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The Contact/Fumigant Adulticidal Effect of Egyptian Oils against the House Fly, *Musca domestica* (Diptera: Muscidae)

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ABSTRACT

The common housefly, *Musca domestica* (Diptera: Muscidae) is a cosmopolitan pest of a major medical and veterinary importance acting as a mechanical vector of pathogens. This study evaluated the toxicity of six essential oils against adult *M. domestica* through contact/fumigant toxicity bioassays. The most effective oil was radish, followed by camphor, mustard, thyme, garlic, and rosemary. The mortality (MO)% 60 min, post-treatment (PT) with 2% of camphor, garlic, mustard, radish, rosemary, and thyme oils were 90.00, 83.33, 86.66, 93.33, 83.33, and 86.66%, respectively. After treatment for one hour, the median lethal concentration, LC_{50} of camphor, garlic, mustard, radish, rosemary, and thyme were 0.305, 0.450, 0.366, 0.250, 0.475, and 0.405%, respectively. The corresponding LC_{99} values were 2.54, 3.19, 2.92, 2.30, 3.14, and 2.96%, respectively. Their toxicity indices were 81.97, 55.56, 68.31, 100.00, 52.63, and 61.73%, respectively. After treatment with 2%, their median lethal time (LT_{50}) values were 16.52, 19.99, 18.29, 16.44, 18.73, and 17.92 min, respectively. The adulticidal effect of radish, mustard, camphor, and rosemary against house flies had a novelty record and the current investigation concluded that all applied oils were effective adulticides. Radish oil was the most potent oil followed by camphor, mustard, and thyme, whereas garlic and rosemary were less effective oils; therefore, the promising oils merit further investigations regarding their field application and ecotoxicological studies.

Key words: Camphor, Garlic, Mustard, Radish, Rosemary, Thyme.

INTRODUCTION

Arthropod-borne diseases have increased all over the world, especially those transmitted by flies, sandflies, mosquitoes, and ticks (Marcondes 2017). The common housefly, *Musca domestica* (Diptera: Muscidae), is a cosmopolitan pest known science ancient civilizations (Khater 2017). Housefly is a major medical and veterinary important insect as it transmits mechanically over and above 100 pathogens including bacteria, fungi, viruses, and parasites (Khamesipour et al. 2018).

House flies are difficult to be managed because of their high fecundity, short developmental periods, and resistance to insecticides (Khan et al. 2013). Conventional insecticides cannot be used in some places and circumstances.

Botanicals mainly essential oils (EOs) have been used daily by the ancient Egyptians (Khater 2017). Alternative parasiticides of botanical origin have long been used throughout history until recently (Seddiek et al. 2011, 2014; Khater 2017; Abbas et al. 2020; Ahmed et al. 2021; Iqbal et al. 2021; Štrbac et al. 2021). Essential oils are pleasing alternatives to conventional insecticides because of their ease of use, public acceptability, besides their low mammalian and avian toxicities. They could be used with suitability in organic production systems if oils are produced organically (Khater 2012a, 2012b, 2013).

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Plant extracts and EOs are widely used for pest control as adulticides (Khater et al. 2014; Abdel-Meguid et al. 2022; Radwan et al. 2022a) and larvicides (Khater and Shalaby 2008; Khater et al. 2011, 2013; Murugan et al. 2015; Roni et al. 2015; Govindarajan et al. 2016a,b; Baz et al. 2021, 2022a,b; Radwan et al. 2022a,b). Botanical insecticides have also been used for controlling the *cycloraphan* flies (Khater 2014; Khater et al. 2009, 2013, 2018; Khater and Geden 2018, 2019).

There are many studies deal with the larvicidal effect of essential oils, but there are few studies about the adulticidal effect of few oils such as thyme (Pavela 2007) and garlic (Nisar et al. 2021). In order to determine the eco-friendly plant oils that are sustainable for housefly management, this investigation aimed to estimate the toxicity of six EOs including four novel oils against adult housefly through contact/fumigant toxicity bioassays, and calculate their lethal concentration and time values, as well as their relative toxicities and toxicity indices.

MATERIALS AND METHODS

Oils

Essential oils (Table 1) were purchased from *EL CAPTAIN Company* for extracting natural *oils*, plants and cosmetics "Cap Pharm", El Obor, Cairo, Egypt.

Housefly Colony

House fly colony was reared in the insectary in the Medical and of Molecular Entomology Section, Entomology Department, Faculty of Science, Benha University, Egypt. Houseflies were maintained at 27±2°C and 75-85% RH in 30×30×30 cm cages. Adult house flies were fed on yeast and granular sucrose. Adult flies were allowed to oviposit eggs on cotton pads soaked in full fat milk. The diet of larval rearing comprised 1:1 vermiculite and oatmeal, and 30 cm^3 yeast extract, then moisturized with full fat milk (Khater and Geden 2019).

Contact/fumigant Toxicity

The efficacy of the applied EOs against adult *M. domestica*, was estimated according to a previous protocol (Khater and Geden 2019) with a little modification. Seven concentrations (0.03, 0.06, 0.13, 0.25, 0.5, 1.0, and 2.0%) were diluted in a solvent (Tween 20®, 5%, plus distilled water). Glass bottles and their caps were treated with a thin layer of each tested concentration. Bottles were turned around to disperse oils. Ten flies were added to each bottle and then covered with a cap. The solvent was used to treat the control group. Thirty flies (three replicates) were used for each treated group. Dead flies were counted 5, 10, 20, 30, and 60 min after placement in the bottles. Bottles were preserved (27± 2°C along with 80± 5% RH).

Data Analysis

Probit analysis was used to analyze the mortality data through SPSS V23 (IBM, USA) to determine lethal concentration (LC) plus lethal time (LT) values. The mortalities were compared via One- Way Analysis of Variance, followed by the Tukey's test, where $P>0.05$ is considered not significant. The toxicity index (TI) (Zidan and Abdel-Mageed 1988), relative toxicity (RT) (Khater and Geden 2018) and Time Potency (TP) were calculated as follows:

TI = LC_{50} of the most toxic plant oil ×100/ LC_{50} of each tested plant oil.

RT = LC_{50} of the least toxic plant oil / LC_{50} of each tested plant oil.

TP = LT_{50} of the least toxic plant oil/ LT_{50} of each tested plant oil.

RESULTS

The present study investigated the *in vitro* efficacy of six plant oils against *M. domestica* (Table 1). The study revealed that all tested oils exhibited adulticidal efficiency against *M. domestica*, depending on the concentration and time of exposure. The most effective oil was radish, followed by camphor, mustard, thyme, garlic, and rosemary. After treatment with 0.06%, the mortality (MO)% of camphor, garlic, mustard, radish, rosemary, and thyme oils were 43.33, 23.33, 30.00, 30.00, 36.66, and 40.00%, respectively, 30 min post- treatment (PT) and 50.00, 36.66, 43.33, 46.66, 43.33, and 46.66%, respectively, 60 min PT. On the other hand, the analogous values PT for 60 min with 2% were 90.00, 83.33, 86.66, 93.33, 83.33, and 86.66%, respectively (Table 2).

After treatment for 60 min, LC_{50} of camphor, garlic, mustard, radish, rosemary, and thyme were 0.305, 0.450, 0.366, 0.250, 0.475 and 0.405%, respectively. The corresponding LC_{99} values were 2.54, 3.19, 2.92, 2.30, 3.14 and 2.96%, respectively. On the other hand, their TIs were 81.97, 55.56, 68.31, 100.00, 52.63 and 61.73%, respectively (Table 3).

After treatment with concentration 0.5%, the median lethal time (LT_{50}) of camphor, garlic, mustard, radish, rosemary, and thyme were 26.04, 30.53, 26.63, 23.26, 29.45, and 28.62 min, respectively. The corresponding LT_{50} values PT with 2% were 16.52, 19.99, 18.29, 16.44, 18.73, and 17.92 min, respectively. The time potency PT with 0.5% of camphor, mustard, radish, rosemary, and thyme were 1.17, 1.15, 1.31, 1.04, and 1.07 times, respectively, faster than garlic, whereas such values PT with 2% were 1.21, 1.09, 1.22, 1.07, and 1.12, respectively (Table 4).

DISCUSSION

EOs are used as an eco-friendly alternative for pest management as they are non-mutagenic, non-toxic to animals and more effective against insecticide- resistant pests (Khater 2012a, b, 2013; Ahmed et al. 2021). The efficacy of EOs against *M. domestica* in this study indicated that all tested plant oils exhibited adulticidal efficiency against depending on the concentration and time of exposure.

Radish oil was the most effective adulticide followed by camphor, mustard, thyme, and garlic and they were 1.9, 1.55, 1.29, 1.17, and 1.05 times more effective than rosemary oil. Radish*, Raphanus sativus,* is a common vegetable oil reputed to possess diverse medicinal properties and all parts of the plant are used in medicines (Ahmad et al. 2012).

This study indicated radish, as its LC_{50} value and toxicity index were 0.250 and 100%, respectively. The insecticidal activity of different fractions of *R. sativus* leaf

Table 1: Binomial, English and family names of the applied oils against adult house fly

Binomial name	English name	*Family name*
Allium sativum	Garlic oil	Amaryllidaceae
Brassica juncea	Mustard oil	Brassicaceae
Cinnamomum camphora	Camphor	Lauraceae
Raphanus sativus	Radish fegl	Brassicaceae
Salvia rosmarinus	Rosemary	Lamiaceae
Thymus vulgaris	Thyme	Lamiaceae

Table 2: Effect of essential oils against the adult stage of *Musca domestica*

Oil name	Time	Mortality (%) Mean± SE							
		Control	0.03%	0.06%	0.13%	0.25%	0.5%	1.0%	2.0%
Camphor	5 min	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
	10 min	0.00±0.00c	(3.33)	(16.66)	(23.33)	(23.33)	(26.66)	(33.33)	(40.00)
			0.33±0.57c	1.66±0.57bc	2.33±0.57ab	2.33±0.57ab	2.66±0.57ab	3.33±0.57ab	4.00±1.00a
	20 min	(3.33)	(13.33)	(26.66)	(33.33)	(36.66)	(43.33)	(50.00)	(60.00)
		0.33±0.57d	1.33±0.57cd	2.66±1.15bcd	3.33±1.15bc	3.66±0.57abc	4.33±0.57ab	5.00±1.00ab	6.00±1.00a
	30 min	(3.33)	(26.66)	(43.33)	(50.00)	(53.33)	(56.66)	(66.66)	(76.66)
		0.33±0.57e	2.66±1.15d	4.33±1.15cd	5.00±0.00bc	5.33±0.57bc	5.66±0.57abc	6.66±0.57ab	7.66±0.57a
	60 min	(6.66)	(30.00)	(50.00)	(60.00)	(63.33)	(73.33)	(80.00)	(90.00)
		0.66±0.57e	3.00±1.73de	5.00±1.73cd	6.00±1.00bc	6.33±0.57abc	7.33±0.57abc	8.00±0.00ab	9.00±1.00a
Garlic	5 min	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
	10 min	0.00±0.00c	(3.33)	(6.66)	(13.33)	(26.66)	(26.66)	(30.00)	(36.66)
			0.33±0.57c	0.66±0.57c	1.33±0.57bc	2.66±0.57ab	2.66±0.57ab	3.00±0.00a	3.66±0.57a
	20 min	(3.33)	(13.33)	(13.33)	(20.00)	(30.00)	3.33±0.57abc	(40.00)	(50.00)
		0.33±0.57e	1.33±0.57de	1.33±0.57de	2.00±1.00cde	3.00±0.00bcd		4.00±0.00ab	5.00±1.00a
	30 min	(3.33)	(16.66)	(23.33)	(36.66)	(43.33)	(50.00)	5.66±0.57ab	6.66±0.57a
		0.33±0.57f	1.66±0.57ef	2.33±0.57de	3.66±0.57cd	4.33±1.54bc	5.00±0.00abc		
	60 min	(6.66)	(26.66)	(36.66)	(53.33)	(63.33)	(70.00)	(70.00)	(83.33)
		0.66±0.57e	2.66±0.57d	3.66±0.57cd	5.33±0.57bc	6.33±0.57b	7.00±1.00ab	7.00±0.00ab	8.33±0.57a
Mustard	5 min	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
	10 min	0.00±0.00c	(6.66)	(10.00)	(20.00)	(20.00)	(26.66)	(33.33)	(40.00)
			0.66±0.57bc	1.00±1.00bc	2.00±1.00abc	2.00±0.00abc	2.66±1.15ab	3.33±0.57	4.00±1.00a
	20 min	(3.33)	(13.33)	(20.00)	(30.00)	(33.33)	(40.00)	(50.00)	(53.33)
		0.33±0.57e	1.33±0.57de	2.00±0.00cde	3.00±1.00bcd	3.33±0.57bcd	4.00±1.00abc	5.00±1.00ab	5.33±0.57a
	30 min	(3.33)	(23.33)	(30.00)	(43.33)	(50.00)	(56.66)	(63.33)	(70.00)
		0.33±0.57e	2.33±1.52de	3.00±0.00cd	4.33±0.57bcd	5.00±0.00abc	5.66±0.57ab	6.33±0.57ab	7.00±1.00a
	60 min	(6.66)	(30.00)	(43.33)	(53.33)	(63.33)	(73.33)	(73.33)	(86.66)
		0.66±0.57e	3.00±1.00de	4.33±0.57cd	5.33±0.57bcd	6.33±1.52abc	7.33±1.15ab	7.33±0.57ab	8.66±0.57a
Radish	5 min	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
	10 min	0.00±0.00d	(10.00)	(10.00)	(23.33)	(33.33)	(33.33)	(36.66)	(43.33)
			1.00±100cd	1.00±1.00cd	2.33±0.57bc	3.33±0.57ab	3.33±0.57ab	3.66±0.57ab	4.336±0.57a
	20 min	(3.33)	(13.33)	(20.00)	(30.00)	(43.33)	(46.66)	(50.00)	(56.66)
		0.33±0.57d	1.33±0.57cd	2.00±1.00cd	3.00±1.00bc	4.33±0.57ab	4.66±0.57ab	5.00±1.00ab	5.66±0.57a
	30 min	(3.33)	(23.33)	(30.00)	(43.33)	(56.66)	(63.33)	(70.00)	(73.33)
		0.33±0.57d	2.33±0.57cd	3.00±1.73c	4.33±1.15bc	5.66±0.57ab	6.33±0.57ab	7.00±1.00a	7.33±0.57a
	60 min	(6.66)	(33.33)	(46.66)	(60.00)	(70.00)	(73.33)	(80.00)	(93.33)
		0.66±0.57e	3.33±1.52d	4.66±1.15cd	6.00±0.00bc	7.00±1.00abc	7.33±0.57ab	8.00±0.00ab	9.33±0.57a
Rosemary	5 min	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
	10 min	0.00±0.00d	(3.33)	(13.33)	(20.00)	(23.33)	(26.66)	(30.00)	(40.00)
			0.33±0.57cd	1.33±0.57bcd	2.00±1.00bc	2.33±0.57ab	2.66±0.00ab	3.00±1.00ab	4.00±1.00a
	20 min	(3.33)	(10.00)	(23.33)	(30.00)	(33.33)	(40.00)	(46.66)	(53.33)
		0.33±0.57e	1.00±0.0de	2.33±0.57cd	3.00±1.007bc	3.33±0.57bc	4.00±1.00abc	4.66±0.57ab	5.33±0.57a
	30 min	(3.33)	(23.33)	(36.66)	(43.33)	(46.66)	(53.33)	(60.00)	(70.00)
		0.33±0.57e	2.33±0.57de	3.66±0.57cd	4.33±0.57bcd	4.66±0.57bc	5.33±1.15abc	6.00±1.00ab	7.00±1.00a
	60 min	(6.66)	(30.00)	(43.33)	(50.00)	(56.66)	(66.66)	(73.33)	(83.33)
		0.66±0.57f	3.00±1.00e	4.33±0.57de	5.00±1.00cd	5.66±0.57bcd	6.66±0.57abc	7.33±0.57ab	8.33±0.57a
Thyme	5 min	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
	10 min	0.00±0.00c	(3.33)	(16.66)	(23.33)	(23.33)	(26.66)	(33.33)	(40.00)
			0.33±0.57c	1.66±0.57bc	2.33±0.57ab	2.33±0.57ab	2.66±0.57ab	3.33±0.57ab	4.00±1.00a
	20 min	(3.33)	(13.33)	(26.66)	(33.33)	(36.66)	(40.00)	(46.66)	(56.66)
		0.33±0.57d	1.33±0.57cd	2.66±1.15bcd	3.33±1.15abc	3.66±0.57abc	4.00±1.00ab	4.66±1.15ab	5.66±0.57a
	30 min	(3.33)	(23.33)	(40.00)	(46.66)	(50.00)	(56.66)	(63.33)	(70.00)
		0.33±0.57d	2.33±0.57cd	4.00±1.00bc	4.66±1.52abc	5.00±1.00ab	5.66±0.57ab	6.33±0.57ab	7.00±1.00a
	60 min	(6.66)	(26.66)	(46.66)	(60.00)	(56.66)	(66.66)	(73.33)	(86.66)
		0.66±0.57e	2.66±1.15de	4.66±1.15cd	6.00±0.00bc	5.66±0.57bc	6.66±1.15abc	7.33±0.57ab	8.66±0.57a

Means followed by the same letter on the same row are not significantly different by ANOVA (P>0.05).

Table 3: Lethal concentration values of oils after treatment of adult *Musca domestica* for one hour

Essential oil	LC50 Upper Lower	LC90 Upper Lower	LC95 Upper Lower	LC99 Upper Lower	Relative toxicity	Toxicity index	Chi df sig	Equation R2
Camphor	0.305	1.54	1.89	2.54	1.55	81.97	30.95	Y=0.05+0.75xX
	-1.42	0.87	1.07	1.43			6	0.794
	1.31	18.64	23.99	34.07			0.000[a]	
Garlic	0.450	1.96	2.39	3.19	1.05	55.56	30.72	Y=0.15+0.63xX
	-1.95	1.095	1.33	1.761			6	0.678
	4.80	104.09	132.87	186.86			0.000[a]	
Mustard	0.366	1.77	2.17	2.92	1.29	68.31	30.23	Y=0.08+0.66xX
	-1.85	0.998	1.22	1.63			6	0.746
	1.92	35.56	45.68	64.68			0.000[a]	
Radish	0.250	1.38	1.70	2.30	1.9	100.00	31.923	Y=6.8E-3+0.8xX
	-2.47	0.77	0.96	1.29			6	0.828
	1.16	26.65	34.62	49.57			0.000[a]	
Rosemary	0.475	1.94	2.36	3.14	1.00	52.63	24.896	Y=0.18+0.66
	-0.35	1.148	1.39	1.83			6	0.811
	1.63	11.83	14.90	20.68			0.000[a]	
Thyme	0.405	1.81	2.21	2.96	1.17	61.73	27.860	Y=0.13+0.68xX
	-0.80	1.04	1.27	1.69			6	0.783
	1.67	17.38	22.12	31.04			0.000[a]	

Relative toxicity = LC50 of the least toxic compound / LC50of the tested compound: Toxicity index = LC50 of the most toxic compound ×100 / LC50of the tested compound: The most toxic oil has given 100 units on the toxicity index scale.

Table 4: Median lethal time values and time potency of essential oils against *Musca domestica* adults

Essential oil	Concentration 0.5%			Concentration2%		
	LT_{50} (Lower-upper)	LT_{95} (Lower-upper)	Time potency	LT_{50} (Lower-upper)	LT_{95} (Lower-upper)	Time potency
Camphor	26.04	152.21	1.17	16.52	66.46	1.21
	20.42	89.94		13.28	47.47	
	34.76	410.66		20.24	116.05	
Garlic	30.53	199.48	1.00	19.99	99.99	1.00
	23.56	108.61		15.85	65.35	
	43.174	666.83		25.30	211.72	
Mustard	26.63	154.79	1.15	18.29	85.36	1.09
	20.89	91.21		14.55	57.70	
	35.67	420.48		22.85	167.71	
Radish	23.26	145.82	1.31	16.44	65.04	1.22
	18.08	85.82		13.26	46.54	
	30.84	397.01		20.12	113.46	
Rosemary	29.45	207.99	1.04	18.73	94.98	1.07
	22.57	110.71		14.77	62.40	
	41.84	739.37		23.64	198.74	
Thyme	28.62	196.80	1.07	17.92	83.34	1.12
	22.02	106.75		14.24	56.57	
	40.12	664.00		22.35	162.26	

Times potency = LT_{50} of the least toxic plant oil/ LT_{50} of each tested plant oil: LT_{50} of the lowest toxic oil was Garlic oil.

extracts against 3rd nymphal instars of *Phenacoccus solenopsis* was recorded (Ibrahim and Abdel-Mogib 2019). The insecticidal effect of fractions of radish root extracts against adults and nymphs of *Aphis gossypii*could be arranged as follows; methylene chloride with LC_{50}= 386.63 and 309.43 ppm, ethyl acetate with LC_{50}= 394.9 and 334.37ppm, and petroleum ether with LC_{50}= 636.2 and 424.56ppm, respectively (Ibrahim et al. 2020).

Mustard oil was effective as adulticide in this work (LC50= 0.366%). Similar insecticidal effect was recorded as radish and mustard (*Brassica compestris)* oils induced larvicidal effects against the third larval instar of the blowfly, *Lucilia sericata* (LC_{50}= 6.93 and 7.92%, respectively) and hindered adult emergence PT with 12 and 8%, respectively (Khater and Khater 2009). Moreover, mustard (*Brassica juncea*) and arugula (*Eruca sativa*) plants repelled the sweet potato whitefly, *Bemisia tabaci* (Legaspi et al. 2016).

Garlic*, Allium sativum*, is a well-known herbal remedy of various health benefits (Tsai et al. 2012; Seddiek et al. 2014). This study revealed the adulticidal efficacy of garlic oil against house fly (LC_{50}= 0.450 PT for one hour). Parallel to our results, garlic juice was effective against the dipteran insects, *Delia radicum* and *M. domestica*; the recorded LC_{50} values for *M. domestica* were 10.1 and 2.2% PT of larvae and adults for 24 h (Prowse et al. 2006). Aqueous garlic extract induced larvicidal effect and adversely affected oviposition, egg hatching, and fecundity of house flies (Nisar et al. 2021). Furthermore, complete larval mortalities of the oestrid fly, *Cephalopina titillator* (Clark); was reached 24h PT with 7.5% garlic oil (LC50= 0.44%) (Khater 2014).

In the current work, camphor, *Cinnamomum camphora,* oil effectively controlled adult house flies (LC_{50}= 0.305%). Analogues studies showed that camphor oil was effective against *C. titillator* (Clark)*;* the mortality

of 2nd larval instars PT for 24h with lavender, camphor, and onion oils was 100, 80, and 52%, respectively, whereas those of 3rd larval instars were 100, 68, and 52%, respectively. Furthermore, the LT_{50}, LT_{90}, and LT_{99} values PT of 2nd larval instars were 3.60, 12.06, and 32.31 h for lavender oil; 6.58, 51.67, and 277.38 h for camphor oil; and 14.24, 120.73, and 689.66 h for onion oils, respectively (Khater et al. 2013). Camphor oil was also effective against the slender pigeon louse, *Columbicola columbae* and *in vitro* treated lice with 1% were died one hour PT (LC_{50}= 0.25%, and LT_{50}= 2.30 min PT with 0.004%). The louse infestations were eliminated seven days PT of infested pigeons (Khater et al. 2014).

This work demonstrated that the least toxic oil was rosemary and its toxicity index was 52.63%. Similarly, rosemary oil was less effective against the predacious mite, *Amblyseius zaheri*, but it was the most toxic to *Amblyseius barkeri* females (Momen and Amer 2000). Moderate efficacy of rosemary was also reported against *Culex pipiens* mosquito, rosemary oil induced a larvicidal effect (LC50=71.37ppm) and adversely affected its pupation rates and adult emergences (Khater and Shalaby 2008); hexane extract of rosemary induced 100% mortality PT of 3rd and 4th instars larvae with 160 ppm (Shalaby and Khater 2005). Furthermore, rosemary oil was effective against *L. sericata* (LC50=6.77%) and sublethal concentrations induced morphological abnormalities plus a dominance of males over females (4:1) which could lead to a population decline (Khater et al. 2011).

A comparable study recorded the repellent, lousicidal, and ovicidal effect of Egyptian EOs against flies and the buffalo louse, *Haematopinus tuberculatus;* four minutes PT of *H. tuberculatus*, *in vitro*, LC_{50} values were 2.74, 22.79, 18.67, 7.28, and 12.35% for camphor, rosemary, chamomile, onion, and peppermint oils, respectively (LT_{50}= 0.89, 11.60, 21.32, 2.75, and 15.39 min, respectively) after treatment with 7.5%; *In vivo* treatments indicated complete morality of lice 0.5–2 min and the number of lice infesting buffaloes was significantly reduced 3, 4, 6, and 6 days PT with camphor, chamomile, peppermint, and onion oils, respectively. Moreover, the oils and *d*-phenothrin significantly repelled flies, *M. domestica, Haematobia irritans, Hippobosca equine,* and *Stomoxys calcitrans* for 6 and 3 days, respectively, PT of infested buffaloes (Khater et al. 2009).

This study indicated that thyme (*Thymus vulgaris*) oil was an effective adulticide (LC_{50}= 0.305%). In agreement, a study indicated the lethal effects of thyme oil against *M. domestica* larvae and adults with 80% MO plus decreased longevity of both sexes (Pavela 2007). Thyme EO was highly effective against *M. domestica* larvae through residual film method followed by clove then basil oils (LC_{50}= 2.82, 3.79, and 5.99 mg/ml, respectively) (Chere et al. 2018).

Against *M. domestica*, findings of this study come along with other studies about using other botanicals against *M. domestica*; higher larvicidal and pupicidal efficacy of *Mentha piperita* than *Mentha citrata* EO in contact and fumigation toxicity assays was recorded (Kumar et al. 2012) and the EOs of mint and lavender have a larvicidal and pupicidal effect (Bosly 2013).

Parallel studies against *M. domestica* revealed that LC_{50} values of 12 EOs and 17 terpenes ranged from 3.9 to 85.2 and from 3.3 to >100mg/dm^3, respectively. *Citrus sinensis* EO was the most effective one (LC_{50}= 3.9 mg/dm^3), then EOs of *Citrus aurantium* (LC_{50}= 4.8 mg/dm^3) and *Eucalyptus cinerea* (LC_{50}= 5.5 mg/dm^3). Moreover, 1, 8-cineole (56.86%), a major constituent of *E. cinerea* EO, was the most effective one (LC_{50}= 3.3 mg/dm^3) (Palacios et al. 2009). Eucalyptus oil had repellent and toxic effect against house flies (Kumar et al. 2011).

Similar to the findings of this study, a corresponding study indicated toxic and repellent efficacy of vetiver, cinnamon, and lavender EOs and their blends against larvae and adult *M. domestica*. Such oils were moderately toxic for eggs. Mortality of 2nd instar larvae reached 94–100% in treated media, 57–78% in dipping assays, and 38–100% in contact assays. Contact/fumigant toxicity of lavender, vetiver, cinnamon, and sunflower oils was 100, 100, 100, and 67%, respectively. Against adults, oil blends were not more effective than the individual oils; nonetheless, diluted blends with sunflower oil were equally effective as the individual oils. Moreover, cinnamon and vetiver EOs were strong larval repellents (78 and 84%, respectively) in treated media, but all oils through olfactometer assays did not repel adult flies, whereas evaluating more materials against flies demonstrated significant repellency for neem oil, vanillin, and p-menthane-3,8-diol (PMD) (Khater and Geden 2019).

Besides their insecticidal effects, EOs prolonged larval and pupal durations, reduced pupation and adult emergency% and induced morphological anomalies of the developmental stages post treatment of the third larval instar of *M. domestica* (Khater 2003; Bosly 2013).

Conclusion

House fly is challenging pest and controlling adult flies would suppress the population shortly. In this work, the adulticidal outcome of radish, mustard, rosemary and camphor against house flies had a novelty record and the current investigation concluded that all applied oils were effective adulticides against housefly. Radish oil was the most potent oil followed by camphor, mustard, and thyme oils, whereas garlic and rosemary were less effective candidates; thus, the promising oils merit further investigations regarding their persistence, field application, and ecotoxocological studies.

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Conflict of interest

The authors declare that there is no conflict of interest.

Authors' contribution

MB, HK: Helped with lab work and writing; RE, MD: Helped with writing; AS, NA: Helped with referencing and editing manuscript.

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