







## Article

# Insecticidal Effect of Wild-Grown *Mentha pulegium* and *Rosmarinus officinalis* Essential Oils and Their Main Monoterpenes against *Culex pipiens* (Diptera: Culicidae)

Amal Ramzi <sup>1</sup>, Abdelhakim El Ouali Lalami <sup>1,2</sup>, Yassine Ez zoubi <sup>1,3</sup> , Amine Assouguem <sup>1,4,\*</sup> , Rafa Almeer <sup>5</sup>, Agnieszka Najda <sup>6</sup> , Riaz Ullah <sup>7</sup> , Sezai Ercisli <sup>8</sup>  and Abdellah Farah <sup>1</sup> 

- <sup>1</sup> Laboratory of Applied Organic Chemistry, Faculty of Sciences and Technologies, Sidi Mohamed Ben Abdellah University, Imouzzet Street, Fez 2202, Morocco; ramzi.amal@usmba.ac.ma (A.R.); eloualilalami@yahoo.fr (A.E.O.L.); y.ezzoubi@uae.ac.ma (Y.E.z.); farah.abdellah1@gmail.com (A.F.)
- <sup>2</sup> Higher Institute of Nursing Professions and Health Techniques, Regional Health Directorate, EL Ghassani Hospital, Fez 30000, Morocco
- <sup>3</sup> Biotechnology, Environmental Technology and Valorization of Bio-Resources Team, Department of Biology, Faculty of Science and Techniques Al-Hoceima, Abdelmalek Essaadi University, Tetouan 2117, Morocco
- <sup>4</sup> Laboratory of Functional Ecology and Environment, Faculty of Sciences and Technologies, Sidi Mohamed Ben Abdellah University, Imouzzet Street, Fez 2202, Morocco
- <sup>5</sup> Department of Zoology, College of Science, King Saud University 2455, Riyadh 11451, Saudi Arabia; ralmeer@ksu.edu.sa
- <sup>6</sup> Department of Vegetable and Herbal Crops, University of Life Sciences, Lublin 50A Doswiadczalna Street, 20-280 Lublin, Poland; agnieszka.najda@up.lublin.pl
- <sup>7</sup> Department of Pharmacognosy, College of Pharmacy, King Saud University, Riyadh 11451, Saudi Arabia; rullah@ksu.edu.sa
- <sup>8</sup> Department of Horticulture, Faculty of Agriculture, Ataturk University, 25240 Erzurum, Turkey; sercisli@gmail.com
- \* Correspondence: assougam@gmail.com



**Citation:** Ramzi, A.; El Ouali Lalami, A.; Ez zoubi, Y.; Assouguem, A.; Almeer, R.; Najda, A.; Ullah, R.; Ercisli, S.; Farah, A. Insecticidal Effect of Wild-Grown *Mentha pulegium* and *Rosmarinus officinalis* Essential Oils and Their Main Monoterpenes against *Culex pipiens* (Diptera: Culicidae). *Plants* **2022**, *11*, 1193. <https://doi.org/10.3390/plants11091193>

Academic Editor: Fabrizio Araniti

Received: 13 April 2022

Accepted: 26 April 2022

Published: 28 April 2022

**Publisher's Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Copyright:** © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

**Abstract:** The present study investigates the insecticidal effect of plant extract such as *Mentha pulegium* and *Rosmarinus officinalis* essential oils and some of their major compounds; these plants are well known for their many biological activities. The fumigant toxicity was evaluated, using glass jars, against female adults of *Culex pipiens* that constitute a mosquito vector of important diseases such as the West Nile virus. The adulticidal test showed that both essential oils and monoterpenes presented an insecticidal effect better than the chemical insecticide (Deltamethrin). The highest mortality percentages for the two essential oils have occurred at 312.5 µL/L air (between 56.14 ± 1.7% and 97.71 ± 3.03% after 24 h and 48 h of treatment). Moreover, all tested monoterpenes (carvone, R(+)-pulegone, 1,8-cineole, camphor and α-pinene) have produced high mortalities that varied depending on the time of the treatment and the concentrations used. Lethal concentrations (LC<sub>50</sub>) obtained for the essential oils and the main compounds have also varied according to the exposure time. *M. pulegium* and *R. officinalis* essential oil exhibited the lowest LC<sub>50</sub> values after 24 h (72.94 and 222.82 µL/L air, respectively) and after 48 h (25.43 and 55.79 µL/L air, respectively) while the pure molecules revealed the lowest LC<sub>50</sub> values after 48 h (between 84.96 and 578.84 µL/L air). This finding proves that the two essential oils and their main compounds have an insecticidal potential, which could help to develop natural toxic fumigants that may be used as an eco-friendly alternative in integrated and sustainable vector management.

**Keywords:** mosquitoes; *Mentha pulegium*; *Rosmarinus officinalis*; essential oils; monoterpenes; fumigant toxicity; *Culex pipiens*

## 1. Introduction

Nowadays, plant-secondary metabolites (essential oils and extracts) have attracted scientific committees since the isolated compounds such as terpenoids, flavonoids, pheno-

lics and alkaloids have exhibited many biological activities [1–3]. Essential oils constitute a great interest for researchers who always try, through their scientific studies, to discover the great potential of these substances as antioxidant, antimicrobial, anti-inflammatory and insecticidal agents. In fact, plants from the Lamiaceae family are well known for their biologically active essential oils, and many reports have documented the presence of various compounds such as terpenes, iridoids, flavonoids and phenolic constituents in species of this family [4]. Moreover, it has been reported that the two Lamiaceae plants, *Mentha pulegium* and *Rosmarinus officinalis* have many important biological activities [5]. *M. pulegium* possesses several biological properties; this aromatic plant has proven antioxidant and anticholinesterase [6], anthelmintic [7], antimicrobial [4] and insecticidal effects [8–10]. Similarly, *R. officinalis* is well known for its beneficial effect as a therapeutic agent [11] and it also displays insecticidal potential [12].

The insecticidal effect of these medicinal plants has been highly reported against stored product insects [13–17], and as larvicidal and repellent agents against some mosquitoes [18–21]. However, there were a few reports on the fumigant activity of these plants on mosquito adults, especially *Culex pipiens* that is considered a mosquito vector of important diseases and well known for their public health and veterinary importance [22]. In addition, few studies have reported the insecticidal effect of monoterpenes against adults of *C. pipiens* [23], yet the insecticidal effect of these compounds was reported against other insect genera [24,25].

Indeed, *Culex pipiens* play a major role in the transmission of harmful viruses that represent a serious threat to public and veterinary health [26]. This mosquito especially induces the West Nile fever disease that has occurred by a virus from the Flaviviridae family; it could affect the nervous system leading to severe symptoms that may induce death [27]. Hence, plant-based natural products could represent an alternative approach for sustainable control since the wide appearance of resistance of *C. pipiens* adults to synthetic insecticides [28,29].

Therefore, this paper aims to investigate the insecticidal potential of *M. pulegium* and *R. officinalis* essential oils against female adults of *C. pipiens*, and also to highlight the comparative toxicity of their main compounds.

## 2. Material and Methods

### 2.1. Material

To evaluate the insecticidal effect, *Mentha pulegium* and *Rosmarinus officinalis* were collected during their flowering period (between July and September for *M. pulegium* and between January and May for *R. officinalis*) from a mountainous zone in Taounate town (northeastern Morocco). The samples were identified at the National Agency for Medicinal and Aromatic Plants in Taounate, Morocco. The pure compounds; 1,8-cineole (99%), camphor (98%),  $\alpha$ -pinene (98%), carvone (98%) and R(+)-pulegone (99%) were purchased from Sigma-Aldrich (Steinheim, Germany). Deltamethrin (0.05%) was used as a positive control at the diagnostic dose suggested by the World Health Organization for mosquito adults.

### 2.2. Essential Oils Isolation and Chemical Analysis by GC-MS

Essential oils (EOs) were obtained from the aerial parts of each plant (stem, flowers and leaves) after their hydrodistillation for 3 h using a Clevenger apparatus. The yield of both EOs was calculated based on the dry weight of the plants. Gas chromatography coupled with mass spectrometry (GC-MS) was adopted to determine the aroma profile of each EO. To elucidate the process, a Hewlett-Packard (HP 6890) Gas Chromatographer coupled with a Mass Spectrometer (HP 5973) was used for the chemical analyses required. The Gas Chromatography was equipped with the column HP-5MS (30 m  $\times$  0.25 mm, film thickness 0.25  $\mu$ m). Helium was chosen as carrier gas with a flow rate of 1.4 mL/min. The split mode was used, and the injection temperature was fixed from 50 to 200 °C at a heating rate of 4 °C/min, for 5min. The mass spectrometry apparatus was operated at specific

conditions, which are the ionisation energy (70 eV); the ionisation source temperature (280 °C), the solvent cut time (3 min) and the mass spectra were recorded over a range of 30 to 1000 atomic mass units at 0.5 s/scan. The compounds were identified based on their retention indices, by comparison with the NIST MS Search database 2012, and by Adams terpene library [30].

### 2.3. *Culex Pipiens* Rearing Conditions

The collection of larvae was performed randomly using a rectangular plastic tray from a site characterized by a high larval density of *Culex pipiens* (*C. pipiens*), it is called Oued El Mehraz and it is situated in an urban area of Fez City (north-east of Morocco). To obtain mosquito adults for ulterior use in bioassays, collected larvae were kept under specific rearing conditions; an average temperature of 22.6 °C ± 2 °C, relative humidity of 70% ± 5%, with dimension cages (24 × 24 × 24 cm). Adults were nourished on sucrose solution. *C. pipiens* adults were morphologically identified using the Moroccan key of Culicidae identification [31], and the identification software of mosquitoes of Mediterranean Africa [32].

### 2.4. Fumigant Toxicity

The Fumigant activity was evaluated as described by Zahran and Abdelgaleil (2011) [23] with slight modifications; it was carried out on female adults of *C. pipiens* (2–3 days) using glass jars. A series of concentrations were prepared for each EO and they were expressed per volume of air (19.53, 39.06, 78.125, 156.25, 312.5 µL/L air) and also for the five pure compounds (50, 100, 156.25, 312.5, 625, 1250, 2500, 5000 µL/L air). Then, 5µL of each concentration was applied on Whatman filter papers that were attached to the lower surface of the jar covers. DMSO was used as a negative control, while Deltamethrin was used as a positive control. Three replicates (20 females per test) were performed. The mortality percentages of the adults exposed to the insecticidal substances were recorded after 24 h and 48 h of treatment; they were calculated using Abbott's formula (1). Probit analysis was used to estimate LC<sub>50</sub> values.

$$\% \text{ Mortality Corrected} = \left[ \frac{\% \text{ Mortality Observed} - \% \text{ Mortality Control}}{100 - \% \text{ Mortality Control}} \right] \times 100 \quad (1)$$

### 2.5. Statistical Analyses

Mortality rates data of both EOs and their main compounds were analyzed statistically by analysis of variance (ANOVA) using IBM SPSS 21 software. LC<sub>50</sub> values were estimated according to Finney's mathematical methods [33].

## 3. Results

### 3.1. Extraction Yield and Chemical Composition

The hydrodistillation of the two aromatic plants provided a variable amount of EOs since the yield of *M. pulegium* was 2.26 ± 0.14%, while it was 1.96 ± 0.33% for *R. officinalis*. Gas chromatography and mass spectrometry revealed that 18 molecules (93.35%) were identified in *M. pulegium* EO; it was dominated by pulegone (74.03%), carvone (5.45%) and dihydrocarvone (3.66%), whereas *R. officinalis* EO contains 23 constituents representing 94.23%. 1,8-cineole (29.31%), camphor (24.66%) and α-pinene (12.76%) were identified as the major components in this EO (Table 1).

**Table 1.** The chemical compounds identified in *M. pulegium* and *R. officinalis* EOs.

Compound	RI (Exp) <sup>a</sup>	RI (Lit) <sup>b</sup>	<i>M. pulegium</i> *	<i>R. officinalis</i> *
$\alpha$ -Thujene	931	924	-	0.48
<b><math>\alpha</math>-Pinene</b>	939	932	0.42	<b>12.76</b>
Cyclohexanone-3-methyl	952	945	0.16	-
Camphene	953	946	-	2.47
$\beta$ -Pinene	976	974	0.33	2.89
Unknown	957	-	-	t
Unknown	958	-	0.08	t
Unknown	961	-	0.07	t
Unknown	985	-	t	-
Myrcene	993	988	0.16	2.54
Octanol-3	993	995	1.32	-
Unknown	995	-	-	t
$\delta$ -2-Carene	1001	998	0.11	-
Unknown	1023	-	0.07	1.5
Limonene	1031	1029	1.34	-
<b>1,8-Cineole</b>	1033	1033	-	<b>29.31</b>
Unknown	1035	-	-	t
Unknown	1040	-	-	t
Unknown	1064	-	t	t
p-Mentha-3,8-diene	1071	1072	2.04	-
Unknown	1075	-	t	1.03
Unknown	1100	-	-	t
<b>Camphor</b>	1143	1141	-	<b>24.66</b>
Unknown	1148	-	-	t
Menthone	1154	1148	0.13	-
Borneol	1165	1166	-	5.46
Pinocarvone	1168	1160	1.21	-
Menthol	1173	1167	0.45	-
$\alpha$ -Terpineol	1185	1186	-	0.63
Dihydrocarvone	1194	1191	3.66	-
Myrtenol	1195	1194	-	1.23
Unknown	1207	-	0.09	-
<b>Pulegone</b>	1238	1233	<b>74.03</b>	-
<b>Carvone</b>	1242	1239	<b>5.45</b>	-
Unknown	1245	-	-	0.2
Peperitone	1252	1249	1.12	-
Unknown	1265	-	-	0.2
Myrtenyl acetate	1322	1324	-	0.22
$\alpha$ -Cubebene	1351	1345	-	0.15
$\alpha$ -Copaene	1381	1374	-	0.10

Table 1. Cont.

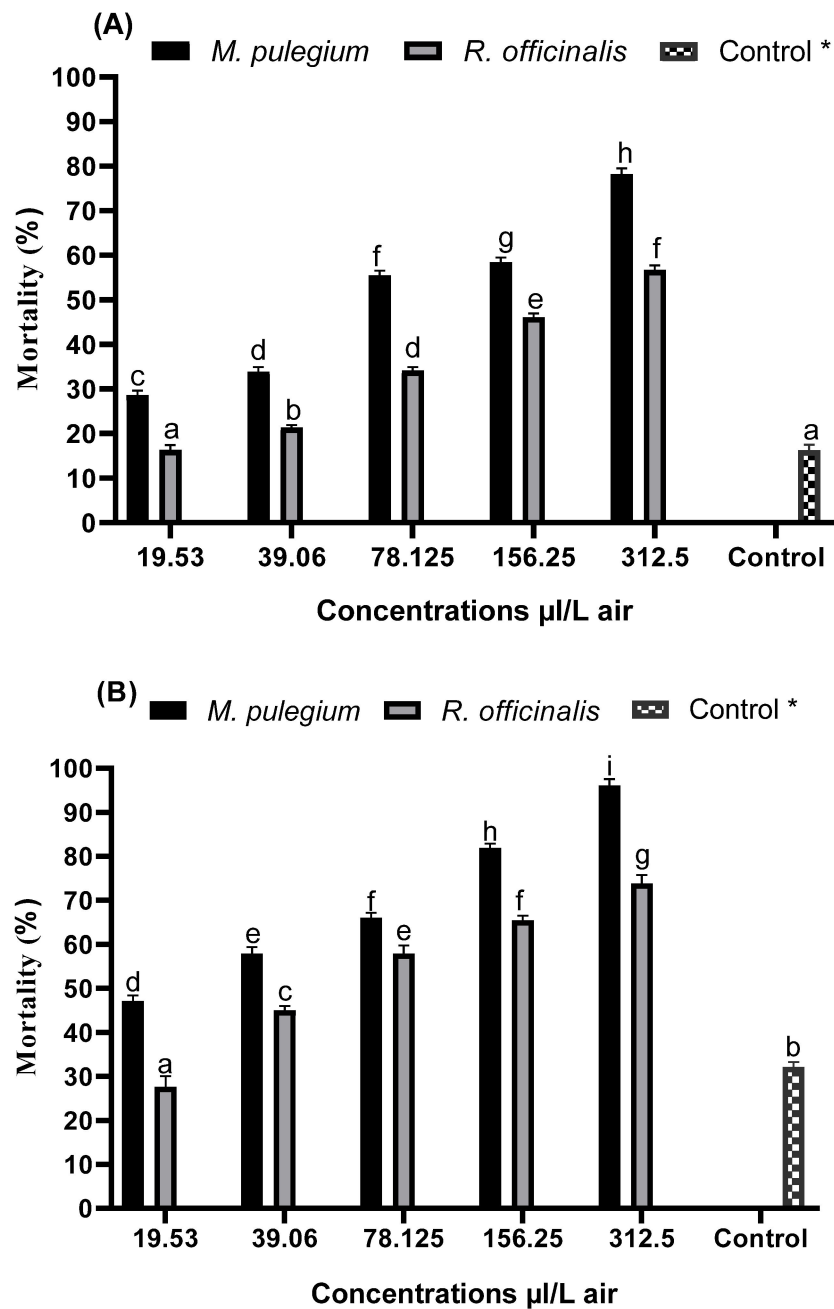
Compound	RI (Exp) <sup>a</sup>	RI (Lit) <sup>b</sup>	<i>M. pulegium</i> *	<i>R. officinalis</i> *
$\beta$ -Bourbonene	1384	1387	-	0.16
Unknown	1397	-	0.06	-
Caryophyllene	1419	1417	0.35	-
$\gamma$ -Gurjunene	1473	1475	-	0.2
Germacrene-D	1480	1484	-	0.42
Ledene	1493	1490	-	2.92
$\alpha$ -Muurolene	1499	1500	-	0.32
$\gamma$ -Cadinene	1513	1513	-	0.8
Caryophyllene oxide	1581	1582	-	2.75
Copaen-4- $\alpha$ -ol	1584	1590	-	0.43
Tetradecanal	1611	1612	-	0.21
$\gamma$ -Eudesmol	1630	1630	0.26	-
$\tau$ -Cadinol	1653	1654	-	0.19
$\alpha$ -Eudesmol	1649	1652	0.44	-
Total identified compounds			93.35	94.23

<sup>a</sup>: Experimental retention indices. <sup>b</sup>: Retention indices from literature [30,34]. \* The quantity of each compound was given by percentages that were presented as a ratio of the areas of the chromatographic peaks. T: trace < 0.05%. The compounds indicated in bold represent the major constituents, in both EOs, that have been tested for their insecticidal effect.

### 3.2. Comparative Toxicities of Both EOs and the Pure Compounds on *C. pipiens* Adults

The fumigant toxicity results indicated that the mortality of *C. pipiens* adults differs between each EO tested and its main compounds, concentrations used, as well as the time of exposure; it could be said that the mortality was concentration and time-dependent. As illustrated in Figure 1, *M. pulegium* EO exerted a high insecticidal effect at all various concentrations tested than *R. officinalis* EO, yet they both have an important insecticidal potential towards adults of *C. pipiens* compared to the chemical insecticide (Deltamethrin). It appears that the mortality efficacy increases with the increase in concentrations and exposure time. At the highest concentration (312  $\mu$ L/L air), *M. pulegium* EO killed  $78.94 \pm 0.16\%$  and  $97.71 \pm 3.03\%$  of mosquitoes after 24 h and 48 h of treatment, respectively, while the mortality rates recorded for *R. officinalis* were calculated at  $56.14 \pm 1.7\%$  and  $75.94 \pm 1.92\%$ , respectively. In contrast, the Deltamethrin displayed mortality of  $19.29 \pm 0.01\%$  and  $34.05 \pm 1.01\%$  after the same exposure periods.

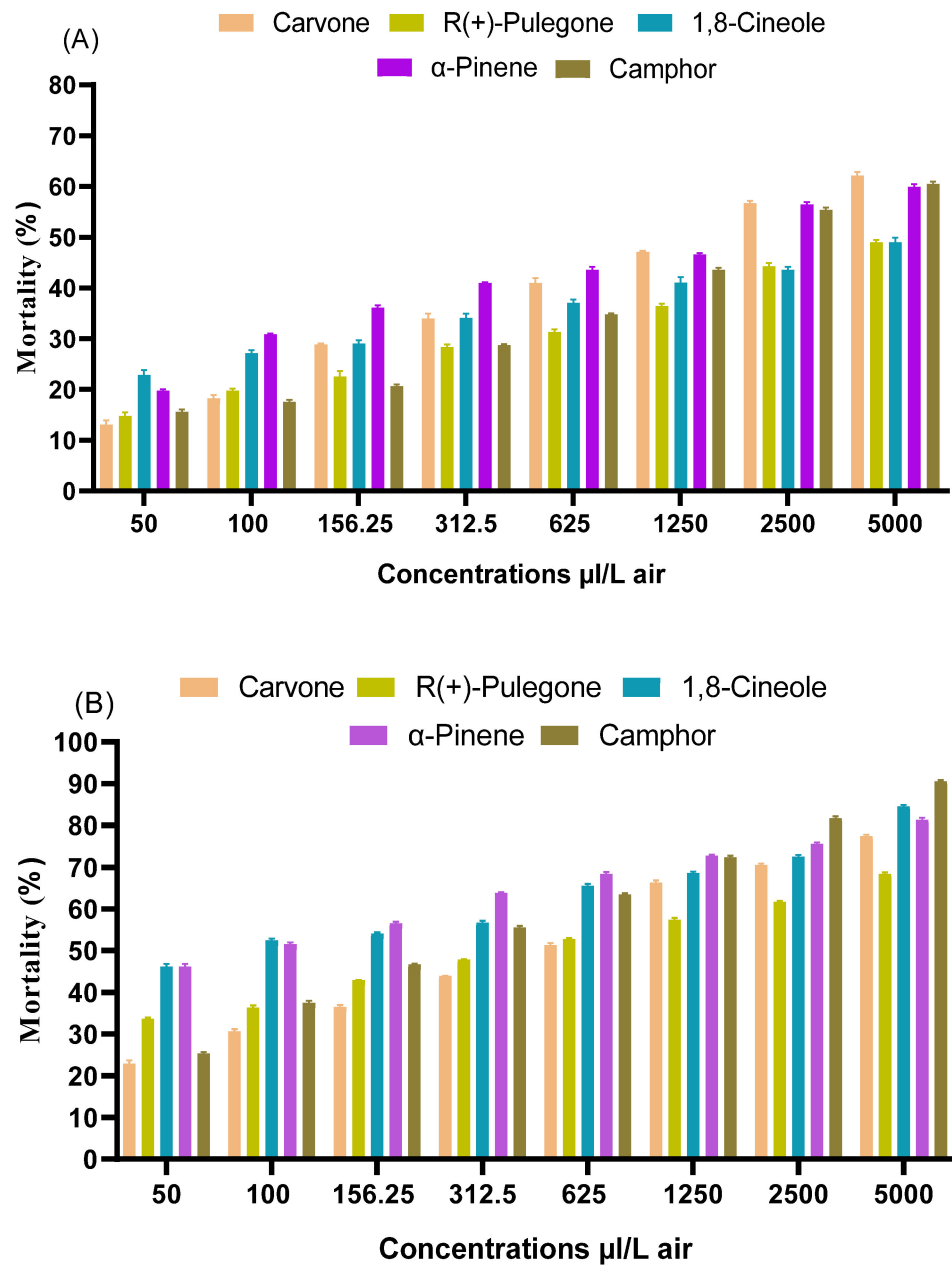
Figure 2 shows the comparative toxicity of monoterpenes at different concentrations. Apparently, the toxicity varies from one compound to another and depends on the concentration applied. Nevertheless, they all have toxic effects on *C. pipiens* adults. At the lowest concentration (50  $\mu$ L/L air), 1,8-cineole, camphor and  $\alpha$ -pinene that constitute the main compounds in *R. officinalis* EO were found to be more effective than carvone and R(+)-pulegone; the principal constituents in *M. pulegium* EO, after 24 h and 48 h of exposure. It also seems that the five monoterpenes exhibited a high toxic effect as the concentrations increased. At 5000  $\mu$ L/L air, all compounds produced high mortality that varies between  $48.63 \pm 1.3\%$  and  $61.5 \pm 0.5\%$  after 24 h and  $68.24 \pm 0.57\%$  and  $90.55 \pm 1.2\%$  after 48 h. 1,8-cineole, camphor and  $\alpha$ -pinene were the most effective at this highest concentration after 48 h, while 1,8-cineole and camphor displayed high mortalities that reached  $84.33 \pm 1.54\%$  and  $90.55 \pm 1.2\%$ . It could be concluded that these monoterpenes have the potential to kill *C. pipiens* adults even at lower concentrations.



**Figure 1.** Evaluation of *M. pulegium* and *R. officinalis* EOs toxicity on *C. pipiens* adults according to different concentrations: (A): After 24 h; (B): After 48 h. (\*): Positive control (Deltamethrin 0.05%). Means followed by the same letter are not significantly different at *p*-value (0.05).

Table 2 summarizes the lethal concentration values, and other parameters obtained from regression lines of the test of both essential oils and the five monoterpenes. It could be extrapolated that LC<sub>50</sub> values for *M. pulegium* EO were estimated at 72.94 and 25.43 µL/L air after 24 and 48 h of treatment, respectively. Whereas their main monoterpenes (carvone and R(+)-pulegone), presented LC<sub>50</sub> values of 1713.36 (1703.33–1723.36) and 5395.58 (5295.58–5494.68) µL/L air after 24 h and 538.96 (512.84–568.36) and 578.84 (578.24–597.64) µL/L air after 48 h, respectively. For *R. officinalis* EO, LC<sub>50</sub> values were obtained at 222.82 (210, 234.29) and 55.79 (50.77–60.81) µL/L air after 24 and 48 h, respectively. However, 1,8-cineole, camphor and α-pinene displayed LC<sub>50</sub> values at 5395.65 (5282.45–5486.55), 2269.64 (2190.41–2354.45) and 1294.64 (1230–1345.14) µL/L air after 24 h

and 84.96 (75.8–95.26), 205.38 (167.83–300.51) and 85.74 (74.04–98.21)  $\mu\text{L}/\text{L}$  air after 48 h, respectively. From the results of mortality rates and  $\text{LC}_{50}$  values, it could be concluded that both EOs killed more female adults and revealed the lowest  $\text{LC}_{50}$  values in comparison to their main constituents.



**Figure 2.** Toxicity of monoterpenes against *C. pipiens* adults at various concentrations after 24 h (A), and 48 h (B) of treatment. Results are means of three replicates ( $n = 3$ ). Bars indicate standard errors. Tests were statistically significant at  $p$ -value (0.05).

**Table 2.** Lethal concentrations (LC<sub>50</sub>) of *M. pulegium* and *R. officinalis* EOs and their main compounds.

EOs and Monoterpenes	Exposure Time (h)	LC <sub>50</sub> <sup>a</sup> (μL/L Air) (95% Confidence Intervals)	Slope <sup>b</sup>	Intercept <sup>c</sup>	R <sup>2</sup>	p-Value <sup>d</sup>
<i>M. pulegium</i>	24	72.94 (60.34–83.32)	1.146 ± 0.15	2.865 ± 0.30	0.94	0.005
	48	25.43 (13.22–38.65)	1.169 ± 0.18	3.357 ± 1.23	0.94	0.005
<i>R. officinalis</i>	24	222.82 (210, 234.29)	0.957 ± 0.11	2.753 ± 0.63	0.93	0.003
	48	55.79 (50.77–60.81)	1.093 ± 0.08	3.091 ± 1.18	0.93	0.003
Carvone	24	1713.36 (1703.33–1723.36)	0.774 ± 0.04	2.497 ± 0.12	0.96	0.000
	48	538.96 (512.84–568.36)	0.827 ± 0.02	2.741 ± 0.07	0.99	0.000
R(+)-Pulegone	24	5395.58 (5295.58–5494.68)	0.515 ± 0.01	3.078 ± 0.02	0.99	0.000
	48	578.84 (578.24–597.64)	0.577 ± 0.05	3.406 ± 0.14	0.93	0.000
1,8-Cineole	24	5395.65 (5282.45–5486.55)	0.362 ± 0.01	3.649 ± 0.03	0.98	0.000
	48	84.96 (75.8–95.26)	0.537 ± 0.05	3.964 ± 0.14	0.90	0.000
Camphor	24	2269.64 (2190.41–2354.45)	0.663 ± 0.01	2.775 ± 0.04	0.98	0.000
	48	205.38 (167.83–300.51)	1.027 ± 0.08	2.6258 ± 0.22	0.94	0.000
α-Pinene	24	1294.64 (1230–1345.14)	0.642 ± 0.06	3.002 ± 0.16	0.92	0.000
	48	85.74 (74.04–98.21)	0.509 ± 0.01	4.016 ± 0.04	0.99	0.000

<sup>a</sup>: Lethal concentration killing 50% of exposed adult population. <sup>b</sup>: Slope of the regression line ± SE. <sup>c</sup>: Intercept of the regression line ± SE. <sup>d</sup>: Significant effect at *p*-value < 0.05.

#### 4. Discussion

In mosquito management programs, control of mosquito adults is still hard given difficulties related to the accessibility to the rearing site, while the control of larvae is just limited to aquatic habitats [23]. Choosing the appropriate method and the insecticidal substances is of great priority in mosquito control. Therefore, this study has been achieved to valorize plant EOs and monoterpenes by evaluating their insecticidal effect against mosquito adults. Our findings indicated that *M. pulegium* and *R. officinalis* EOs exhibited toxic effects against *C. pipiens* female adults as well as their selected major compounds (1,8-cineole, camphor, α-pinene, carvone and R(+)-pulegone). Among the five pure molecules, 1,8-cineole, camphor and α-pinene that represent the main substances in *R. officinalis* EO were found to be more toxic, but generally, all compounds possess an insecticidal potential. In fact, all obtained results demonstrated that the two EOs presented fumigant toxicity better than their pure components. This variability in the insecticidal effectiveness could be explained by the fact that EOs are mixtures of chemical constituents and their biological effect could be attributed to the major monoterpenes components, or minor components, or probably the synergistic or antagonistic effect between various natural products, with no individual compound making a dominating contribution [35].

Recently, EOs are considered one of the best strategies in mosquito control, they have proven an effective mosquitocidal effect. The fumigant toxicity against adults of *C. pipiens* using the two EOs and even the five monoterpenes have not been documented in some countries including Morocco. However, the larvicidal activity of essential oils against *C. pipiens* has been reported [36,37]. Similarly, the larvicidal effect of monoterpenes such as 1,8-cineole, (R)-carvone and (R)-camphor was evaluated towards *C. pipiens* [23]. 1,8-cineole and camphene were also tested against larvae of *C. pipiens* pallens [38]. The larvicidal toxicity of pinenes (enantiomers of α- and β-) against the same mosquito species was also investigated by Michaelakis et al. (2009) [37]. Chen et al. (2021) [39] have also reported the insecticidal potential of fifteen pure compounds including (+)-camphor and 1,8-cineole on larvae of the beet armyworm *Spodoptera exigua* while they showed LC<sub>50</sub> values of 161.22 (154.48–168.24) and 104.17 (98.71–109.94) μg/insect, respectively.



Worldwide, EOs isolated from Chinese plants revealed fumigant toxicity against *C. pipiens* adults such as *Mentha piperita*, which belongs to the same genus and was among the tested oils [40]. Additionally, EO obtained from an Egyptian plant which was *Mentha microphylla* a genus of the mint family (Lamiaceae), also has a proven fumigant effect against *C. pipiens* adults [41]. The fumigant effect of another genus, *Mentha longifolia*, has also been achieved against the females of *C. pipiens*. This plant with pulegone (74/95%), 1,8-cineole (7.35%) and eucarvone (2.68%) were the main compounds exerting toxicity of  $LC_{50} = 0.215 \mu\text{L/L}$  [42]. Our results are in agreement with those obtained previously by Zahran and his collaborators, in 2017 [43], who confirmed that *R. officinalis* was among the EOs that were the most potent fumigants against adults of *C. pipiens*. Furthermore, five essential oils including *Mentha piperita* were tested for their repellency effect against the adult females of *C. pipiens* [44].

The insecticidal effect of these EOs has also been reported against another insect genus; Brahmi and his coauthors (2016) [45] evaluated the contact toxicity, fumigant toxicity and repellency effect of *Mentha pulegium* and *Mentha rotundifolia* from Algeria against adults of *Rhyzopertha dominica*, the principal pest of wheat. Indeed, pulegone (70.4%) was the main component found in *M. pulegium* EO. The fumigant effect of both EOs revealed a mortality rate of 39.2% and 44.3%, respectively, at a concentration of 2000  $\mu\text{L/L}$ . Similarly, Isikber et al., (2006) [46] evaluated the fumigant toxicity of *R. officinalis* EO against all life stages of *Tribolium confusum*, a common pest insect of stored flour and grain.

The fumigant toxicity of *M. pulegium* and *R. officinalis* EOs may be attributed to their major or minor monoterpenes as EOs contain different components that may act together on different ways. It had been reported that monoterpenes proved an insecticidal effect when they were tested alone, noting, for instance, certain main components such as  $\alpha$ -pinene, limonene,  $\alpha$ -terpineol,  $\beta$ -pinene, 1,8-cineole, camphor,  $\beta$ -citronellol, geraniol, linalool and  $\alpha$ -citral that showed a fumigant effect against the *C. pipiens* adults [23,47], and also against other mosquitos. Zahran et al. (2011) [23] evaluated the adulticidal effect of twelve monoterpenes; they found that the monoterpenes tested against *C. pipiens* adults caused mortalities higher than 50% at the lowest concentration (10 mg/L) after 24 h of exposure. (R)-carvone and (R)-camphor showed high toxicity against adults at all three tested concentrations: they exhibited  $73.3 \pm 6.71\%$  and  $53.3 \pm 8.88\%$  of mortality at 10 mg/L,  $86.7 \pm 8.88\%$  and  $66.7 \pm 8.88\%$  at 50 mg/L air,  $100 \pm 0.0\%$  and  $90 \pm 5.8\%$  at 100 mg/L air after 24 h, respectively, while  $80 \pm 5.81\%$  and  $63.3 \pm 3.36\%$ ,  $96.7 \pm 3.36\%$  and  $86.7 \pm 8.88\%$ ,  $100 \pm 0.0\%$  and  $96.7 \pm 3.36\%$  of mortalities were recorded after 48 h, respectively. In previous literature, Rice and Coats (1994) [48] discovered that certain ketones such as carvone and pulegone were found to be more effective fumigants than alcohols. However, Zahran et al. (2011) [23] reported that menthol (monoterpene alcohol) had more adulticidal activity than camphor (monoterpene ketone) and camphene (monoterpene hydrocarbon) with mortality percentages of 63.3, 53.3 and 10%, respectively after 24 h of treatment. Against other insects, various EOs pure molecules were reported to be toxic fumigants. Rozman et al. (2007) [24] investigated the insecticidal effect of many monoterpenes such as 1,8-cineole, camphor, eugenol, linalool, carvacrol, thymol, borneol, bornyl acetate and linalyl acetate where 1,8-cineole was highly effective against adults of *Sitophilus oryzae* when it was applied at the lowest concentration (0.1 mL/720 mL volume) after 24 h of exposure, whereas, camphor was found to be more effective towards *Rhyzopertha dominica* with mortality of 100%. However, it has been documented that camphor presents a danger; it is a very toxic substance and many cases of camphor poisoning have been reported. Camphor poisoning could occur through inhalation, ingestion and also contact [49–52].

Otherwise, many other medicinal and aromatic herbs have proved their pesticidal potential against several insect families. In a recent review, Ebadollahi and his colleagues (2020) [53] highlighted the pesticidal efficacy of various plant-derived EOs obtained from the Lamiaceae plant family indicating *Agastache Gronovius*, *Hyptis Jacquin*, *Lavandula L.*, *Lepechinia Willdenow*, *Mentha L.*, *Melissa L.*, *Ocimum L.*, *Origanum L.*, *Perilla L.*, *Perovskia Kar.*, *Phlomis L.*, *Rosmarinus L.*, *Salvia L.*, *Satureja L.*, *Teucrium L.*, *Thymus L.*, *Zataria Boissier*

and *Zhumeria* Rech. In addition, Al-Harbi et al. (2021) [54] have evaluated the insecticidal effect of EOs isolated from *Ocimum basilicum*, *Nigella sativa* and *Lavandula angustifolia* on adults of *Sitophilus oryzae*. Against the *Culex* genus, Ramar et al. (2014) [55] investigated the insecticidal effect of twelve EOs including, for example, *Pimpinella anisum*, *Cinnamomum verum* J.S.Presl, *Cymbopogon nardus*, *Myrtus caryophyllus*, *Eucalyptus globulus* and *Pelargonium graveollens*.

All of these findings shed light on the promising insecticidal properties of EOs and their bioactive products. Until now, they are still the best alternative to synthetic chemical insecticides, especially with the emergence of resistant insect mosquitoes to different synthetic families [29,56,57]. Thus, plant-based natural products could be used as mosquito-cidal botanicals in mosquito control programs, reducing the environmental and health toxic effect that the chemical products have created.

## 5. Conclusions

This study highlighted the insecticidal effect of *M. pulegium* and *R. officinalis* EOs, and their main compounds. The obtained results revealed the effectiveness variability between the tested substances, yet in general, they have all displayed fumigant toxicity. Based on the promising results, these natural products are recommended as suitable active products for possible botanical insecticides. However, further research should be conducted on the synergistic effect of these EOs and their bioactive compounds to enhance the mosquito-cidal potential. The biosafety of these products on non-target organisms should be also evaluated.

**Author Contributions:** A.R.: methodology, data analysis and writing. A.A.: helped in the manuscript writing. A.F.: supervision and data curation. A.E.O.L., Y.E.z., R.A., A.N., R.U. and S.E.: writing—supervision and editing. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by the Researchers Supporting Project number (RSP-2021/96), King Saud University, Riyadh, Saudi Arabia.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** All related data are within the manuscript.

**Acknowledgments:** The authors would like to extend their sincere appreciation to the Researchers Supporting Project number (RSP-2021/96), King Saud University, Riyadh, Saudi Arabia.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Macêdo, N.S.; Silveira, Z.S.; Bezerra, A.H.; Costa, J.G.M.D.; Coutinho, H.D.M.; Romano, B.; Capasso, R.; Cunha, F.A.B.D.; da Silva, M.V. *Caesalpinia ferrea* C. Mart. (Fabaceae) Phytochemistry, Ethnobotany, and Bioactivities: A Review. *Molecules* **2020**, *25*, 3831. [[CrossRef](#)] [[PubMed](#)]
2. Fahad, F.I.; Barua, N.; Islam, M.S.; Sayem, S.A.J.; Barua, K.; Uddin, M.J.; Chy, M.N.U.; Adnan, M.; Islam, M.N.; Sayeed, M.A.; et al. Investigation of the Pharmacological Properties of *Lepidagathis hyalina* Nees through Experimental Approaches. *Life* **2021**, *11*, 180. [[CrossRef](#)] [[PubMed](#)]
3. Bouyahya, A.; Bakri, Y.; Et-Touys, A.; Talbaoui, A.; Khouchlaa, A.; El Idrissi, A.E.; Abrini, J.; Dakka, N. In vitro Screening of Antibacterial and Antioxidant Activities of Essential Oils from Four Moroccan Medicinal Plants. *Microbiol. Res. J. Int.* **2017**, *18*, 1–10. [[CrossRef](#)] [[PubMed](#)]
4. Andrade, J.M.; Faustino, C.; Garcia, C.; Ladeiras, D.; Reis, C.P.; Rijo, P. *Rosmarinus officinalis* L.: An update review of its phytochemistry and biological activity. *Future Sci.* **2018**, *4*, FSO283. [[CrossRef](#)]
5. Bouyahya, A.; Et-Touys, A.; Bakri, Y.; Talbaoui, A.; Fellah, H.; Abrini, J.; Dakka, N. Chemical composition of *Mentha pulegium* and *Rosmarinus officinalis* essential oils and their antileishmanial, antibacterial and antioxidant activities. *Microb. Pathog.* **2017**, *111*, 41–49. [[CrossRef](#)]
6. Yakoubi, R.; Megateli, S.; Hadj Sadok, T.; Bensouici, C.; Bağci, E. A synergistic interactions of Algerian essential oils of *Laurus nobilis* L.; *Lavandula stoechas* L. and *Mentha pulegium* L. on anticholinesterase and antioxidant activities. *Biocatal. Agric. Biotechnol.* **2021**, *31*, 101891. [[CrossRef](#)]

7. Sebai, E.; Serairi, R.; Saratsi, K.; Abidi, A.; Sendi, N.; Darghouth, M.A.; Wilson, M.S.; Sotiraki, S.; Akkari, H. Hydro-Ethanollic Extract of *Mentha pulegium* Exhibit Anthelmintic and Antioxidant Proprieties In Vitro and In Vivo. *Acta Parasitol.* **2020**, *65*, 375–387. [[CrossRef](#)]
8. Rocha, D.; Novo, M.; Matos, O.C.; Figueiredo, A.; Delgado, M.D.; Cabral, M.; Liberato, M.; Moiteiro, C. Potential of *Mentha pulegium* for mosquito control. *Rev. Ciênc. Agrár.* **2015**, *38*, 155–165.
9. Ahmed, A.; Ayoub, K.; Chaima, A.J.; Hanaa, L.; Abdelaziz, C. Effect of drying methods on yield, chemical composition and bioactivities of essential oil obtained from Moroccan *Mentha pulegium* L. *Biocatal. Agric. Biotechnol.* **2018**, *16*, 638–643. [[CrossRef](#)]
10. Domingues, P.M.; Santos, L. Industrial Crops & Products Essential oil of pennyroyal (*Mentha pulegium*): Composition and applications as alternatives to pesticides—New tendencies. *Ind. Crop. Prod.* **2019**, *139*, 111534. [[CrossRef](#)]
11. Chraïbi, M.; Farah, A. Antimicrobial effects of Moroccan rosemary essential oil, and its synergistic antimicrobial potential with carvacrol. *J. Adv. Pharm. Technol. Res.* **2020**, *11*, 25–29. [[CrossRef](#)] [[PubMed](#)]
12. Kumar, P.; Mishra, S.; Malik, A.; Satya, S. Insecticidal properties of *Mentha* species: A review. *Ind. Crop. Prod.* **2011**, *34*, 802–817. [[CrossRef](#)]
13. Pavela, R. Insecticidal activity of essential oils against cabbage aphid *Brevicoryne brassicae*. *J. Essent. Oil-Bearing Plants* **2006**, *9*, 99–106. [[CrossRef](#)]
14. Badreddine, B.S.; Olfa, E.; Samir, D.; Hnia, C.; Lahbib, B.J.M. Chemical composition of *Rosmarinus* and *Lavandula* essential oils and their insecticidal effects on *Orgyia trigotephras* (Lepidoptera, Lymantriidae). *Asian Pac. J. Trop. Med.* **2015**, *8*, 98–103. [[CrossRef](#)]
15. Abdelli, M.; Moghrani, H.; Aboun, A.; Maachi, R. Algerian *Mentha pulegium* L. leaves essential oil: Chemical composition, antimicrobial, insecticidal and antioxidant activities. *Ind. Crop. Prod.* **2016**, *94*, 197–205. [[CrossRef](#)]
16. Aimad, A.; Sanae, R.; Anas, F.; Abdelfattah, E.M.; Bourhia, M.; Mohammad Salamatullah, A.; Alzahrani, A.; Alyahya, H.K.; Albadr, N.A.; Abdelkrim, A.; et al. Chemical Characterization and Antioxidant, Antimicrobial, and Insecticidal Properties of Essential Oil from *Mentha pulegium* L. Evidence-based Complement. *Altern. Med.* **2021**, *2021*, 1108133. [[CrossRef](#)]
17. Salem, N.; Bachrouch, O.; Sriti, J.; Msaada, K.; Khammassi, S.; Hammami, M.; Selmi, S.; Boushah, E.; Koorani, S.; Abderraba, M.; et al. Fumigant and repellent potentials of *Ricinus communis* and *Mentha pulegium* essential oils against *Tribolium castaneum* and *Lasioderma serricorne*. *Int. J. Food Prop.* **2018**, *20*, S2899–S2913. [[CrossRef](#)]
18. Koliopoulos, G.; Pitarokili, D.; Kioulos, E.; Michaelakis, A.; Tzakou, O. Chemical composition and larvicidal evaluation of *Mentha*, *Salvia*, and *Melissa* essential oils against the West Nile virus mosquito *Culex pipiens*. *Parasitol. Res.* **2010**, *107*, 327–335. [[CrossRef](#)]
19. Conti, B.; Canale, A.; Bertoli, A.; Gozzini, F.; Pistelli, L. Essential oil composition and larvicidal activity of six Mediterranean aromatic plants against the mosquito *Aedes albopictus* (Diptera: Culicidae). *Parasitol. Res.* **2010**, *107*, 1455–1461. [[CrossRef](#)]
20. Kazempour, S.; Shayeghi, M.; Abai, M.R.; Vatandoost, H.; Pirmohammadi, M. Larvicidal activities of essential oils of indigenous medicinal plants, *Mentha pulegium* L.; *Satureja hortensis* L.; and *Thymus vulgaris* L. against malaria vector, *Anopheles stephensi*. *S. Afr. J. Bot.* **2021**, *139*, 38–41. [[CrossRef](#)]
21. Tine-Djebbar, F.; Guenez, R.; Soltani, N. Chemical composition and insecticide properties of the essential oils from *mentha pulegium* against *aedes caspius* (Diptera: Culicidae). *Adv. Sci. Technol. Innov.* **2018**, 503–505. [[CrossRef](#)]
22. Benelli, G. Plant-borne ovicides in the fight against mosquito vectors of medical and veterinary importance: A systematic review. *Parasitol. Res.* **2015**, *114*, 3201–3212. [[CrossRef](#)] [[PubMed](#)]
23. Zahran, H.E.D.M.; Abdelgaleil, S.A.M. Insecticidal and developmental inhibitory properties of monoterpenes on *Culex pipiens* L. (Diptera: Culicidae). *J. Asia. Pac. Entomol.* **2011**, *14*, 46–51. [[CrossRef](#)]
24. Rozman, V.; Kalinovic, I.; Korunic, Z. Toxicity of naturally occurring compounds of Lamiaceae and Lauraceae to three stored-product insects. *J. Stored Prod. Res.* **2007**, *43*, 349–355. [[CrossRef](#)]
25. Samir, A.M.; Al-Nagar, N.; Abou-Taleb, H.K.; Shawir, M.S. Effect of monoterpenes, phenylpropenes and sesquiterpenes on development, fecundity and fertility of *Spodoptera littoralis* (Boisduval). *Int. J. Trop. Insect Sci.* **2021**, *40*, 1–11. [[CrossRef](#)]
26. Victor, A.; Brugman, L.M.; Hernández-Triana, J.M.; Medlock, A.R.; Fooks, S.C.; Nicholas, J. The Role of *Culex pipiens* L. (Diptera: Culicidae) in Virus Transmission in Europe. *Int. J. Environ. Res. Public Health* **2018**, *15*, 389. [[CrossRef](#)]
27. García-Carrasco, J.M.; Muñoz, A.R.; Olivero, J.; Segura, M.; Real, R. Predicting the spatio-temporal spread of West Nile virus in Europe. *PLoS Negl. Trop. Dis.* **2021**, *15*, e0009022. [[CrossRef](#)]
28. Jeffrey, G.S.; Melissa, H.; Yoshimizu, S.K. Pyrethroid resistance in *Culex pipiens* mosquitoes. *Pestic. Biochem. Physiol.* **2015**, *120*, 68–76.
29. Tmimi, F.Z.; Faraj, C.; Bkhache, M.; Mounaji, K.; Failloux, A.B.; Sarih, M. Insecticide resistance and target site mutations (G119S ace-1 and L1014F kdr) of *Culex pipiens* in Morocco. *Parasites Vectors* **2018**, *11*, 1–9. [[CrossRef](#)]
30. Adams, R.P. *Identification of Essential Oil Components by Gas Chromatography/Mass Spectrometry*, 4th ed.; Allured Pub Corp: Carol Stream, IL, USA, 2007.
31. Himmi, O.; Dakki, M.; Trari, B.; El Agbani, M.A. *The Culicidae of Morocco: Identification KEYS with biological and Ecological Data (Work of the Scientific Institute)*; Zoology of series; Scientific Institute of Rabat: Rabat, Morocco, 1995; p. 44.1-51.
32. Brunhes, J.; Rhaim, A.; Geoffroy, B.; Hervy, J. *P Mosquitoes of the Mediterranean Africa: Software Identification and Education*, CD-ROM (Didactiques), IRDIRD editions; IRD & IPT: Paris, France, 2000.
33. Finney, D. *Probit Analysis: A Statistical Treatment of the Sigmoid Response Curve*; Cambridge University Press: Cambridge, UK, 1952.
34. Babushok, V.I.; Linstrom, P.J.; Zenkevich, I.G. Retention Indices for Frequently Reported Compounds of Plant Essential Oils. *J. Phys. Chem. Ref. Data* **2011**, *40*, 043101. [[CrossRef](#)]

35. Isman, M.B.; Miresmailli, S.; MacHial, C. Commercial opportunities for pesticides based on plant essential oils in agriculture, industry and consumer products. *Phytochem. Rev.* **2011**, *10*, 197–204. [[CrossRef](#)]
36. Traboulsi, A.F.; Taoubi, K.; El-Haj, S.; Bessiere, J.M.; Rammal, S. Insecticidal properties of essential plant oils against the mosquito *Culex pipiens molestus* (Diptera: Culicidae). *Pest Manag. Sci.* **2002**, *58*, 491–495. [[CrossRef](#)] [[PubMed](#)]
37. Michaelakis, A.; Papachristos, D.; Kimbaris, A.; Koliopoulos, G.; Giatropoulos, A.; Polissiou, M.G. Citrus essential oils and four enantiomeric pinenes against *Culex pipiens* (Diptera: Culicidae). *Parasitol. Res.* **2009**, *105*, 769–773. [[CrossRef](#)] [[PubMed](#)]
38. Kim, N.J.; Byun, S.G.; Cho, J.E.; Chung, K.; Ahn, Y.J. Larvicidal activity of *Kaempferia galangal* rhizome phenylpropanoids towards three mosquito species. *Pest Manag. Sci.* **2008**, *64*, 857–862.
39. Chen, Y.; Luo, J.; Zhang, N.; Yu, W.; Jiang, J.; Dai, G. Insecticidal activities of *Salvia hispanica* L. essential oil and combinations of their main compounds against the beet armyworm *Spodoptera exigua*. *Ind. Crop. Prod.* **2021**, *162*, 113271. [[CrossRef](#)]
40. Yang, P.; Ma, Y.; Zheng, S. Adulticidal activity of five essential oils against *Culex pipiens quinquefasciatus*. *J. Pestic. Sci.* **2005**, *30*, 84–89. [[CrossRef](#)]
41. El-Aswad, A.F.; Abdelgaleil, S.A.M. Insecticidal, antifeedant and molluscicidal potential of essential oils extracted from Egyptian plants. *J. Egypt. Soc. Toxicol.* **2008**, *38*, 81–91.
42. Al-Sarar, A.S.; Hussein, H.I.; Abobakr, Y. Chemical composition, adulticidal and repellent activity of essential oils from *Mentha longifolia* L. and *Lavandula dentata* L. against *Culex pipiens* L. *J. Plant Prot. Path. Mansoura Univ.* **2015**, *5*, 817–826. [[CrossRef](#)]
43. Zahran, H.E.D.M.; Abou-Taleb, H.K.; Abdelgaleil, S.A.M. Adulticidal, larvicidal and biochemical properties of essential oils against *Culex pipiens* L. *J. Asia. Pac. Entomol.* **2017**, *20*, 133–139. [[CrossRef](#)]
44. Erler, F.; Ulug, I.; Yalcinkaya, B. Repellent activity of five essential oils against *Culex pipiens*. *Fitoterapia* **2006**, *77*, 491–494. [[CrossRef](#)]
45. Brahmi, F.; Abdenour, A.; Bruno, M.; Silvia, P.; Alessandra, P.; Danilo, F.; Drifa, Y.G.; Fahmi, E.M.; Khodir, M.; Mohamed, C. Chemical composition and in vitro antimicrobial, insecticidal and antioxidant activities of the essential oils of *Mentha pulegium* L. and *Mentha rotundifolia* (L.) Huds growing in Algeria. *Ind. Crop. Prod.* **2016**, *88*, 96–105. [[CrossRef](#)]
46. Isikber, A.A.; Alma, M.H.; Kanat, M.; Karci, A. Fumigant toxicity of essential oils from *Laurus nobilis* and *Rosmarinus officinalis* against all life stages of *Tribolium confusum*. *Phytoparasitica* **2006**, *34*, 167–177. [[CrossRef](#)]
47. Bin, M.W.; Feng, J.T.; Jiang, Z.L.; Wu, H.; Ma, Z.Q.; Zhang, X. Fumigant activity of eleven essential oil compounds and their selected binary mixtures against *Culex pipiens pallens* (Diptera: Culicidae). *Parasitol. Res.* **2014**, *113*, 3631–3637. [[CrossRef](#)]
48. Rice, P.J.; Coats, J.R. Insecticidal properties of several monoterpenoids to the housefly (Diptera: Muscidae), red flour beetle (Coleoptera : Tenebrionidae) and southern corn root-worm (Coleoptera : Chrysomelidae). *J. Econ. Entomol.* **1994**, *87*, 1172–1179. [[CrossRef](#)] [[PubMed](#)]
49. Manoguerra, A.S.; Andrew, R.; Paul, M.W.; Lewis, S.N.; Caravati, E.M.; Cobaugh, D.J.; Chyka, P.A.; Olson, K.R.; Booze, L.L.; Wolf, A.D.; et al. Camphor Poisoning: An Evidence-Based Practice Guideline for Out-of-Hospital Management. *Clin. Toxicol.* **2008**, *44*, 357–370. [[CrossRef](#)] [[PubMed](#)]
50. Chen, W.; Vermaak, I.; Viljoen, A. Camphor—A Fumigant during the Black Death and a Coveted Fragrant Wood in Ancient Egypt and Babylon—A Review. *Molecules* **2013**, *18*, 5434–5454. [[CrossRef](#)]
51. Hnin, K.; Weiss, D.; Nathan, G.; Hoffman, R.S.; Esteban-Cruciani, N.; Avner, J.R. A Cluster of Children with Seizures Caused by Camphor Poisoning. *Pediatrics* **2009**, *123*, 1269–1272. [[CrossRef](#)]
52. Rahimi, M.; Shokri, F.; Moghaddam, H.H.; Zamani, N.; Pajoumand, A.; Shadnia, S. Severe camphor poisoning, a seven-year observational study. *Environ. Toxicol. Pharmacol.* **2017**, *52*, 8–13. [[CrossRef](#)]
53. Ebadollahi, A.; Ziaee, M.; Palla, F. Essential oils extracted from different species of the Lamiaceae plant family as prospective bioagents against several detrimental pests. *Molecules* **2020**, *25*, 1556. [[CrossRef](#)]
54. Al-Harbi, N.A.; Al Attar, N.M.; Hikal, D.M.; Mohamed, S.E.; Abdel Latef, A.A.H.; Ibrahim, A.A.; Abdein, M.A. Evaluation of Insecticidal Effects of Plants Essential Oils Extracted from Basil, Black Seeds and Lavender against *Sitophilus oryzae*. *Plants* **2021**, *10*, 829. [[CrossRef](#)]
55. Ramar, M.; Ignacimuthu, S.; Gabriel Paulraj, M. Mosquito knock-down and adulticidal activities of essential oils by vaporizer, impregnated filter paper and aerosol methods. *Int. J. Mosq. Res.* **2014**, *1*, 26–32.
56. Trari, B. Mosquitoes (Insects, Diptera) from Morocco: Distribution Atlas and Epidemiological Studies. Ph.D. Thesis, Abdelmalek Essaâdi University, Tangier, Morocco, 1 April 2017. [[CrossRef](#)]
57. Aboulfadl, S.; Mellouki, F.; Aouinty, B.; Faraj, C. Susceptibility status of *Culex pipiens* larvae (Diptera: Culicidae) to the main insecticides used in larval control in the regions of Rabat and Casablanca in Morocco. *Int. J. Pest Manag.* **2020**. [[CrossRef](#)]