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Assessing the Attractiveness, Fumigant and Insecticidal Efficiency of Monoterpenes and Phenylpropenes Along with their Latent Effects on *Ceratitis Capitata* (Diptera: *Tephritidae*)

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Abstract: Crop-damaging and highly invasive species are found in the family Tephritidae (Diptera). They are constantly growing as a result of international commerce, globalization, and human relocation. A tephritid fly, like the Mediterranean fruit fly *Ceratitis capitata*, control continues to rely primarily on synthetic pesticides, which have detrimental consequences for both human health and the environment. In this regard, six monoterpenes (menthone [90%], nerolidol [95%], carvone [98%], ±citronellal [95%], cuminaldehyde [98%], and geraniol [98%]) as well as one phenylpropene (trans-cinnamaldehyde [99%]) were assessed for their ability to attract and kill (fumigant and insecticidal) *C. capitata*. Furthermore, how these substances effect on some biological activity. The examined compounds exhibit varying degrees of fumigant toxicity, with nerolidol (LC50 = 62.74 mg/liter air) being the most effective compound, followed by menthone (LC50 = 93.72 mg/liter air). The fruit flies have a tendency with a higher general mean attraction towards the nerolidol (24.10) than the others, while the citronellal (1.47) was the lowest attracting flies. In the insecticidal activity assay, nerolidol and menthone showed the highest mortality with increasing the concentration (23.3% and 20%, respectively) within 96 h at 5 mg/L concentration. Menthone increased the period of pre-oviposition (9.33 days) more than nerolidol (8.67 days) at a concentration of 5 mg/L, compared to the control (5.33 days). Moreover, menthone decreased the period of oviposition (9.8 days) more than nerolidol (10.4 days) at a concentration of 5 mg/L, compared to the control (15.7 days). Also, Nerolidol and menthone treatments resulted in a significant decrease in the mean number of eggs deposited per female (10.3-20.2, respectively) at 5 mg/L, compared to the control (85.8eggs/female). Menthone and nerolidol decreased fertility (24.2%-22.5%, respectively) compared to control treatments, which were 71.3%. Monoterpenes provide an environmentally responsible and sustainable alternative for treating *C. capitata*, but additional research is needed to ensure their effective implementation into integrated pest management strategies.

Keywords: *Ceratitis capitata*, The Mediterranean Fruit Fly, Monoterpenes and Phenylpropenes, Fumigant toxicity, Attraction, Biological aspects

1. Introduction

Tropical pest populations in temperate zone nations have increased during the last few decades. Climate change is one of the main reasons for this growth. Increased winter temperatures result in an expanded habitable zone for pests originating from tropical regions (**(Szyniszewska and Tatem 2014; Gilioli *et al*., 2022; Szyniszewska *et al*., 2024).** A prominent example of this is the Mediterranean fly, or Mediterranean fruit fly, *Ceratitis capitata* Wied: (Diptera, Tephritidae), which is regarded as one of the most significant pests for the production of fresh fruit and one of the most damaging pests globally because of its high polyphagy and capacity for invasion (**Giunti *et al.* 2023**), and classified as a quarantine pest in several countries.

Many tropical and temperate regions of the world have seen effective medfly expansion (**Deschepper *et al*., 2021; EPPO 2024**). As of now, *C. capitata* has spread to North Africa, Europe, South and Central America, Australia, and Hawaii (**Deschepper *et al*., 2021**). It is most frequently seen in California in the USA (**Gutierrez and Ponti, 2011; Papadopoulos *et al*., 2013**). With over 350 host plants from over 70 families, it is extremely polyphagous **(Liquido and Onon, 2020; EPPO 2024)**. These include crop species that are highly significant for the European and Mediterranean Plant Protection Organization (EPPO) region, such as apple (**Duyck *et al*., 2008).** Apricot, pear, and citrus (**De Meyer *et al*., 2002**).

In North Africa and Europe, conventional medfly management has relied on cover sprays, particularly those containing organophosphates (such as Malathion and dimethoate) (**Kheder *et al*., 2012**). Malathion and dimethoate are both banned in Europe for usage in open-field situations, although they are nevertheless widely used elsewhere. Although the number of approved active ingredients has decreased in some parts of the world, organophosphates, pyrethroids, chitin synthesis inhibitors, spinosad, and neonicotinoids are still used to control medfly. The overuse of cover sprays, however, and the harm these chemicals do to the environment, human health, and the emergence of insecticide resistance to various active components. It has been shown that medflies may become resistant to a variety of pesticide classes, such as lambda-cyhalothrin and Malathion (**Magaña *et al*., 2007; Couso-Ferrer *et al*., 2011; Arouri *et al*., 2015**). Additionally, medfly populations in Brazil and Spain have recently been found to be resistant to deltamethrin (**Lisi Demant *et al*., 2019; Castells-Sierra *et al*., 2022**). According to the **IARC (2017)**, the new EU strategy aims to drastically reduce the use of pesticides, including outright banning important pesticide classes like organophosphates.

Sustainable management of medflies remains difficult in many regions of the world, despite a long history of excellent scientific efforts (**Pinto Dias *et al*., 2022; Giunti*et al*., 2023**). A widespread trend in many regions of the world is to replace environmentally friendly and sustainable pesticides with synthetic spray treatments. Among these intriguing options is the utilization of natural plant compounds, which are known to be less detrimental to non-target creatures, the environment, and human health.

Monoterpenes and phenylpropenes are plant secondary metabolites with low molecular weight and boiling temperatures. Plant essential oils often contain these chemicals as primary ingredients. The monoterpenes are divided into two categories: oxygenated monoterpenes and monoterpene hydrocarbons. Monoterpenes and phenylpropenes have been shown to have numerous biological activities, such as fungicidal, insecticidal, antifeedant, antibacterial, and herbicidal effects on agricultural pests (**Sharma *et al*., 2013; Ahuja *et al*., 2015; Saad *et al*., 2018**). These properties make monoterpenes and phenylpropenes attractive as pest control agents and lead compounds for developing insecticides that are safe, effective, and completely biodegradable.

Monoterpenes, phenylpropenes, and sesquiterpenes have been shown to have diverse biological effects against several insect pests, including the ability to serve as insecticides (**Abdelgaleil *et al*., 2009; Saad *et al*., 2018**). Prior research found that monoterpenes have toxic action against *C. capitata* and documented their fumigant toxicity against the species (**Hamraoui *et al*., 1997**). Also, **Papanastasiou *et al*. (2017)** also found that following topical application, 1,8-cineole and α-pinene were highly toxic to adults of *C. capitata*. Furthermore, **Sadraoui *et al*. (2023)** claimed that *Eucalyptus cinerea*'s potent insecticidal action against adult *C. capitata* was caused by contact toxicity when applied topically to a high fraction of oxygenated monoterpenes especially1,8-cineole. Additionally, **Zhang *et al*. (2016)** demonstrated that (±)-pulegone, cuminaldehyde, citral, carvacrol, thymol, and (±)-citronellal were all efficient fumigants against *Drosophila melanogaster*. There have been reports of contact toxicity against *Sitophilus oryzae* for both a phenylpropene (eugenol) and a monoterpene (α-pinene) (**Park *et al*., 2003; Kanda *et al*., 2017**).

The attraction, fumigant and insecticidal properties of phenylpropenes and monoterpenes, as well as their impact on some biological activities of the Mediterranean fruit fly *C. capitata*, have not been studied in the literature. Also, as mentioned above, A few investigations have been carried out on these compounds' ability to control other insects. Thus, in the present work, we continue looking for beneficial natural substances for crop protection, six monoterpenes (menthone [90%], nerolidol [95%], carvone [98%], ±citronellal [95%], cuminaldehyde [98%], and geraniol [98%]) as well as one phenylpropene (trans-cinnamaldehyde [99%]) were assessed for their ability to attract and kill (fumigant and insecticidal) *C. capitata*. Furthermore, how these substances affect on some biological activity of *C. capitata*.

2. Materials and Methods

2.1. Monoterpenes and phenylpropenes

Six monoterpenes [Menthone (90%), NeroLidol (95%), Carvone (98%), ±Citronellal (95%), Cuminaldehyde (98%), Geraniol (98%),] and one phenylpropene [trans-cinnamaldehyde (99%)] products of Sigma–Aldrich Chemical Co. (Germany).

The examined monoterpenes fall into a number of subgroups, including alcohols, ketones, oxygenated sesquiterpenes, aldehydes, oxides, and oxygenated monoterpenes. The chemical structures of the tested monoterpenes and phenylpropenes that were examined are displayed in Figure 1.

2.2. Insect culture and rearing

Experiments were carried out on sexually mature adult medflies, *C. capitata*, aged 3-5 days, obtained from Plant Protection Reasearch Institute (PPRI), Department of Pests Horticultural Crops, Research Agricultural Research Center (ARC), Giza, Egypt. Flies were kept in cages (30 × 30 × 30 cm) enclosed with mesh screens and had cloth sleeves at the front and back sides to provide water and a regular diet (hydrolyzed yeast and sugar in a 1:3 ratio) (**Khan *et al*., 2016**). Each cage contained roughly 100 adults of both sexes (approximately one male for every female). The insects were housed at a regulated temperature of 25 ± 2 °C, photoperiod of 14:10 (L:D), and relative humidity of 70 ± 5% until the start of the trials.

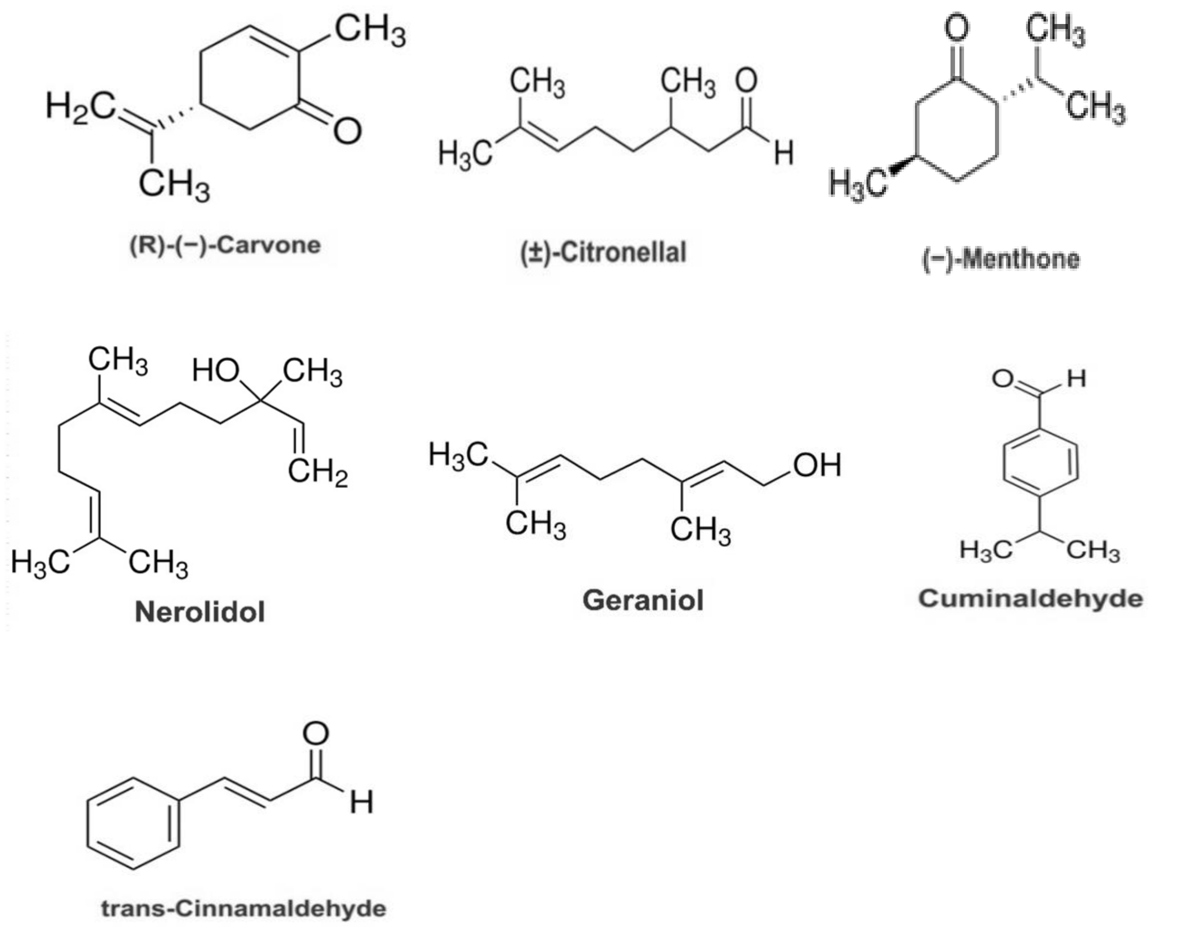

Fig. (1). The molecular structures and the names of the tested phenylpropenes and monoterpenes

2.3. Bioassay for fumigant activity

The toxicity of phenylpropene and monoterpenes investigated as a fumigant against adults of *C. capitata* was evaluated using a fumigant toxicity test (**Scharf *et al.*, 2006**). In short, 1 L glass jars were used as fumigation chambers. Different dosages of compounds (25, 50, and 100 mg/L air) were impregnated on filter paper (2 × 3 cm) that was attached to the undersides of jar screw lids. The jar, which contained twenty flies, had its cap securely fastened. Control jars with filter paper including acetone. Each treatment was duplicated Three times and control. Mortality percentages were computed by counting the number of dead insects following a 12, 24, 48 and 72-hour exposure period. To determine the lethal concentration (LC50), probit analysis was employed.

2.4. Attractiveness tests

The attraction of investigated monoterpenes and phenylpropenes to adult *C. capitata* was assessed in laboratory experiments using a simple olfactometer (**Pow *et al.*, 1999**) at various concentrations. One hundred adults of *C. capitata* of both sexes (50 females and 50 males) five days old were placed in a plastic container (9 cm x 18 cm x 23 cm) and monitored for displacement following exposure to monoterpenes and phenylpropenes. The container had eight arms of similar length (50 cm) set equidistantly from a central location where the insects are released. The arms were connected with clear plastic containers (8 cm × 16 cm). The tested monoterpene concentrations (25 and 50 mg/L) were put on filter paper and placed in plastic containers measuring 16 cm by 8 cm. The number of attracted flies in each clear container was recorded, and the percentage of attracted flies was determined at 12, 24, 48, 72, and 96 hours. The trials were carried out and replicated three times.

2.5. The direct exposition and oviposition assays

The investigated monoterpenes and phenylpropenes with good attraction activity were selected to study their insecticidal activity against adults of *C. capitata* as described by **Ouarhach *et al*. (2022).** Briefly, ten adult females and ten adult males, both newly emerged (1-2 days old), were housed in a 25 cm by 25 cm cage with a regular diet consisting of sugar and hydrolyzed yeast in a 1:3 ratio, along with 2 ml of menthone and nerolidol dissolved in 90% ethanol to achieve final concentrations of 2.5 and 5 mg/L. The flies were given water through a moist yellow sponge. After the solvent evaporated, the mixture and the newly emerging adults were housed in the plastic cage. A negative control was prepared using distilled water and 90% ethanol. Under a 12:12 h photoperiod, the flies were kept at 25 ± 0.5°C and 70% relative humidity. Fly mortality was tracked every day for 96 hours, three duplicates were used for each test, and the count of eggs laid for each treatment was assessed every 24 hours for twelve days.

2.6. Statistical analysis

Lethal concentration (LC50) was calculated using Ldp Line software, which was utilized to perform probit analysis of concentration-mortality data in accordance with **Finney (1971)**. Furthermore, data collected in this experiment were analyzed using analysis of variance (ANOVA) followed by least significant difference (LSD). The probability of 0.05 or less was considered significant. All tests were conducted using (Costat, Version: 6.303). All data are presented as means ± standard deviation (SD), and all experiments were performed in triplicate.

3. Results and Discussion

3.1. Monoterpene and phenylpropene fumigant toxicities

Results of the probit analysis for bioassays on *C. capitata* are displayed in Table 1. The examined monoterpenes and phenylpropenes showed the greatest toxicity to *C. capitata*, after 24 hours was shown by nerolidol (95%) and menthone (90%) (LC50 = 62.74 and 93.72 mg/liter air, respectively). The other monoterpenes and phenylpropenes exhibited relatively weak toxicities against *C. capitata* adult compared to the nerolidol toxicities and menthone. While the LC50 estimations for all other compounds ranged from 96.49 to 436.8 mg/liter air. The compounds that were most toxic to *C. capitata* after 48 hours were cuminaldehyde and geraniol (LC50 = 6.47 and 2.12 mg/liter air, respectively). Table 1 indicates that after 72 hours, the most toxic substances against *C. capitata* were geraniol and cuminaldehyde (LC50 = 0.085 and 12.62 mg/liter air, respectively).

As far as we are aware, this is the first investigation into the fumigant toxicities of phenylpropenes and monoterpenes to *C. capitata*. Based on the results from Table 1, nerolidol and menthone were determined to be more toxic after treatment. The current study's findings mostly concurred with those of **Ajayi *et al*. (2014),** who documented that menthone exhibited the highest fumigant toxicity against *Callosobruchus maculatus*. Furthermore, **Regnault-Roger and Hamraoui (1995)** found that carvacrol, linalool, and terpineol were the most effective fumigants against *Acanthoscelides obtectus* adults. Monoterpenes demonstrated fumigant toxic action in confined or semi-aerated conditions on *Rhopalosiphum padi* and *C. capitata* insects, according to **Hamraoui and Regnault-Roger (1997).** The fumigant toxicity of (-)-menthol against *Aphis nerii* was also greater, according to **Abdelgaleil *et al*. (2022)**. Some monoterpenes, including (-)-menthol, (L)-fenchone, (+)-camphor, 1,8-cineole, (-)-carvone and (-)- limonene, showed increased fumigant toxicity to *S. littoralis* (**Abdelgaleil, 2010**). Additionally, according to reports, menthol has fumigant toxicity against insects that are stored in products, such *Rhyzopertha dominica, Tribolillm castaneum*, *C. maclllatlls*, and *Sitophillls oryzae* (**Aggarwal *et al*., 2001**). Also, **Swapna *et al*. (2025)** reported that the fumigant activity of β-citronellol, followed by citral, exhibited high fumigant toxicity against *S. oryzae* at 72 hours after exposure.

A possible explanation for the increased fumigant toxicity is that the test chemicals interact with the physiological processes of insects by quickly reaching the target areas and penetrating the respiratory system more effectively than the insect cuticle. According to a number of studies, monoterpenes and phenylpropenes may have insecticidal effects via inhibiting ATPases and AChE (**Picollo *et al*., 2008; Abdel galeil *et al*., 2009, 2021**). Moreover, monoterpene toxicity against insects may be mediated via interactions with GABA- gated chloride ion channels (**Hold *et al*., 2000**) and octopamine receptors (**Enan, 2001**).

Table (1). Fumigant toxicity of monoterpenes and phenylpropenes against the adults of *C. capitata* after 12, 24, 48 and72 hours of exposure

Compound	Time	LC_{50} mg/liters	Confidence limits		Slope	X^2
			Lower	Upper		
Menthon (90%)	12 hr	1247	890	1342	0.46±.47	0.26
	24hr	93.72	87.56	133.4	1.89±.33	5.90
	48hr	62.2	56.7	89.43	1.76±.312	4.50
	72hr	34.9	15.6	58.9	1.92±.32	4.90
NeroLidol (95%)	12 hr	116.8	91.9	184.9	2.72±.42	2.30
	24hr	62.74	55.3	72.1	4.09±.41	1.62
	48hr	43.68	36.71	51.16	3.04±.35	0.59
	72hr	31.25	23.64	37.76	2.64±.35	3.09
trans-cinnamaldehyde (99%)	12 hr	509.9	356	723	1.38±.45	2.23
	24hr	119.6	99.8	245	2.91±.45	7.62
	48hr	92.61	77.79	120.9	3.22±.41	2.35
	72hr	70.49	61.42	83.14	3.71±.39	0.04
Carvone (98%)	12 hr	462.8	355.9	784.2	1.17±.34	8.20
	24hr	158.6	95.15	1255	1.31±.33	0.03
	48hr	127.6	79.37	999.2	1.179±.32	0.75
	72hr	82.84	55.32	108.7	0.779±.30	0.14
Citronellal (95%)	12 hr	1246	1004	1345	0.46±.47	0.26
	24hr	231.1	132.2	789.9	1.77±.41	0.31
	48hr	190.6	118.9	836.8	1.83±.39	0.06
	72hr	174.1	112.9	611.2	1.89±.39	0.24
Cuminaldehyde (98%)	12 hr	191.3	98.51	322.4	0.23±.31	6.08
	24hr	96.49	72.14	122.8	0.49±.30	0.02
	48hr	6.47	2.55	10.97	0.45±.30	0.37
	72hr	2.12	1.65	5.34	0.56±.33	0.15
Geraniol (98%)	12 hr	883.3	763.1	930.8	0.81±.37	1.37
	24hr	436.8	213.6	771.2	0.30±.29	0.02
	48hr	12.62	9.196	20.99	0.68±.31	0.43
	72hr	0.08	0.02	0.36	0.28±.33	0.26

3.2. Performance of *Ceratitis capitate* Adults to Attractants

The responses of the adults of *C. capitata* in the olfactometer for all concentrations of the monoterpenes and phenylpropenes that were tested are displayed in Table 2. The general mean of one phenylpropene [trans-cinnamaldehyde (99%)] and six monoterpenes [Menthone (90%), Nerolidol (95%), Carvone (98%), ±Citronellal (95%), Cuminaldehyde (98%), and Geraniol (98%)] at a 25% concentration were 9.50, 21.40, 8.29, 1.47, 16.00, 17.8, and 1.67), respectively, in comparison to the control (0.33). The fruit flies were more attracted to nerolidol (21.40) than the others, whereas citronellal (1.47) attracted the fewest insects. The fourth day had the highest mean number of fly attractions, which went to nerolidol (32.00), followed by nerolidol (27.00) on the third day. On the second day, nerolidol and geraniol were the most superior (22.50, 22.30, respectively), on the first day, nerolidol and geraniol were the most superior (17.30), and after 24 hours, nerolidol and geraniol were the most superior. The attractiveness power of tested monoterpenes and phenylpropenes increased gradually until the third day. While nerolidol and geraniol increased attraction till the end of the experiment.

Table 2 presents the findings on *C. capitata* preferred odor in response to 50% concentrations of monoterpenes and phenylpropenes. The fruit flies have a tendency with a higher general mean attraction towards the nerolidol (24.10) than the others, while the citronellal (1.47) was the lowest attracting flies. The highest average number of fly attractants was the fourth day, which goes to menthone and nerolidol (36.70, 34.00, respectively), followed on the third day by nerolidol and menthone, which were the most superior (29.70, 29.00, respectively). On the second day, nerolidol was the most superior (27.30), on the first day geraniol was the most superior (21.30), and after 24 hours carvone and nerolidol were the most superior (10.70, 10.00, respectively). The attractiveness power of tested monoterpenes and phenylpropenes increased gradually until the third day. While menthone, nerolidol, and cuminaldehyde increased, attracting till the end of the experiment.

Nonetheless, the aforementioned results are consistent with several scientists' findings about different monoterpenes and insect species. **Niogret and Epsky (2018)** reported that Linalool alone attracted an equal percentage of *C. capitata* flies and confirmed that this chemical was responsible primarily for attraction to ginger root oil. Furthermore, **Dewitte *et al*. (2021)** discovered that *Drosophila suzukii* was strongly attracted to the components of blackberries (*Rubus fruticosus*), acetaldehyde, hexyl acetate, linalool, myrtenol, L-limonene, and camphene.

Table (2). Attraction of *Ceratitis capitata* adults to monoterpenes and phenylpropenes after 12, 24, 48, 72, and 96 hours under laboratory conditions

Compounds	Conc. (mg/L)	Mean number of flies Attracted / hour ± SD					GM
		12	24	48	72	96	
Menthone (90%)	25	4.00±0.58^{e}	6.50±1.53^{d}	10.50±1.53^{de}	14.00±1.00^{d}	12.50±1.53^{f}	9.5
	50	6.67±0.58^{d}	12.30±1.53^{c}	19.00±2^{c}	29.00±1.73^{a}	36.70±1.53^{a}	20.7
NeroLidol (95%)	25	8.50±1.52^{abc}	17.00±1.53^{b}	22.50±0.58^{b}	27.00±2.00^{b}	32.00±1.15^{c}	21.4
	50	10.0±1.00^{ab}	19.30±2.08^{ab}	27.30±2.08^{a}	29.70±2.52^{a}	34.00±1.00^{b}	24.1
trans-cinnamaldehyde (99%)	25	1.00±0.00^{f}	1.00±0.00^{e}	2.00±1.00^{g}	2.33±0.58^{g}	2.00±1.00ij	1.67
	50	1.00±0.00^{f}	1.00±0.00^{e}	2.00±1.00^{g}	2.33±0.58^{g}	2.00±1.00ij	1.67
Carvone (98%)	25	5.50±0.58^{e}	7.33±2.08^{d}	10.30±1.15^{ef}	10.30±0.58^{e}	8.00±1.00g^{h}	8.29
	50	10.70±1.15^{a}	17.30±1.53^{b}	13.30±2.31^{d}	10.70±2.08^{e}	3.33±1.15^{i}	11.1
Citronellal (95%)	25	1.00±0.00^{f}	1.00±0.00^{e}	2.33±0.58^{g}	2.00±1.00^{g}	1.00±0.00j	1.47
	50	1.00±0.00^{f}	1.00±0.00^{e}	2.33±0.58^{g}	2.00±1.00^{g}	1.00±0.00j	1.47
Cuminaldehyde (98%)	25	7.33±1.53^{d}	14.00±1.73^{c}	16.70±0.57^{c}	17.30±0.58^{c}	24.70±0.58^{d}	16.00
	50	7.67±2.08^{cd}	12.00±2.64^{c}	8.00±1.73^{f}	7.00±1.00^{f}	9.00±1.00^{g}	8.74
Geraniol (98%)	25	8.33±1.52^{bcd}	17.30±1.53^{b}	22.30±1.53^{b}	23.70±2.08^{b}	17.30±2.08^{e}	17.8
	50	7.00±0.00^{d}	21.30±2.08^{a}	24.00±2.00^{b}	16.70±1.53^{c}	7.00±1.00^{h}	15.2
Control	-	1.00±0.00^{f}	0.33±0.58^{e}	0.00±0.00^{g}	0.33±0.58^{g}	0.00±0.00^{j}	0.33
LSD (0.05)	-	1.65	2.54	2.36	2.35	1.83	-

Means followed by the same letter in column and row are not significantly different according to the L.S.D. test at the 0.05 probability level. **GM**; overall mean

3.3. Adulticidal activity of Monoterpenes on *Ceratitis capitata*

The insecticidal activity of menthone and nerolidol, as shown in Table 3, increased mortality among adult Mediterranean fruit flies. In nerolidol response tests, *C. capitata* mortality was 23.3%

within 96 hours at a 5% concentration. For menthone application within 96 hours, mortality was 20% at a 5% concentration. Statistical analysis showed highly significant differences and the LSD = 5.25. These results indicated that the mortality effects of menthone and nerolidol were concentration-dependent. This observation supports the well-established premise that the concentration of monoterpenes influences their effectiveness as insecticides. Our results are consistent with those of **Papanastasiou *et al.* (2017)**, who noted that limonene, linalool, and α-pinene are equally toxic to both sexes of *C. capitata*, although males appear to be more susceptible to these substances than females. Nerolidol had significant insecticidal action against *Spodoptera littoralis* development stages (**Ghoneim *et al.*, 2021**). When it came to the aphid *Metopolophium dirhodum*, **Benelli *et al.* (2020)** found that (E)-nerolidol was very toxic. Furthermore, it was reported that thymol and geraniol exhibited the highest toxicity against *S. oryzae* (**Swapna *et al*., 2025**). Furthermore, the toxicity of oxygenated monoterpenes was demonstrated to be stronger against third instar *S. littoralis* larvae (**Abdelgaleil, 2010**). Additionally, carvacrol and (+)-pulegone were also identified by **Xie *et al.* (2014)** as the monoterpenes that were more toxic to *Reticulitermes chinensis*. **Kordali *et al.* (2006)** found that monoterpene hydrocarbons were the most toxic to *Leptinotarsa decemlineata* larvae. When it came to *Lasioderma serricorne* (F.) adults, **Nishchala *et al*. (2021)** found that geraniol, β-citronellol, and trans-cinnamaldehyde were the most effective toxicants.

Table (3). Impact of varying monoterpene concentrations on mortality and some biological aspects of *Ceratitis capitata* adults

Compounds	**Conc** mg/L	**Mortality after 96 h.** (% ±SD)	**Pre-oviposition al period** (Days) ± SD	**Ovipositional period** (Days) ± SD	**No. laid eggs / female** ± SD	**%Hatched eggs** ± SD
Menthone (90%)	2.5	8.33±2.8 9 b	8.30±0.26[b]	11.20±0.92[b]	48.3±2.57[b]	35.9±2.99[b]
	5.0	20.00±5.00 a	9.33±0.15[a]	9.80±0.51[b]	20.2±2.52[d]	24.2±4.90[c]
NeroLidol (95%)	2.5	10.00±0.00 b	8.60±0.26[ab]	10.40±0.46[b]	30.3±2.75[c]	41.3±4.59[c]
	5.0	23.30±2.89 a	8.67±0.25[ab]	10.40±0.86[b]	10.3±3.25[e]	22.5±2.50[b]
Control	-	00.00±0.00[c]	5.33±0.71[c]	15.70±0.86[a]	85.8±8.46[a]	71.3±3.10[a]
LSD (0.05)	-	5.25	1.25	2.30	15.30	12.20

3.4. Impact of monoterpenes on ovarian maturation (pre-ovulation period)

Results showed that the menthone and nerolidol had a biological action; these effects were observed in some aspects of *C. capitata*. Data in Table (3) revealed that menthone and nerolidol treatments showed a remarkable delay in sexual maturity and the beginning of laying of eggs (pre-oviposition period) compared to the control (5.33 days), but menthone increased the period of pre-oviposition (9.33 days) more than nerolidol (8.67 days) at a concentration of 5 mg/L, and the pre-oviposition period increased with increasing menthone concentration, whereas it did not change significantly with nerolidol treatment. Statistical analysis showed highly significant differences and the LSD = 1.25. This result was consistent with the findings of **Hamadah *et al*. (2020)**, who found that nerolidol successfully prolonged the oviposition period of *S. littoralis*. It is important to note that prolonged pre-oviposition in insects may indicate a delay or slowdown in the rate of ovarian maturation. The effect of menthone and nerolidol in delaying or slowing the pre-oviposition period in C. capitata may be explained by the affected germ cell range, or the number of germ cells produced in the embryo (**Hodin and Riddiford, 1998**). Furthermore, ovarian development in insects is known to be regulated by the endocrine system (**Kaur and Rup, 2002**). This appears to be related to interference with the inhibition of ecdysterone production, as very low levels of ecdysone, or ecdysterone, are observed in the ovaries of developing adult females (**Acheuk *et al*., 2012**).

3.5. Effect of monoterpenes on oviposition period

There are no findings on the impact of nerolidol and menthone compounds on the egg-laying period in *C. capitata*, all tested monoterpenes shortened oviposition period of *C. capitata* remarkably compared to the control (15.7 days). This finding might be explained by the enforcing impact of menthone and nerolidol on ovipositing adult females of *C. capitata*, causing them to deposit eggs in a short period of time in order to escape this harmful xenobiotic factor (**Tanani and Ghoneim, 2017**). However, the actual mechanism of this imposing effect remains unclear to us. On other hand, menthone decreased the period of oviposition (9.8 days) more than nerolidol (10.4 days) at a concentration of 5 mg/L, whereas increasing the concentration did not change significantly with nerolidol treatment. Statistical analysis showed highly significant differences and the LSD = 2.30. This finding was consistent with the results published for *S. littoralis* by **Hamadah *et al*. (2020),** who reported that nerolidol successfully reduced the oviposition duration. The effects of the tested monoterpenes on oviposition of various insects were recorded. **Choubey (2012)** reported that two monoterpenes, α-pinene and β-caryophyllene, significantly inhibited the ability of *T. castaneum* to lay eggs. **Hamada *et al*. (2020)** also observed that nerolidol was successful in reduced the oviposition period in *S. littoralis*. In female *B. zonata*, (R)-camphor, menthol and (R)-carvone have destructive effects on the ovary and ovarioles, which can result in total suppression of oviposition **((El-Minshawy *et al*., 2018**). In addition, **Antonatos *et al*. (2021)** indicated that (±)-linalool inhibits the egg-laying process by reducing egg production. For the *C. capitata*, linalool was shown to inhibit oviposition, whilst limonene was discovered to stimulate oviposition (**Ioannou *et al*., 2012; Papanastasiou *et al*. 2020**).

3.6. Effect of monoterpenes on fecundity

Table 3 displays the impact of nerolidol and menthone at 2.5 and 5 mg/L on the fecundity (mean number of eggs/♀) of *C. capitata*. The studied monoterpenes drastically decreased the number of eggs deposited per female. Adult fecundity was reduced more significantly by nerolidol and menthone at 5 mg/L than at 2.5 mg/L. Overall, menthone and nerolidol treatments resulted in a significant decrease in the number of eggs deposited per female compared to the control (85.8 eggs/female). Statistical analysis showed highly significant differences and the LSD = 15.3. These results were supported by earlier research, such as that conducted by **Papanastasiou *et al*. (2020),** which found that linalool can inhibit the quantity of eggs that female *C. capitata* lay on citrus fruits. Also, monoterpenes (geraniol, 1,8-cineole, linalool, R-(+)-limonene, and terpinen-4-ol) were shown to reduce *T. confusum* fertility (**Stamopoulos *et al*., 2007**). Furthermore, **Mbatha and Payton (2013)** found that mated *C. maculatus* females treated with low dosages of monoterpenoids did not deposit eggs after being given cowpea seeds. Nerolidol was shown to have an inhibitory impact on S. littoralis oviposition efficiency by **Hamadah *et al*. (2020)** because the oviposition rate was negatively regressed in a dose-dependent manner. Also, Nerolidol was shown to have a notable suppressive impact on *Tetranychus mexicanus*, a Mexican mite, in terms of fertility (**Amaral *et al*., 2017**).

In light of the current decline in C. capitata fecundity, it is worth noting that some plant compounds act as hormonal regulators of insect molt and metamorphosis due to blockage and delay in the release of ecdysteroids and juvenile hormone from their neurohaemal organs. Consequently, it is well known that the plant products prevent the growth and development of the testes as well as the ovary (**El-Zoghaby, 1992; El-Sabrout, 2013**). The significant decrease in fertility of *C. capitata* following adult treatment with nerolidol and menthone may be the result of this substance interfering with one or more reproductive physiologic systems. It might be reasonable to hypothesize that the current study's findings regarding the prohibited fecundity of *C. capitata* could be caused by a combination of factors, including suboptimal nutrition from reduced feeding, altered mating behavior due to sublethal intoxication, or the inhibitory effects of menthone and nerolidol on the synthesis of both RNA and DNA.

3.7. Effect of monoterpenes on fertility

Fertility (the percentage of eggs that hatch) is an informative indicator of insect reproductive potential. However, diminishing fertility indicates increased sterility. Menthone and nerolidol decreased fertility in the current study, as seen in Table 3; at concentrations of 5 mg/L compared to 2.5 mg/L, both menthone and nerolidol significantly decreased *C. capitata* fertility. The hatching percentage was 24.2% in the menthone treatment and decreased to 22.5% in the nerolidol treatment. In contrast, the egg-hatching percentage in control treatments was 71.3%. Statistical analysis showed highly significant differences and the LSD = 12.2.

This finding was consistent with a study by **Hamadah *et al*. (2020)** that found that nerolidol significantly reduced *S. littoralis* fecundity and fertility, which disrupted the reproductive capacity. **Stamopoulos *et al*. (2007)** also found that monoterpenes (geraniol, 1,8-cineole, linalool, R-(+)-limonene, and terpene-4-ol) reduced *T. confusum* egg hatchability. Additionally, at 7.22 mg/cm² surface treatment, carvone inhibited *T. castaneum* egg hatching (**Tripathi *et al*., 2003**). Furthermore, various compounds such as trans-anethole and α-pinene demonstrated great promise as hatching inhibitors or larvicides for controlling *Pseudaletia unipuncta* (**Rose *et al*., 2015**). In other work, **Abdelgaleil *et al*. (2021)** found that (Z,E)-nerolidol 1,8-cineole, (−)-carvone, trans-Cinnamaldehyde, and (−)-citronellal were most effective in reducing egg laying and hatching of *S. littoralis* eggs.

4. Conclusion

The investigated monoterpenes, nerolidol and menthone, demonstrated promising biological activity against *Ceratitis capitata*, including ovarian damaging effects, sterilizing, oviposition period, and fecundity. According to these findings, the monoterpenes under examination exhibit a variety of ways of action, such as adulticidal activity and fumigant toxicity test the attractiveness. The investigated monoterpenes may be beneficial in various pest management programs and initiatives with a lower risk of resistance development and environmental contamination. As a result, the monoterpenes that were examined may offer appropriate elements for *C. capitata* integrated pest management (IPM).

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