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Insecticidal Potential of *Matricaria chamomilla*'s Essential Oil and Its Components (E)-β-Farnesene, Germacrene D, and α-Bisabolol Oxide A against Agricultural Pests, Malaria, and Zika Virus Vectors

Khalid A. Al-Ghanim [1,*], Kaliyamoorthy Krishnappa [2], Jeganathan Pandiyan [2], Marcello Nicoletti [3], Baskar Gurunathan [4] and Marimuthu Govindarajan [5,6,*]

1 Department of Zoology, College of Science, King Saud University, Riyadh 11451, Saudi Arabia
2 Department of Zoology and Wildlife Biology, A.V.C. College, Mannampandal, Mayiladuthurai 609 305, Tamil Nadu, India
3 Department of Environmental Biology, Foundation in Unam Sapientiam, Sapienza University of Rome, 00185 Rome, Italy; marcello.nicoletti@uniroma1.it
4 Department of Biotechnology, St. Joseph's College of Engineering, Chennai 600 119, Tamil Nadu, India
5 Unit of Mycology and Parasitology, Department of Zoology, Annamalai University, Annamalainagar 608 002, Tamil Nadu, India
6 Unit of Natural Products and Nanotechnology, Department of Zoology, Government College for Women (Autonomous), Kumbakonam 612 001, Tamil Nadu, India
* Correspondence: kghanim@ksu.edu.sa (K.A.A.-G.); drgovind1979@gmail.com or dr.m.govindarajan@gcwk.ac.in (M.G.)

Abstract: Agricultural and medical insect pests are damaging edible crops, spreading diseases, and harming non-target fauna and flora. Prominent polyphagous insect pests harass farmers in the agronomy sector, causing uncountable revenue corrosion. Ecofriendly phytopesticides can avoid the consequences of the bulk usage of synthetic chemicals. In this study, the toxic effect on third-instar larvae of four different insect species (*Spodoptera litura*, *Helicoverpa armigera*, *Aedes vittatus*, and *Anopheles subpictus*) and the bio-toxicity on non-target fauna (NTF) (*Stegodyphus sarasinorum* and *Gambusia affinis*) were evaluated using *Matricaria chamomilla* (*Mc*) essential oil (EO) and its major phytoconstituents (*Mc*-MPCs). GC–MS analysis of the studied *M. chamomilla* EO gathered 39 constituents, with (E)-β-Farnesene (24.3%), Germacrene D (9.4%), and α-Bisabolol oxide A (10.2%) accounting for the major constituents. Remarkable larval death was seen in *H. armigera* and *Ae. vittatus*. In addition, (E)-β-Farnesene, Germacrene D, and α-Bisabolol oxide A exhibited a relevant maximum toxic effect on the target pest's third-instar larvae. The bio-toxicity of *M. chamomilla* EO and *Mc*-MPCs was tested on terrestrial and aquatic NTF. The LC_{50} values for *S. sarasinorum* and *G. affinis* ranged from 922.65 to 1750.49 µg/mL. *M. chamomilla* EO and its MPCs evidenced prospective phytopesticidal efficiency on selected agricultural and medical insect pests.

Keywords: phytoconstituents; pesticide; insecticide; larvae; non-target fauna; ecofriendly

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1. Introduction

Globally, agri-pests play a pivotal role in the deterioration of several high-value agri-products. Due to human activities, vector proliferation in tropical and subtropical environments has dramatically increased [1,2]. Among arthropods, mosquitoes are massive blood-sucking vectors that cause several public health problems. The effects of blood-sucking vectors on the human population have increased yearly [3–6] in terms of death and morbidity. Vectors are a major cause of significant, worrying economic problems in many parts of the world, as well as are responsible for transmitting a wide variety of infectious illnesses to humans and other species that rely on humans for their vascular system [7]. *Spodoptera litura* (Fab.) (*Cotton leafworm*) and *Helicoverpa armigera* Hubner (*Cotton bollworm*)

are major polyphagous pests. They can attack more than 300 plant hosts, of which around 100 hosts have been documented in India alone [8–10]. Cotton leafworms and Cotton bollworms are equipped to feed on various parts of the host, such as the seed, seed coat, fruits, flower, stem, rhizome, etc., hence resulting in extensive loss of productivity and quality [11–13]. These insects are strong fliers and can traverse great distances, fast evading any natural deterrents. They are anticipated to be the most prevalent agri-pests on the Asian continent, causing extensive damage to food crops [14]. In India, agronomy and its byproducts are crucial to the livelihoods of the vast majority of rural residents. Insects have severely harmed several crops, leading to a production and income crisis [15].

The socioeconomic disasters caused by mosquito-borne diseases (MBDs) in developing and rising countries are extraordinarily complicated [16–20]. The MBDs spread by the *Aedes* and *Anopheles* vectors are a serious problem in healthcare facilities throughout various continents [21–27]. Pest management is vital to every continent's economic and public health practices. Treating the location of their emergence/breeding places [28] is the most efficient and effective method for controlling pests. For many decades, flexible synthetic chemical insecticides (SCPs) were used to reduce pest populations and avoid disease impacts on people and agricultural goods [29–31]. However, arbitrary practices of SCPs result in several negative effects: ecological fragility, the extermination of natural predators/enemies of pests, greater levels of harmful residues in foods, and the development of insecticidal resistance in both agricultural and medicinal pests [32,33]. It is vital to seek out and resolve the present major issues, but they may be solved using naturally occurring phytoconstituents, the most effective and promising weapons for managing insect pests. The ideal phytoconstituents should minimize damages and diseases in non-target species and consist in easily accessible, cost-effective, biodegradable, commercial products, all of which are indigenous approaches in global situations [34,35].

In the past, numerous phytoproducts have been shown as feasible and promising alternatives to standard operating procedures (SOPs) for controlling several agricultural/medical insect pests [36,37]. Thus, most study communities/scientists intended to address the pest problem using organic pesticides, particularly by naturally occurring phytoproducts [38]. Several studies have been conducted on the bio-efficacy of essential oils (EOs) and their phytoconstituents derived from medicinal plants, including *Tanacetum argenteum* [39], *Illicium henryi* [40], *Echinophora lamondiana* [41], *Zingiber officinale* [42], *Citrus aurantium* [43], *Syzygium lanceolatum* [44], *Zingiber nimmonii* [45], *Blumea eriantha* [46], *Artemisia absinthium* [47], *Citrus aurantifolia* [48], *Lippia alba* [49], and *Croton linearis* [50], which can affect various life stages of mosquitoes. As a result of the above, we have settled on the leaves of the *Matricaria chamomilla* plant. In light of the potential usefulness and wide availability of these leaves, they were selected instead of the flowers, the most often used raw resource of this species.

The purpose of this research was to determine the efficacy of *M. chamomilla* EO and its major phytoconstituents (MPCs) in preventing the development of larval Lepidopteran pests (*S. litura* and *H. armigera*) and Dipteran insects (*Ae. vittatus* and *An. subpictus*). In addition, the bio-toxicity was evaluated for both *Stegodyphus sarasinorum* and *Gambusia affinis*, two species of non-target fauna (NTF).

2. Materials and Methods

2.1. Floral Processing and Oil Extraction

Matured and cleaned leaves of *M. chamomilla* L. were collected during February 2020, in the Theni District (Latitude 10°7′–10°28′ N and Longitude 77°16′–77°46′ E), Tamil Nadu, India. The floral specimen (MCFS: 3061) was identified using a field guide and was confirmed by a Plant Taxonomist (Dr. C. Radhakrishnan, Plant Taxonomist, Annamalai University, Chidambaram, Tamil Nadu, India). The leaves were desiccated in shadow at 28 °C for 20 days for dehydration (without moisture content in the selected leaves) and made into fine powder. Then, 300 g of powder was hydro-distilled (1000 mL of de-chlorinated water) through hydro-distillation equipment for 5 h. The end product

was tightly packed in an Amber Glass Bottle, which was stockpiled at 4 °C for further examinations [51].

2.2. GC–MS Examination

M. chamomilla leaf EO was examined by *GC–MS* to detect different phytoconstituents. Analysis by gas chromatography-mass spectrometry was performed using an Agilent 6890N gas chromatograph, 5973N mass selective detector (EIMS, electron energy, 70 eV), and ChemStation data system. With a film thickness of 0.25 m, a length of 30 m, and an internal diameter of 0.25 mm, the GC column was an HP-5ms fused silica capillary packed with 5% phenyl methylpolysiloxane. The GC–MS spectroscopic detection was conducted using the ionization of electrons that consumed higher electron energy (70 eV). The 'He' gas (99.99%) was taken as a transporter gas at a stream degree of 1 milliliter per minute. Initially, the temperature was programmed into 50–10 °C and enhanced to about 3–5 °C/min for about 15 min. Ultimately, the temperature was allowed to elevate to 275 °C at 15 C/min. One microliter of the prepared 1% oil was diluted and injected in splitless mode. The flexible amount of the phytoconstituents observed in the essential oil of *M. chamomilla* leaf was expressed as %, based on the highest point marked in the chromatogram. In order to identify and separate components using a mass spectrometer, the numbers of the peak with retention index were more helpful as a starting point. The pure organic MPCs were procured from Sigma Aldrich Chemicals P Ltd., Bengaluru, India.

2.3. Target Agricultural and Medical Pests

In the Mayiladuthurai District of Tamil Nadu, India, the groundnut fields of Alaveli Village were scoured for eggs and larvae of the Lepidopteran field pests *S. litura* and *H. armigera*. Insectariums were kept at precise temperatures (28 ± 2 °C) and humidity levels (72 ± 5%), with supplemental nutrients including cane sugar mixed with 1–5 drops of multivitamins and *Apis florea* natural honey to promote development and reproduction [6,28]. *Ae. vittatus* and *An. subpictus*, two species of blood-sucking ectoparasitic mosquitoes, were established at the Insectarium of Vector Control lab at Annamalai University in Tamil Nadu, India, and were afterward purchased from the Indian Council of Medical Research (ICMR) in Madurai, India. The healthy mosquitoes were used in a variety of bio-analysis tests [36].

2.4. Larval Toxicity of Agricultural and Medical Pests

The toxic effects of *M. chamomilla* EO and its MPCs on the larvae of selected agricultural pests were evaluated [29], and LC_{50} and LC_{90} death rates were determined. Five unique batches of 25 healthy and evenly proportioned 3rd-instar larvae of *S. litura* and *H. armigera* were exposed in 100 × 15 mm glass petri dish plates at 0–8 h of age, which was the process used for every selected concentration in the laboratory setup with a separate group of individuals. The death rates of *M. chamomilla* EO (60–300 µg/mL) and MPCs were tested at a range of concentrations (3–60 µg/mL). The mortality of larvae was monitored every six hours. Overall, the percentage of death was assessed and acquired five times. In this study, we tested the effects of *M. chamomilla* EO and MPCs on mosquito larvae in the third instar of their development for evidence of their toxicity [52]. The 1 mL DMSO (Dimethyl sulfoxide) digest containing EO (20–100 µg/mL) and MPCs (3–30 µg/mL) was consistently dissolved in 249 mL of heat-filtered H_2O. In a 500 mL well transference glass beaker, with the requisite concentration of EO and *Mc*-MPCs, 25 mosquito larvae were placed, and the test was replicated five times in all bioassay activities. Preliminary screening by broad range to narrow range test fixed the chosen concentration of EO and its MPCs.

2.5. Biotoxicity of Non-Target Fauna (NTF)

S. sarasinorum and *G. affinis* comprised the terrestrial and aquatic NTF. These were gathered in distinct sites and stored in large plastic containers for transport (100 cm diam. and 50 cm depth). The effects of *M. chamomilla* EO (4000 to 20,000 µg/mL) and its major phytoconstituents (400 to 3500 µg/mL) were evaluated [53]. *M. chamomilla* EO and its MPCs

were assessed against NTF at dosages 50 times higher than the larval LC_{50} values. Two days after exposure, the mortality rate, normal behavioral activities (swimming, feeding, and hunting ability), and other relevant anomalies of the NTF were tracked attentively.

2.6. Data Analysis

The mortality rates of agricultural and medical pest larvae and non-target fauna were carefully observed and validated after applying IBM-SPSS Statistics Version 26.0 to the proper post-treatment of phytoconstituents. The mortality rate, fatal toxicity, bio-toxicity, abnormalities, and suitability index were measured. The suitability index was calculated by dividing the LC_{50} of the non-target pest by the LC_{50} of the target pest [54–56]. Each NTF was analyzed for both pests that shared a larval habitat with nearby aquatic and terrestrial NTF and the results with $p \leq 0.05$ were considered to be statistically significant.

3. Results

3.1. GC–MS Analysis of M. Chamomilla EO

The GC–MS analysis of 2.4% yield dried weight of *M. chamomilla* leaf essential oil revealed 39 different phytoconstituents accounting for 95.5% of the total volume, of which (E)-β-Farnesene (24.3%), Germacrene D (9.4%), and α-Bisabolol oxide A (6.2%) were considered to be major ones (Figure 1). The other 36 phytoconstituents were represented at 0.2–5.3% (Table 1).

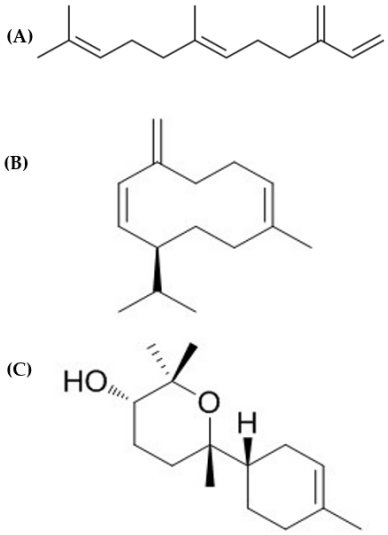

Figure 1. The major phytoconstituents of *M. chamomilla*: (**A**) (E)-β-Farnesene; (**B**) Germacrene D; and (**C**) α-Bisabolol oxide A.

Table 1. Essential oils from *M. chamomilla* and their chemical composition.

Peak	Compounds	RI Exp. [a]	RI Lit. [b]	Composition (%)	Mode of Identification [c]
1	α-Thujene	923	925	0.6	RI, MS
2	α-Pinene	934	933	2.1	RI, MS
3	Sabinene	970	968	0.9	RI, MS
4	β-Pinene	973	972	0.4	RI, MS
5	Myrcene	986	987	1.1	RI, MS
6	α-Terpinene	1013	1013	0.7	RI, MS
7	*o*-Cymene	1021	1022	0.5	RI, MS

Table 1. *Cont.*

Peak	Compounds	RI Exp. [a]	RI Lit. [b]	Composition (%)	Mode of Identification [c]
8	Limonene	1025	1024	0.8	RI, MS
9	1,8-Cineole	1027	1026	0.4	RI, MS
10	(Z)-β-Ocimene	1034	1033	0.7	RI, MS
11	(E)-β-Ocimene	1045	1045	3.2	RI, MS
12	γ-Terpinene	1056	1056	0.9	RI, MS
13	Terpinolene	1086	1087	0.5	RI, MS
14	Linalool	1096	1096	0.4	RI, MS
15	Menthone	1156	1147	0.6	RI, MS
16	Menthol	1173	1165	0.8	RI, MS
17	Methyl chavicol	1196	1195	0.5	RI, MS
18	Menthyl acetate	1295	1293	0.3	RI, MS
19	Tridecane	1298	1300	0.4	RI, MS
20	δ-Elemene	1341	1338	1.8	RI, MS
21	α-Isocomene	1394	1386	0.5	RI, MS
22	β-Elemene	1396	1388	0.6	RI, MS
23	(E)-Caryophyllene	1426	1417	0.9	RI, MS
24	β-Copaene	1438	1430	0.6	RI, MS
25	(E)-β-Farnesene	1458	1457	24.3	RI, MS
26	Germacrene D	1486	1485	11.4	RI, MS
27	β-Selinene	1493	1486	0.9	RI, MS
28	Bicyclogermacrene	1501	1500	1.8	RI, MS
29	(E,E)-α-Farnesene	1507	1506	3.1	RI, MS
30	γ-Cadinene	1518	1514	0.2	RI, MS
31	δ-Cadinene	1526	1521	0.6	RI, MS
32	(E)-Nerolidol	1565	1563	0.9	RI, MS
33	α-Bisabolol oxide B	1662	1659	4.1	RI, MS
34	α-Bisabolol	1686	1685	3.2	RI, MS
35	α-Bisabolone oxide A	1688	1686	3.9	RI, MS
36	Chamazulene	1737	1734	5.3	RI, MS
37	α-Bisabolol oxide A	1751	1749	10.2	RI, MS
38	(Z)-Spiroether	1887	1878	4.8	RI, MS
39	(E)-Spiroether	1899	1890	0.6	RI, MS
				95.5%	

[a] Retention index experimentally calculated on a BP-I capillary column using a standard mixture of *n*-alkanes; [b] retention index taken from Adams (2007) or the literature; [c] identification methods: RI, based on comparison of calculated RI with those reported in ADAMS; MS, based on comparison of the mass spectrum with those of MASS FINDER 3.1, ADAMS, and NIST 08 libraries.

3.2. Larval Death Effect of M. chamomilla EO

Tables 2–5 show the results of tests conducted on third-instar larvae of the agronomic and medical pests *S. litura*, *H. armigera*, *Ae. vittatus*, and *An. subpictus* to determine the effectiveness of *M. chamomilla* EO and its MPCs in killing these insects. When tested on *H. armigera* and *Ae. vittatus*, the LC_{50} values for *M. chamomilla* EO were 138.25 and 51.52 µg/mL, respectively. However, the MPCs of (E)-β-Farnesene, Germacrene D, and α-Bisabolol oxide A

showed a superior larval killing impact on chosen target pests, with LC_{50} values of 16.13, 21.88, 30.40, 15.50, 21.25, 27.75, 5.66, 9.11, 12.13, 6.08, 10.95, and 13.18 µg/mL reported for *S. litura*, *H. armigera*, *Ae. vittatus*, and *An. subpictus,* correspondingly.

Table 2. Larvicidal activity of *Matricaria chamomilla* essential oil and its major *phytoconstituents* against 3rd-instar larvae of *Spodoptera litura*.

Phytoconstituents	Concentration (µg/mL)	Mortality (%) ± SD	LC_{50} (µg/mL) (LCL-UCL)	LC_{90} (µg/mL) (LCL-UCL)	R Values	χ^2
Essential oil	60 120 180 240 300	25.4 ± 1.2 33.3 ± 1.6 64.8 ± 1.4 75.7 ± 1.4 96.5 ± 1.2	146.82 (132.59–159.94)	282.14 (261.12–310.28)	y = 1.46 + 0.01x	7.650 *
(E)-β-Farnesene	8 16 24 32 40	33.4 ± 1.2 42.7 ± 1.4 72.1 ± 1.8 83.8 ± 1.6 100.0 ± 0.0	16.13 (8.16–21.14)	33.42 (27.30–48.71)	y = 1.01 + 0.06x	9.453 *
Germacrene D	10 20 30 40 50	31.4 ± 1.4 40.6 ± 1.8 64.8 ± 1.4 81.2 ± 1.4 97.4 ± 1.4	21.88 (19.25–24.21)	45.35 (41.80–50.15)	y = 1.3 + 0.06x	5.792 *
α-Bisabolol oxide A	12 24 36 48 60	25.6 ± 1.2 34.4 ± 1.4 58.5 ± 1.6 73.8 ± 1.2 94.7 ± 1.4	30.40 (27.42–33.16)	59.45 (54.79–65.78)	y = 1.39 + 0.05x	5.491 *

Mortality observed in 24 h exposure period with values replicated five times, µg/mL. LC_{50}: 50% larval toxicity occurring concentration; LC_{90}: 90% larval toxicity occurring concentration; LCL: Lower Confidence Limit; UCL: Upper Confidence Limit; R values: Regression values; χ^2: Chi-square. IBM-SPSS Statistics Version 26.0 was used to calculate the LC_{50}, LC_{90}, R values, and χ^2. * Significant at $p \leq 0.05$.

Table 3. Larvicidal activity of *Matricaria chamomilla* essential oil and its major phytoconstituents against 3rd-instar larvae of *Helicoverpa armigera.*

Phytoconstituents	Concentration (µg/mL)	Mortality (%) ± SD	LC_{50} (µg/mL) (LCL-UCL)	LC_{90} (µg/mL) (LCL-UCL)	R Values	χ^2
Essential oil	60 120 180 240 300	29.7 ± 1.2 35.9 ± 1.4 65.2 ± 1.6 76.4 ± 1.4 100.0 ± 0.0	138.25 (58.08–189.01)	271.98 (213.80–477.73)	y = 1.07 + 7.51x	15.052 *
(E)-β-Farnesene	8 16 24 32 40	33.3 ± 1.4 47.5 ± 1.6 72.6 ± 1.2 85.3 ± 1.8 100.0 ± 0.0	15.50 (13.38–17.31)	32.72 (30.21–36.06)	y = 0.99 + 0.06x	6.618 *
Germacrene D	10 20 30 40 50	30.3 ± 1.4 42.5 ± 1.4 68.6 ± 1.6 83.4 ± 1.2 97.2 ± 1.8	21.25 (18.64–23.53)	43.89 (40.53–48.40)	y = 1.27 + 0.06x	3.286 *
α-Bisabolol oxide A	12 24 36 48 60	27.2 ± 1.4 38.9 ± 1.4 65.5 ± 1.6 79.4 ± 1.6 94.6 ± 1.4	27.75 (24.65–30.53)	56.32 (51.94–62.25)	y = 1.27 + 0.05x	2.385 *

Mortality observed in 24 h exposure period with values replicated five times, µg/mL. LC_{50}: 50% larval toxicity occurring concentration; LC_{90}: 90% larval toxicity occurring concentration; LCL: Lower Confidence Limit; UCL: Upper Confidence Limit; R values: Regression values; χ^2: Chi-square. IBM-SPSS Statistics Version 26.0 was used to calculate the $LC_{50,}$ $LC_{90,}$ R values, and χ^2. * Significant at $p \leq 0.05$.

Table 4. Larvicidal activity of *Matricaria chamomilla* essential oil and its major phytoconstituents against 3rd-instar larvae of *Aedes vittatus*.

Phytoconstituents	Concentration (µg/mL)	Mortality (%) ± SD	LC_{50} (µg/mL) (LCL-UCL)	LC_{90} (µg/mL) (LCL-UCL)	R Values	χ^2
Essential oil	20 40 60 80 100	22.2 ± 1.2 34.4 ± 1.8 61.2 ± 1.6 72.4 ± 1.8 94.3 ± 1.4	51.52 (46.73–56.01)	98.49 (90.99–108.61)	y = 1.45 + 0.03x	4.561 *
(E)-β-Farnesene	3 6 9 12 15	33.7 ± 1.6 47.9 ± 1.4 74.4 ± 1.6 88.6 ± 1.8 100.0 ± 0.0	5.66 (4.89–6.32)	11.80 (10.91–12.98)	y = 1.05 + 0.19x	5.323 *
Germacrene D	5 10 15 20 25	34.4 ± 1.4 48.9 ± 1.6 78.5 ± 1.4 87.4 ± 1.4 97.5 ± 1.2	9.11 (7.67–10.31)	20.27 (18.68–22.40)	y = 1.08 + 0.12x	2.699 *
α-Bisabolol oxide A	6 12 18 24 30	31.9 ± 1.4 45.7 ± 1.2 72.3 ± 1.4 82.2 ± 1.4 94.3 ± 1.8	12.13 (10.31–13.66)	27.25 (25.01–30.33)	y = 1.04 + 0.09x	1.660 *

Mortality observed in 24 h exposure period with values replicated five times, µg/mL. LC_{50}: 50% larval toxicity occurring concentration; LC_{90}: 90% larval toxicity occurring concentration; LCL: Lower Confidence Limit; UCL: Upper Confidence Limit; R values: Regression values; χ^2: Chi-square. IBM-SPSS Statistics Version 26.0 was used to calculate the LC_{50}, LC_{90}, R values, and χ^2. * Significant at $p \leq 0.05$.

Table 5. Larvicidal activity of *Matricaria chamomilla* essential oil and its major phytoconstituents against 3rd-instar larvae of *Anopheles subpictus*.

Phytoconstituents	Concentration (µg/mL)	Mortality (%) ± SD	LC_{50} (µg/mL) (LCL-UCL)	LC_{90} (µg/mL) (LCL-UCL)	R Values	χ^2
Essential oil	20 40 60 80 100	21.2 ± 1.4 34.3 ± 1.6 61.8 ± 1.8 70.6 ± 1.2 93.4 ± 1.4	52.28 (47.44–56.82)	100.04 (92.34–110.47)	y = 1.44 + 0.03x	4.821 *
(E)-β-Farnesene	3 6 9 12 15	32.7 ± 1.4 45.0 ± 1.4 68.2 ± 1.6 85.3 ± 1.4 100.0 ± 0.0	6.08 (5.31–6.74)	12.53 (11.58–13.80)	y = 1.04 + 0.17x	7.737 *
Germacrene D	5 10 15 20 25	27.4 ± 1.4 41.6 ± 1.8 67.7 ± 1.2 83.5 ± 1.0 98.6 ± 1.4	10.95 (9.77–12.02)	21.48 (19.91–23.55)	y = 1.47 + 0.14x	4.373 *
α-Bisabolol oxide A	6 12 18 24 30	26.4 ± 1.4 43.9 ± 1.6 68.7 ± 1.4 81.2 ± 1.8 96.4 ± 1.4	13.18 (11.65–14.54)	26.77 (24.74–29.49)	y = 1.29 + 0.1x	1.970 *

Mortality observed in 24 h exposure period with values replicated five times, µg/mL. LC_{50}: 50% larval toxicity occurring concentration; LC_{90}: 90% larval toxicity occurring concentration; LCL: Lower Confidence Limit; UCL: Upper Confidence Limit; R values: Regression values; χ^2: Chi-square. IBM-SPSS Statistics Version 26.0 was used to calculate the LC_{50}, LC_{90}, R values, and χ^2. * Significant at $p \leq 0.05$.

3.3. Non-Target Effects of EOs and Mc-MPCs

Tables 6 and 7 show the effects of *M. chamomilla* EO and its MPCs ((E)-β-Farnesene, Germacrene D, and α-Bisabolol oxide A) on the terrestrial NTF (*S. sarasinorum*) and the aquatic NTF (*G. affinis*). EO LC_{50} values varied between 8103.92 and 8799.01 µg/mL when

tested on *S. sarasinorum* and *G. affinis*, respectively. The MPCs (E)-β-Farnesene, Germacrene D, and α-Bisabolol oxide A had LC_{50} values of 922.65, 1204.23, and 1722.06 and 914.33, 1185.05, and 1750.49 µg/mL against *S. sarasinorum* and *G. affinis*, respectively. According to the NTF suitability index, *M. chamomilla* EO and its MPCs are very safe for NTF use (Table 8). Furthermore, *M. chamomilla* EO and its MPC treatments had no discernible effect on the tested NTF species' swimming, feeding, and hunting abilities.

Table 6. The effect of *Matricaria chamomilla* essential oil and its major phytoconstituents against terrestrial non-target fauna (NTF) *Stegodyphus sarasinorum*.

Phytoconstituents	Concentration (µg/mL)	Mortality (%) ± SD	LC_{50} (µg/mL) (LCL-UCL)	LC_{90} (µg/mL) (LCL-UCL)	R Values	χ^2
Essential oil	4000 8000 12,000 16,000 20,000	27.3 ± 1.8 42.8 ± 1.4 68.9 ± 1.4 80.4 ± 1.2 98.3 ± 1.6	8103.92 (7105.65–8975.10)	16,523.20 (15,282.75–18,169.16)	y = 1.07 + 1.32x	7.372 *
(E)-β-Farnesene	400 800 1200 1600 2000	26.5 ± 1.4 37.2 ± 1.6 60.2 ± 1.4 75.4 ± 1.8 100.0 ± 0.0	922.65 (637.71–1144.60)	1715.78 (1436.83–2330.97)	y = 1.29 + 1.38x	8.502 *
Germacrene D	500 1000 1500 2000 2500	23.2 ± 1.6 34.5 ± 1.4 60.3 ± 1.6 73.3 ± 1.2 98.6 ± 1.8	1204.23 (766.94–1542.01)	2204.95 (1802.65–3259.21)	y = 1.31 + 1.06x	11.744 *
α-Bisabolol oxide A	700 1400 2100 2800 3500	23.9 ± 1.6 31.5 ± 1.4 64.2 ± 1.6 73.2 ± 1.4 95.4 ± 1.8	1722.06 (1566.28–1867.07)	3196.29 (2969.66–3494.83)	y = 1.6 + 9.45x	7.163 *

Mortality observed in 48 h exposure period with values replicated five times, µg/mL. LC_{50}: 50% larval toxicity occurring concentration; LC_{90}: 90% larval toxicity occurring concentration; LCL: Lower Confidence Limit; UCL: Upper Confidence Limit; R values: Regression values; χ^2: Chi-square. IBM-SPSS Statistics Version 26.0 was used to calculate the LC_{50}, LC_{90}, R values, and χ^2. * Significant at $p \leq 0.05$.

Table 7. The effect of *Matricaria chamomilla* essential oil and its major phytoconstituents against aquatic non-target fauna (NTF) *Gambusia affinis*.

Phytoconstituents	Concentration (µg/mL)	Mortality (%) ± SD	LC_{50} (µg/mL) (LCL-UCL)	LC_{90} (µg/mL) (LCL-UCL)	R Values	χ^2
Essential oil	4000 8000 12,000 16,000 20,000	32.4 ± 1.4 44.8 ± 1.6 68.4 ± 1.8 86.5 ± 1.4 100.0 ± 0.0	8799.01 (4622.01–11,532)	17,745.02 (14,368.92–26,989.04)	y = 1.03 + 1.15x	10.645 *
(E)-β-Farnesene	400 800 1200 1600 2000	25.4 ± 1.4 37.4 ± 1.8 64.6 ± 1.4 82.7 ± 1.6 100.0 ± 0.0	914.33 (439.80–1227.01)	1768.56 (1406.97–2916.11)	y = 1.14 + 1.22x	14.070 *
Germacrene D	500 1000 1500 2000 2500	24.2 ± 1.8 33.3 ± 1.4 64.8 ± 1.6 78.7 ± 1.4 100.0 ± 0.0	1185.05 (592.43–1587.49)	2300.97 (1828.12–3845.47)	y = 1.1 + 8.88x	13.742 *
α-Bisabolol oxide A	700 1400 2100 2800 3500	22.2 ± 1.8 34.2 ± 1.6 65.8 ± 1.4 76.4 ± 1.6 97.6 ± 1.8	1750.49 (1591.04–1899.49)	3283.23 (3043.81–3601.54)	y = 1.56 + 9.08x	5.791 *

Mortality observed in 48 h exposure period with values replicated five times, µg/mL. LC_{50}: 50% larval toxicity occurring concentration; LC_{90}: 90% larval toxicity occurring concentration; LCL: Lower Confidence Limit; UCL: Upper Confidence Limit; R values: Regression values; χ^2: Chi-square. IBM-SPSS Statistics Version 26.0 was used to calculate the LC_{50}, LC_{90}, R values, and χ^2. * Significant at $p \leq 0.05$.

Table 8. The suitability index of aquatic and terrestrial non-target fauna is shared by several agricultural and medicinal pests exposed to *Matricaria chamomilla* essential oil and its major phytoconstituents.

Treatment	Non-Target Organism (Terrestrial)	*S. litura*	*H. armigera*	Non-Target Organism (Aquatic)	*Ae. vittatus*	*An. subpictus*
Essential oil	*S. sarasinorum*	55.19	58.61	*G. affinis*	170.78	168.30
(E)-β-Farnesene	*S. sarasinorum*	57.20	59.52	*G. affinis*	161.54	150.38
Germacrene D	*S. sarasinorum*	55.03	56.66	*G. affinis*	130.08	108.22
α-Bisabolol oxide A	*S. sarasinorum*	56.64	62.05	*G. affinis*	144.31	132.81

4. Discussion

EO and the MPCs isolated from *M. chamomilla* leaves were investigated for their bio-efficacy against the third-instar larval stage of the agricultural and medical pests *S. litura*, *H. armigera, Ae. vittatus*, and *An. subpictus*. The EO from *M. chamomilla* leaves and its MPCs are effective agents against certain pests, with EO LC_{50} values below 150 µg/mL and MPC LC_{50} values below 30 µg/mL. In addition, the EO of *M. chamomilla* leaves its MPCs might stand in for other SCPs that are less dangerous to NTF. Recent research has shown that EOs are the most valuable natural resource due to their efficacy as insecticides against a wide range of pests [57–61]. Yet, similar to previous research conducted all over the globe, the present study showed significant effectiveness of using the EOs and MPCs for treating pests and non-target fauna. There was a greater than 90% death rate among *Cx. pipiens* fourth-instar larvae when exposed to *Ricinus communis*, *Pimpinella anisum*, *M. chamomilla*, *Vitis vinifera*, *Allium sativum*, *Jasminum sambac*, *Cinnamomum verum*, and *Rosmarinus officinalis*, according to the research [62].

In addition, the EOs with their MPCs also experimentally show the most effective insecticidal activity against *An. stephensi*, *Ae. aegypti*, and *Cx. quinquefasciatus*, which are spreading various diseases. The *Hedychium larsenii* EO or its MPCs ar-curcumene and epi-β-Bisabolol have proven insecticidal agents, particularly against *An. stephensi* (LC_{50} 10.45 and 14.68 µg/mL), *Ae. aegypti* (LC_{50} 11.24 and 15.83 µg/mL), and *Cx. quinquefasciatus* (LC_{50} 12.24 and 17.27 µg/mL) [63]. Likewise, the mosquito larval toxicity effects of *Amomum subulatum* EO showed a significant toxic effect for *An. Subpictus* (LC_{50} 41.25 µg/mL), *Ae. albopictus* (LC_{50} 44.11 µg/mL), and *Cx. Tritaeniorhynchus* (LC_{50} 48.12 µg/mL) [64] and negligible toxicity against the non-target fauna *Anisops bouvieri*, *Diplonychus indicus*, *Poecilia reticulate*, and *Gambusia affinis*. Moreover, the *Zanthoxylum armatum* EO was harmful to *Ae. aegypti* (LC_{50} 54 µg/mL), *Cx. quinquefasciatus* (LC_{50} 49 µg/mL), and *An. stephensi* (LC_{50} 58 µg/mL) larvae [65].

EOs are a relatively new agent for controlling pests throughout their life cycle, and they play a crucial role in agricultural and other pest management at trace levels or at least dosages against different instars of pests. Research showed that even at the lowest dosage, the EOs extracted from plants, including *Lactuca sativa*, *M. chamomilla*, *P. anisum*, and *R. officinalis*, were very toxic to *Lucilia sericata* third-instar larvae [66]. Additionally, lavender, camphor, and onion EOs exhibited outstanding benefits in suppressing second- and third-instar larvae of *Cephalopina titillator* by insecticidal and repellent actions [67]. On the other hand, the EOs from *Alpinia galangal* and *Ocimum basilicum* and its MPCs linalool and 1,8-cineole demonstrated to be potential agents against *S. litura* second-instar larvae when compared to the other commercially available pesticides [68].

The present research yielded impressive outcomes in the treatment of different insects that carry multiple illnesses throughout their life cycles, particularly mosquitoes in their instar stages. One significant impact of the EOs and MPCs of the plant characteristics was the presence of efficient phytoconstituents in the plants employed in the research for the management of larvae of different insects without causing harm to non-target animals. As with *S. litura* fourth-instar larvae, *Wedelia prostrata* EO and its MPCs Camphene, γ-Elemene, α-Humulene, and (E,E)-α-Farnesene showed stronger impacts on their treatment process, with LC_{50} values of 167.46, 6.28, 10.64, 12.89, and 16.77 µg/mL, respectively [69]. Simi-

larly, the MPCs Zerumbone, α-Humulene, and Camphene found in *Cheilocostus speciosus* EO showed reasonable mortality effects on the *H. armigera* third-instar larvae with the LC_{50} values of 10.64, 17.16, and 20.86 µg/mL, respectively [70].

In accordance with previous research [71,72], our study found that phytoproducts derived from *Foeniculum vulgare* and *Trewia nudiflora* had a negligible harmful impact on certain NTF. EOs and MPCs were tested for their toxicity to medical and agronomic pest larvae, and the results show that they are more suitable for NTF. Using the chosen phytoconstituents, it may be possible to analyze the target and non-target toxicity of *M. chamomilla* EO and its MPCs on selected pests and NTF.

Essential oil research has shown promising results in the fight against disease vectors; however, in many cases, the tested plant is not widely available, well-known, or grown. In contrast, chamomile can be found almost everywhere and is readily available, plus it produces a sizable amount of essential oil. The same oil is used in cosmetics and phytomedicine to treat skin and eye issues, and it is very stable, dilutable, ecologically friendly, and safe for the user. When planning to use essential oil in an industrial setting as a phytopesticide, it is important to consider all of these factors. The reported activity of *M. chamomilla* is the first step of a project, including the microencapsulation to obtain available nanoparticles and test their capacity.

5. Conclusions

This paper is part of a project focused on environmentally friendly phytopesticides to become a viable solution to the damages caused by pests. The project considers several characteristics in addition to efficacy, such as low cost, easy and abundant production, low damage to the habitat, simple use, and traditional and medical utilization, as essential. *M. chamomilla* is a medicinal plant widely cultivated for its flowers containing an essential oil, which is considered medically useful and devoid of damage to mammals. In temperate regions, the plant is cultivated on a large scale for the capitula. The reported data evidenced that both the EO and *Mc*-MPCs extracted from *M. chamomilla* leaves are very effective in their respective pesticide actions, while posing little to no risks to NTF. Therefore, the data here reported evidence a potential use of the leaves, usually underexploited, of this important medicinal plant. The same phytoproducts used in the laboratory will be evaluated in the field against a wide range of medicinal and agricultural pests in future investigations.

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