.0 ± 2.4ab	14.2 ± 0.2c	10.2 ± 0.4b
	1	74.0 ± 5.4a	12.2 ± 0.4b	10.0 ± 0.0b
	Control	6.0 ± 0.0c	5.2 ± 0.4a	4.2 ± 0.4a
		F=21.610, p < 0.000	F=1429.625, p <0.000	F = 1090.500, p < 0.000
Foeniculum vulgare	10	100.0 ± 0.0d	-	-
	5	80.0 ± 1.4d	7.4 ± 0.2b	-
	2.5	64.2.0 ± 1.1bc	7.2 ± 0.2b	14.2 ± 0.5b
	1	46.0 ± 1.1a	7.1 ± 0.2b	14.2 ± 0.5b
	Control	6.0 ± 0.0c	5.2 ± 0.4a	4.2 ± 0.4a
		F = 2451.34, p < 0.000	F = 561.33, p < 0.000	F = 2170.50, p < 0.000
		F = 469.72, df = 20;4, p < 0.000	F = 561.33, df = 20;4, p < 0.000	F = 302.35, p < 0.000
Cinnamomum verum	10	100.0 ± 0.0b	-	-
	5	100.0 ± 0.0b	-	-
	2.5	100.0 ± 0.0b	-	-
	1	100.0 ± 0.0b	-	-
	Control	6.0 ± 0.0a	5.2 ± 0.4a	4.2 ± 0.4a
		F = 560.485 df = 20;4, p < 0.000	F = 532.667, df = 20;4, p < 0.000	F = 522.667, p < 0.000
Allium sativum	10	100.0 ± 0.0d	-	-
	5	84.0 ± 0.0c	7.4 ± 0.2b	-
	2.5	74.4 ± 0.9b	7.2 ± 0.2b	14.2 ± 0.5b
	1	57.8 ± 0.8a	7.0 ± 0.0b	14.2 ± 0.5b
	Control	6.0 ± 0.0cd	5.2 ± 0.4a	4.2 ± 0.4a
		F = 947.0, df = 20;4, p < 0.000	F = 398.0, df = 20;4, p < 0.000	F = 3208.250, p < 0.000

*Means in the same column followed by different letters are different by Tukey test at 5% significance.



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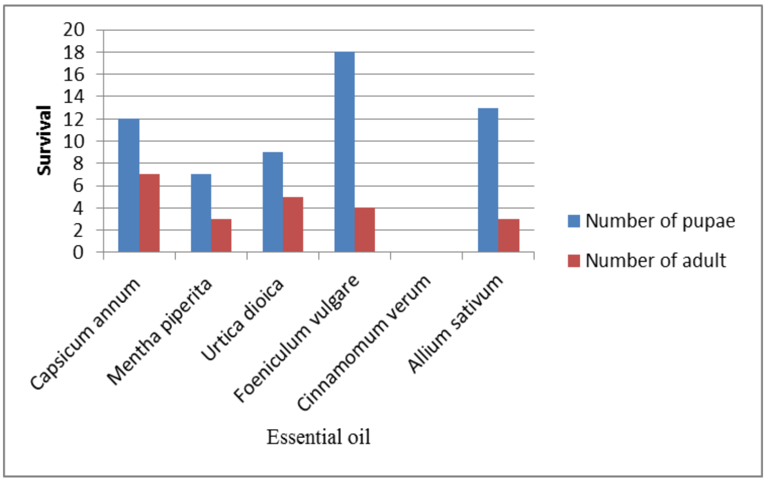

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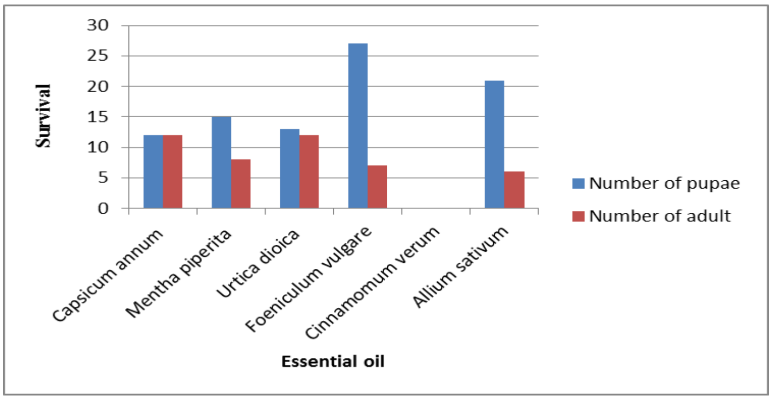

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Figure 1. Mean mortality of 3rd instar larvae of *M. domestica* (L) at various concentrations of various essential oil (a: 5%, b: 2.5%, c: 1% concentration)

Table 2. Mortality rate of essential oil against larvae of *M. domestica* (L.) after 24 hour of exposure

Concentration of essential oil	10	5	2.5	1	F value
	Mortality percent after 24 h exposure				
Capsicum annum	72.00b	0.00a	0.00a	0.00a*	F=152.4, p <0.000
Mentha piperita	96.00b	0.00a	0.00a	0.00a	F=1536.0, p <0.000
Urtica dioica	94.00c	64.00b	6.00a	0.00a	F=77.0, p < 0.000
Foeniculum vulgare	89.60c	42.00c	26.00 b	16.80a	F = 3496.17, p < 0.000
Cinnamomum verum	100.00d	100.00c	76.00 b	46.00a	F = 120.923, df = 3,16, p < 0.000
Allium sativum	74.80d	43.00c	28.20 b	20.40a	F = 947.104, p < 0.000

*Means in the same column followed by different letters are different by Tukey test at 5% significance.

Table 3. Lethal concentrations of six essential oils against housefly larvae in larvicidal assay with their LC_{50} and LC_{90} values.

Essential oil	Lethal Concentration	
	LC_{50}	LC_{90}
Capsicum annum	0.311	3.249
Mentha piperita	0.565	2.358
Urtica dioica	0.239	2.298
Foeniculum vulgare	1.327	3.312
Cinnamomum verum	0.021	1.688
Allium sativum	0.831	2.772

Table 4. Percentage inhibition rate (PIR) against pupae of *M. domestica* with different concentrations of six essential oils in contact toxicity assay.

Esential oil	Concentration of oil (µ/L)	PIR
Capsicum annum	10	92.10
	5	78.94
	2.5	73.68
	1	71.05
Mentha piperita	10	92.10
	5	76.31
	2.5	71.05
	1	63.15
Urtica dioica	10	100
	5	92.10
	2.5	81.57
	1	71.05
Foeniculum vulgare	10	86.84
	5	76.31
	2.5	68.42
	1	52.63
Cinnamomum verum	10	100
	5	100
	2.5	100
	1	97.36
Allium sativum	10	100
	5	94.73
	2.5	92.10
	1	89.47

was achieved by *Foeniculum vulgare*. In a present study, the *Cinnamomum verum* EOs at a 5,10% concentration caused 100% mortality in larvae of *M. domestica* after 24 h of exposure. The mortality effect of the *Cinnamomum verum* EOs was 100% after 5 days of exposure at a concentration of 2.5% and after 10 days of exposure at a concentration of 1%. At all four concentrations tested for *Cinnamomum verum* EOs (1, 2.5, 5, 10%), the mortality rate was 100%. Similarly, Khater and Geden (2019) reported the essential oil of cinnamon exhibited a 100% larvicidal bioassay at a 5% concentration against *M. domestica*. Khater et al. (2018) reported that cinnamon oils showed the highest mortalities against larvae of *Lucilia sericata* (Meigen 1826) (Diptera: Calliphoridae) in contact assays. These results are in line with our results. Contrary to our study, Morey and Khandagle (2012) reported that *C.verum* EOs observed strong larvicidal activity against houseflies but that *M. piperita* EOs was more effective than *Cinnamomum verum* EOs in a larvicidal bioassay.

Cinnamomum verum EOs had a strong larvicidal activity, with an LC_{50} value of 0.021 µl/cm^2, and LC_{90} value (1.688) (Table 3). Morey and Khandagle (2012) tested the larvicidal activity (LC_{50}) of *C. verum* oil against *M. domestica*. *C. verum* oil exhibited moderate larvicidal activity (LC_{50} 159 ppm).

Among the six oils, *U. dioica* and *M. piperita* were highly effective against larvae of *M. domestica*. *U. dioica* EOs at 10%, 5%, 2.5%, and 1% concentrations exhibited larvicidal activity with a mortality rate of 100, 94, 82, and 74% respectively. *M. piperita* EOs at 10%, 5%, 2.5% and 1% concentrations exhibited larvicidal activity with a mortality rate of 100, 96, 86, and 70% respectively. The LC_{50} value was 0.565, while the LC_{90} value 2.358 was Kumar et al. (2011a and 2012a) reported potential larvicidal activity of *M. citrata* and *M. piperita* against the larvae of houseflies. Similarly, *Mentha spicata* EO_s showed high larvicidal activity against *Anopheles stephensi* Liston, 1901 (Diptera: Culicidae), *Culex quinquefasciatus* (Say, 1823) (Diptera: Culicidae), and *Aedes aegypti* (Linnaeus 1762) (Diptera: Culicidae) with LC_{50} of, 49.71, 56.08, and 62.62ppm, respectively (Govindarajan et al., 2012). EOs are also known to decrease levels of lipids, glycogen, proteins, and enzyme activity which leads to retarded growth, and poor nutrient utilization. The reduction in enzyme activity due to treatment with EOs causes the cytotoxic effect (disrupting cell membrane) on epithelial cells of the gut (Chintalchere et al., 2013). Meanwhile, the essential oil disrupts normal neurotransmission and the neuroendocrine system, resulting in developmental abnormalities (Mansour et al., 2011; Mohamed et al., 2016; Khater and Khater, 2009; Nasiruddin and Mordue, 1993). The results of the present study indicated that *A. sativum*

EOs at 10%, 5%, 2.5%, and 1% concentrations produced a mortality rate at 100, 84, 74.4, 57.8% , respectively. The LC_{50} value was 0.831, while the LC_{90} value was 2.772. Previous studies have reported that garlic juice and oils have insecticidal effectiveness against pest invertebrates (Inyang and Emosairue, 2005; Chiam et al., 1999; Karci and Isikber, 2007; Isikber et al., 2009). In the same vein, Meriga et al. (2012) observed that the *A. sativum* EOs (methanol extracts) against *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae) larvae exhibited high mortality (81%) at 1% concentration. These results are in line with Prowse et al. (2006) who observed *A. sativum* juice achieved high mortality of *M. domestica* (about 90%) at 5% concentration. Similarly, Shahriari et al. (2018) demonstrated the insecticidal effect of *A. sativum* against *M. domestica* was dependent upon exposure time, and concentrations. Levchenko et al. (2021) showed A. *sativum* EOs against *M. domestica* exhibited strong mortality (99%) at a 0.066% concentration. In the present study, at 10% concentration, all essential oils tested exhibited the highest mortality against *M. domestica* larvae with 100% mortality. *F. vulgare* EOs were found to be less effective against housefly larvae compared to other tested essential oil in our study. The treatment of *F. vulgare* EOs at 10%, 5%, 2.5%, and 1 % concentrations was exhibited as 100%, 80%, 64.2%, and 46% for larval stage. LC_{50} and LC_{90} for *F. vulgare* EOs were 1.327 and 3.312 respectively. Similarly, Chantawee and Soonwera (2018a) reported that *F. vulgare* EOs at 1%, 5%, and 10% concentrations exhibited larvicidal activity against housefly with a mortality rate of 16.3%, 45.7%, and 89.3%, respectively. El Zayyat et al. (2017) reported that *F. vulgare* EOs observed the highest toxicity against *Lasioderma serricorne* F. (Coleoptera: Anobiidae), *Callosobruchus chinensis* Linnaeus 1758 (Coleoptera: Bruchidae), and *Sitophilus oryzae* (L) (Coleoptera: Curculionidae). Contrary to our results, Chantawee and Soonwera (2018b) indicated that 10% and 5% *F. vulgare* EOs exhibited a strong larvicidal activity (100%) against *A. aegypti* at 24 h after exposure. Sedaghat et al. (2011) reported that *F. vulgare* EOs were the most effective against larvae of *An. stephensi* with an LC_{50} value of 20.10 ppm and LC_{90} value of 44.51 ppm, respectively. Levchenko et al., 2021 indicated *E. caryophyllata*, *F. vulgare*, and *A. sativum* EOs against the *M. domestica* had the highest insecticidal effectiveness at the dilution of 1:500.

The results indicated that the larval and pupal developmental time were significantly extended in EOs treatments. Similarily, Roel et al. (2010) indicated that the duration of the development period of *Spodoptera frugiperda* (Smith, 1797) (Lepidoptera: Noctuidae), was significantly prolonged at different concentrations of *Azadirachta indica* (Meliaceae) essential oil. *Spodoptera littoralis* (Boisduval) (Lepidoptera: Noctuidae) was found to be prolonged in the larval and pupal stages by *Mentha piperita* by Yousef et al. (2018).

The essential oil may impact insect development and metabolism (Moutassem et al., 2021). However, EOs causes reduced food ingestion (Roel et al., 2010), inhibits digestive enzymes (Yousef et al., 2018) and can result in prolongation of the development duration. Previously research showed that essential oil caused impaired feeding performance and inactivation of digestive (Bezzar-Bendjazia et al., 2017). The pupicidal assay performed by contact toxicity against the pupae of *M. domestica* showed important variation in growth and development inhibition with different concentrations of the tested EOs. Further, it was observed that with an increase in the concentration of six essential oil % mortality also increased in the pupae of *M. domestica*. The failure of pupation and adult emergence can appear as a result of several factors: unsatur-ated fatty acids, which accelerate the melanization process; hardening of the opercular suture and insufficient pressure in the ptilinum (Mohamed et al., 2016; Khater and Khater, 2009). *C. verum* essential oils were the most toxic to exposed pupae, followed by *A. sativum*, and *U. dioica* essential oils, in that order. In present study, *M. piperita* oil was relatively moderately performer with PIR value between 63.15 and 92.10%, for different concentrations among tested essential oil. The pupicidal potential of M. *piperita* has been reported by different researchers. Kumar et al. (2012b) reported PIR of *M.piperita* oil varied between 54 and 100% against house fly pupae. In this investigation, *F. vulgare* recorded the lowest pupicidal activity compared to tested essential oil and pupicidal bioassays of *M. domestica* with *F. vulgare* essential oil exhibited the percentage inhibition rate of 52.63-86.84% at different concentrations. These investigations were in accordance with that reported by Chantawee and Soonwera (2018a) as they observed that ten percent of *F. vulgare* EOs exhibited the highest toxicity against the pupae with 76% mortality rate at 10 days. These findings were contradicted by the studies of Abdel-Bakı et al. (2021) as they reported that the concentration of 10% of essential oil from *F. vulgare* caused complete inhibition (100% mortality) in the pupae of *M. domestica*.

CONCLUSION

This experiment was conducted to evaluate the insecticidal activities of *F. vulgare, A.sativum, C. verum, C. annum, M. piperita* and *U. dioica* against the pupae and larvae of *M. domestica*. The present results demonstrated that the percent of larval and pupal mortality was increased by increasing concentration and exposure time for all tested essential oils. The essential oils were reported to increase pupal and larval mortality, and developmental time. The current results suggest that the *C. verum* essential oil was found to be most effective against larvae and pupae of *M. domestica* among tested essential oils.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest

The authors declared that for this research article, they have no actual, potential or perceived conflict of interest.

Author contribution

The contribution of the authors to the present study is equal. All the authors read and approved the final manuscript. All the authors verify that the Text, Figures, and Tables are original and that they have not been published before.

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