Origanum majorana Essential Oil—Chemistry and Pesticide Activity

Subjects: Chemistry, Analytical

Contributor: Eleni Kakouri, Dimitra Daferera, Charalabos Kanakis, Panagiota-Kyriaki Revelou, Eleftheria H. Kaparakou, Sofia Dervisoglou, Dionysios Perdikis, Petros A. Tarantilis

Origanum majorana is a medicinal and aromatic plant that belongs to the Lamiaceae family. It is cultivated in several parts of the world and, due to its splendid aroma and taste, is widely used for culinary purposes and in perfumes. The essential oil of the plant, to which is attributed its aroma, contains many secondary metabolites with valuable biological activity. One of them is the pesticide activity, which has attracted much interest. Given the necessity of replacing synthetic pesticides, essential oils are studied in an attempt to find naturally derived products.

Keywords: Origanum majorana ; essential oil ; natural pesticide ; repellent ; fumigant ; insecticide

1. Introduction

Aromatic plants are plants that produce and exude from their different plant organs (leaves, flowers, etc.) aromatic substances, which are used for cosmetic and culinary purposes. On the other hand, according to WHO, medicinal plants are defined as those plants (wild or cultivated) that contain a mixture of active compounds, able to prevent, relieve or cure diseases or serve as lead molecules for the discovery of new drug formulations. These compounds are synthesized through common biochemical pathways shared by primary and secondary metabolism and are commonly known as secondary metabolites. Plants provide a plethora of secondary metabolites that exert significant biological activity.

Lamiaceae is a family well studied for the presence of secondary metabolites, which includes volatile and nonvolatile compounds that are present as complex mixtures. These complex mixtures provide significant biological activity, making these plants useful in the food, cosmetic and pharmaceutical industries [1][2].

O. majorana L. belongs to the large family of Lamiaceae plants, which consists of 230 genera and almost 7000 species [3]. It is a perennial aromatic, annual herb. Its synonym and accepted botanical name is *Majorana hortensis*, while the plant is commonly known as sweet marjoram. The plant is native to Greece, Cyprus and Turkey; however, it has also been cultivated in Morocco, Egypt, Tunisia, Algeria and elsewhere [4][5].

O. majorana is among the well-studied species of the Lamiaceae family. Its rich chemical profile, either referring to the essential oil fraction or the extracts of the plant, has classified *O. majorana* as a plant with valuable pharmacological activities [5][6][7][8][9]. In particular, the biological activity of the essential oil derived from the aerial part of the plant has been examined in various studies. Many properties have been attributed to this fraction of secondary metabolites, including antioxidant, antimicrobial, anti-inflammatory, antiacetylcholinesterase, anticancer, antidepressant and analgesic [10][11][12][13][14][15][16]. Apart from the above-mentioned biological activities, the repellent and insecticidal activity of the essential oil of the plant is of maximum importance [17][18][19]. Nowadays, in order to ensure food availability, crops are treated with synthetic pesticides, for which is intensively discussed their negative impact on human health and the environment as well [20]. Biological replacements for synthetic pesticides currently in use could be essential oils [21]. Thus, a considerable number of studies examine the biological activity of essential oils as candidate pesticides against many insect species [22][23][24]. These naturally derived products aim to protect crops in an eco-friendly manner and at the same time not to adversely affect human health. In particular, regarding the essential oil of *O. majorana*, its insecticidal, larvicidal, repellent and fumigant activities have been evaluated [19][24][25][26][27][28][29][30][31].

2. Chemical Profile of *O. majorana* Essential Oil

Essential oils are complex mixtures, consisting of volatile, usually aromatic, colorless compounds, poorly soluble in water but highly soluble in many organic solvents such as acetone, ethanol and diethyl ether. They are products of the secretory system of the plants, obtained via different procedures, which depend on the plant part used. The most common isolation methods are hydrodistillation and steam distillation, applied when the essential oil is obtained from the aerial parts of the plant.

Volatiles are accumulated at the glandular trichomes of the reproductive and vegetative organs of the plants that belong to the Lamiaceae family. In particular, they are more abundant in reproductive organs and young leaves [32]. Thus, in general, the most popular parts of the plants used are stems, flowers and leaves, from which essential oil is extracted mainly by steam distillation.

Typical constituents of the essential oils are terpenoids and more precisely monoterpenes, which are flavor compounds and sesquiterpenes, oxygenated or not. Other constituents include derivates of monoterpenes, which means compounds bearing different functional groups such as esters, acetates and alcohols [33]. Monoterpenes and sesquiterpenes are indicated by the molecular formula $(C_5H_8)n$, in which $n = 2$ in the monoterpenes case since they consist of two isoprene units. On the other hand, sesquiterpenes consist of three isoprene units; thus, n equals 3.

For *O. majorana*, characteristic volatile compounds presented in great quantities are monoterpenes hydrocarbons and oxygenated monoterpenes. Other constituents, less in quantity, are sesquiterpenes, oxygenated or not (**Table 1**). As discussed below, the oxygenated monoterpenes prevail in most cases in the *O. majorana* essential oil derived from different geographical regions, with terpinen-4-ol being the most abundant compound [34][35][36][37][38][39][40][41][42][43][44][45][46][47].

In most studies, compounds detected in abundance were terpinen-4-ol, *cis*-sabinene hydrate and *γ*-terpinene, while in some cases, the essential oil is rich in carvacrol and thymol, with the concentration of terpinen-4-ol being half of carvacrol or even absent [19][47][48][49][50][51][52][53][54]. Thus, researchers have classified *O. majorana* into two main chemotypes, based on qualitative criteria. The first one is the terpinen-4-ol/cis-sabinene hydrate chemotype, and the second belongs to the carvacrol/thymol type [55][56][57]. However, according to literature data, this is not always the case, as minor exceptions exist. For example, Chaves et al. (2020) [58] studied a sample of *O. majorana* originating from Brazil, which was found rich in pulegone (57.05%). Interestingly, no terpinen-4-ol or *cis*-sabinene hydrate or carvacrol were detected [58]. Furthermore, of the four studies that were found to analyze *O. majorana* from Morocco, one of them classified the studied sample as terpinen-4-ol chemotype (however without the second major in quantity compound being *cis*-sabinene hydrate) [59]; the other study identified the compound found in abundance as 4-terpinene [26], and in the rest of the studies, linalool (32.68%), sabinene hydrate (14.08%) and *trans*-sabinene hydrate (16.0%) were the most characteristic compounds [60][61][62]. However, remarkably, in the first two studies is the presence of terpinen-4-ol (22.30% and 13.07%, respectively).

Other studies that classified *O. majorana* to a different chemotype are those of Yang et al. (2009), Waller et al. (2016), Baj et al. (2018), Barazandeh et al. (2001) and Dantas et al. (2016) [63][64][65][66][67]. The first two studies [63][64] analyzed samples from India and Egypt, respectively, and found the major constituent being 1.8 cineole (50.96% and 20.9%, respectively). On the other hand, samples from Ukraine and Iran were rich in linalyl acetate (16.0% and 26.1%) [65][66]. Dantas et al. (2016) [67] studied a sample from Egypt. However, a different chemotype was observed, with **γ**-terpinene being the compound in abundance followed by α-terpinene.

Origanum majorana grown in Greece is classified into three chemotypes. Komaitis et al. (1992) [68] determined a terpinen-4-ol chemotype. This cyclic monoterpene constitutes 37.10% of the total content of essential oil, with *p*-cymene and α-terpineol being constituents that consist of 50% of the essential oil composition. Daferera et al. (2000) [56] also described an intermediate chemotype of thymol (14.0%) as the main compound. Carvacrol concentration reached 0.2%, while the other compounds found at higher concentrations were 3-carene (10.4%), 2-carene (7.8%), terpinen-4-ol (7.8%) and sabinene hydrate (6.0%). Finally, Giatropoulos et al. (2018) [18] identified a clear carvacrol chemotype, in which the concentration of carvacrol reached 74.8%.

In **Table 1** is given summarized information about the collected literature data regarding the volatile profile of *O. majorana*. The most popular parts of the plant used are stems, flowers and leaves [[32]], from which essential oil is extracted mainly by steam distillation, a method adopted by the majority of researchers, as concluded from **Table 1**. Considerable variability is observed regarding the chemical composition of the plant, as well as the percentage yield of its essential oil. Terpinen-4-ol, *cis/trans*-sabinene hydrate, γ-terpinene, *cis*-β-terpineol, carvacrol and thymol are the compounds mentioned in abundance in the studied samples. Regarding the essential oil yield from the aerial parts of the plant, the % yield ranges from 0.4 to 1.85 mL/100 g of dry material, while when only leaves were used, the extent of the % yield ranges from 0.09 to 2.5 mL/100 g of dry material.

This chemical diversity of essential oil isolated from *O. majorana* samples is a product of different parameters such as the growth stage of the plant, climate variability, irrigated or arid crops, geographical area, soil salinity, storage conditions and method of distillation [69][70]. All these variables influence the production of secondary metabolites, thus affecting both the qualitative and quantitative composition of an essential oil. In particular, limited water availability is a factor that decreases crop yield and essential oil yield, or is even responsible for altering an essential oil composition.

Table 1. *Origanum majorana* essential oil from different geographic regions.

Plant Material	Extraction Method	Column Used for the GC Analysis	% Yield	Chemical Composition	Region	Reference
200 g of plant material (the part used is not identified)	Hydrodistillation (clevenger apparatus)	VB-5 30 × 0.25 mm, 0.25 µm	0.8 mL/100 g dry material	4-terpinene (28.96%), γ-terpinene (18.57%) and *α*-terpinene (12.72%), sabinene (8.02%)	Morocco	[26]
1000 g of the aerial parts	Hydrodistillation (according to European Pharmacopeia 5th edition guidelines)	DB-5 30 m × 0.25 mm, 0.33 µm	0.97 mL/100 g dry material	terpinen-4-ol (34.1%), *α*-terpinene (19.2%), terpineol (8.9%)	South West Morocco	[59]
10 g of plant material	Steam distillation (Likens–Nickerson apparatus)	CP-Sil 8 30 m, 0.32 mm	-	thymol (14.0%), 3-carene (10.4%), 2-carene (7.8%), terpinen-4-ol (7.8%), sabinene hydrate (6.0%)	Greece	[56]
100 g of aerial part (stems, leaves and flowers)	Hydrodistillation (clevenger apparatus)	HP-5MS 30 m × 0.25 mm, 0.25 µm	1.85 mL/100 g dry material	terpinen-4-ol (23.2%), *cis*-sabinene hydrate (17.5%), γ-terpinene (10.5%), p-cymene (9%), *α*-terpineol (5.6%)	Tunisia	[57]
100 g of leaves	Hydrodistillation (Quik-fit apparatus)	HP-5MS 30 m × 0.25 mm, 0.25 mm	0.09 mL/100 g dry material	terpinen-4-ol (555.1 µg/g dw), γ-terpinene (192.8 mg/g dw), *cis* sabinene hydrate (168.8 mg/g dw)	Tunisia	[34]
100 g of aerial parts) three developmental stages: vegetative, flowering and post-flowering)	Hydrodistillation (clevenger apparatus)	HP-5MS 30 m × 250 m, 0.25 µM	-	terpinen-4-ol (76.94–37.15), cyclohexanol 3,3,5 trimethyl (15.99–5.41), α-terpineol (11.34–0.94); β-cymene (10.56–1.88)	Tunisia	[46]
-	Steam distillation	Carbowax 20M 25 m × 0.3 mm	0.20 mL/100 g dry material	terpinen-4-ol (37.10%), p-cymene (12.05%), *α*-terpineol (7.15%)	Greece	[68]

Plant Material	Extraction Method	Column Used for the GC Analysis	% Yield	Chemical Composition	Region	Reference
Leaves	Hydrodistillation (clevenger apparatus)	DB-5MS 30 m × 0.25 mm × 0.25 μm	1.2 mL/100 g dry material	terpinen-4-ol (29.97%), γ-terpinene (15.40%), *trans*-sabinene hydrate (10.93%), *α*-terpinene (6.86%) and *α*-terpineol (6.54%)	Egypt	[13]
5 g	Hydrodistillation (clevenger apparatus)	Rtx-5MS 30 m × 0.25 mm × 0.25 μm	-	terpinen-4-ol (19.7%), *γ*-terpinene (18.4), *α*-terpinene (11.4%), *cis*-sabinene hydrate (8.6%), sabinene (7.8%)	Commercial sample Germany	[71]
Leaves	Hydrodistillation (clevenger apparatus)	DB5 30 m × 0.25 mm × 0.25 μm	-	carvacrol (57.86%), thymol (13.54%), *trans*-caryophyllene (11.52%), cymene (6.78%)	Iran	[48]
Aerial parts	Hydrodistillation (clevenger apparatus)	DB-5 30 m × 0.25 mm, 0.25 μm	-	terpinen-4-ol (31.15%), *cis*-sabinene hydrate (15.76%), p-cymene (6.83%), sabinene (6.91%), *trans*-sabinene hydrate (3.86%), *α*-terpineol (3.71%)	India	[35]
500 g of leaves	Hydrodistillation (clevenger apparatus)	HP-5MS 30 m × 0.25 mm, 0.25 μm	0.6 mL/100 g dry material	*cis*-sabinene hydrate (30.2%), terpinen-4-ol (28.8%), γ-terpinene (7.2%), *α*-terpineol (6.9%), *trans*-sabinene hydrate (4.4%), linalyl acetate (3.8%), *α*-terpinene (3.6%)	Venezuela	[72]

Plant Material	Extraction Method	Column Used for the GC Analysis	% Yield	Chemical Composition	Region	Reference
20 g of aerial part (two vegetative and two generative growth stages)	**Hydrodistillation**	**HP-Innowax 30 m × 0.25 mm × 0.25 mm**	**0.04 to 0.09 mL/100 g dry material**	**terpinen-4-ol (29.13–32.57%), *cis*-sabinene hydrate (19.9–29.27%), *trans*-sabinene hydrate (3.5–11.61%), γ-terpinene (2.11–8.20%), bornyl acetate (1.52–2.94%), linalool (1.05–1.39%)**	**Tunisia**	[36]
-	**Hydrodistillation**	**Supelcowax 10, 60 m × 0.25 mm, 0.25 μm**	**0.8 mL/100 g dry material**	**terpinen-4-ol (30.3%), γ-terpinene (14%), linalool (12%), p-cymol (9.8%), *α*-pinene (5.9%), camphene (5.8%)**	**Hungary**	[37]
Flowering plants	**Hydrodistillation (clevenger apparatus)**	**Carbowax 20 M, 50 m × 0.32 mm i.d, 0.20 μm**	**1 mL/100 g dry material**	**terpinen-4-ol (38.4%), *cis*-sabinene hydrate (15.0%), p-cymene (7.0%), γ-terpinene (6.9%).**	**Reunion Island**	[38]
-	**Hydrodistillation (clevenger apparatus)**	**Equity-5 60 m × 0.32 mm, 0.25 μm**	**0.45–0.50 mL/100 g dry material**	***cis*-sabinene hydrate (20.23–46.27%), terpinen-4-ol (9.32–23.43%), γ-terpinene (5.67–13.76%), *α*-terpinene (2.98–8.38%), sabinene (4.90–8.17%), *trans*-sabinene hydrate (5.01–7.34%), *α*-terpineol (3.41–4.17%)**	**India**	[49]
Leaves	**Hydrodistillation (clevenger apparatus)**	**DB-5 (5% phenylmethylpolysiloxane) capillary column, 60 m × 0.25 mm**	**1.6 mL/100 g dry material**	**terpinen-4-ol (30.0%), γ-terpinene (11.3%), *trans*-sabinene hydrate (10.8%)**	**Egypt**	[25]
131 g leaves	**Hydrodistillation (clevenger apparatus)**	**OPTIMAL-5 0.25 μm, 30 M, 0.25 mm**	**-**	**pulegone (57.05%), verbenone (16.92%), *trans*-menthone (8.57%)**	**Brasil**	[59]
0.5 kg of aerial part	**Hydrodistillation (clevenger apparatus)**	**HP-5 30 m × 0.25 mm, 0.25 μm**	**-**	**carvacrol (74.8%), thymol (2.7%)**	**Greece**	[18]

Plant Material	Extraction Method	Column Used for the GC Analysis	% Yield	Chemical Composition	Region	Reference
-	-	DB-1MS 30 m × 0.25 mm, 0.25 μm	-	terpinen-4-ol (22.96%), linalool (15.32%), γ-terpinene (12.92%), p-cymene (6.37%)	Commercial sample, Korea	[23]
-	-	VF-5MS 30 m × 0.25 mm, 0.25 μm	-	terpinen-4-ol (33.8%), terpinolene (16.5%), linalool (14.7%), *α*-terpinene (6.8%)	Commercial sample	[73]
20 g dried leaves	Hydrodistillation (clevenger apparatus)	-	12.70 μL·g^{-1}	terpinen-4-ol (23.83%) *cis*-β-terpineol (21.63%),	-	[74]
-	-	DB-5MS 30 m × 0.25 mm, 0.25 μm	-	1,8-cineole (50.96%), linalool (24.04%), limonene (6.38%)	India	[63]
Two samples from different regions were analyzed	Hydrodistillation	-	6.5–7.7 mL/100 g dry material	carvacrol (78.27–79.46%), p-cymene (4.31–4.68%), γ-terpinene (3.72–4.84%)	Turkey	[55]
100 g of fresh plant material	Steam distillation	SE-54 50 m × 0.32 mm		linalool (32.68%), terpinen-4-ol (22.30%), p-cymene (8.07%)	Morocco	[60]
80 g of aerial parts	Hydrodistillation (clevenger apparatus)	HP-5MS 30 m × 0.25 mm, 0.25 μm	17.2 g/kg	terpinen-4-ol (20.9%), linalool (15.7%), linalyl acetate (13.9%), limonene (13.4%), *α*-terpineol (8.57%)	Pakistan	[39]
1 kg of dried aerial parts	Hydrodistillation	DB-5 30 m × 0.25 mm, 0.33 μm	0.4 mL/100 g dry material	terpinen-4-ol (29.6%), δ-2-carene (20.1%), camphene (13.4%), *α*-pinene (7.9%)	Italy	[11]
100 g dried aerial parts	Hydrodistillation (clevenger apparatus)	Cp WAX 52 CB 50 m × 0.32 mm, 1.2 μm	-	carvacrol (52.5%), linalool (45.4%),	Turkey	[50]

Plant Material	Extraction Method	Column Used for the GC Analysis	% Yield	Chemical Composition	Region	Reference
100 g of dried aerial part	▪ Microwave-assisted extraction (MWE) ▪ Hydrodistillation (HD) ▪ Steam distillation (SD)	TR-5 MS 30 m × 0.32 mm, 0.25 μm	(HD) 0.73 mL/100 g dry material (MWE) 0.80 mL/100 g dry material (SD) 0.66 mL/100 g dry material	terpinen-4-ol MWE: 22.28%, HD: 28.49%, SD: 26.72% *trans*-sabinene hydrate MWE: 13.05%, HD: 11.69%, SD: 3.04% γ-terpinene MWE: 13.20%, HD: 7.87%, SD: 13.72% *α*-terpinene MWE: 9.07%, HD 3.89%, SD: 9.46%	Egypt	[47]
300 g of plant material	Hydrodistillation (clevenger apparatus)	-	1.7 mL/100 g dry material	terpin-4-ol (27.32%), γ-terpinene (15.67%), α-terpinene (11.08%) *α*-terpineol (6.90%), sabinene (5.53%)	Tunisia	[51]
Aerial parts	Extraction with organic solvent	ZB-5MS (Phenomenex), 30 m × 0.25 mm, 0.25 μm		*trans*-sabinene hydrate (16.0%), sabinene (14.1%), *cis*-sabinene hydrate (11.8%), γ-terpinene (10.2%), *α*-terpinyl acetate (10.0%), *α*-terpinene (8.9%)	Yemen	[62]
-	-	DB-5 30 × 0.25 × 2.5 mm	-	terpinen-4-ol (20.55%), terpinene (13.13%), *trans*-terpineol (12.67%), 2-carene (7.67%), sabinene (6.96%)	-	[40]
-	-	ZB-5 MS 30 m, 0.25 mm, 0.25 μm	-	linalyl acetate (16.0%), linalool (14.7%), *α*-terpineol (13.8%), limonene (11.5%)	Commercial sample produced in Ukraine	[65]
-	Hydrodistillation (clevenger apparatus)	HP-5MS 30 m× 0.25 mm, 0.25 mm	-	terpinen-4-ol (32.69%), γ-terpinene (12.88%), *trans*-sabinene hydrate (8.47%), *α*-terpinene (7.98%), sabinene (6.21%)	-	[15]

Plant Material	Extraction Method	Column Used for the GC Analysis	% Yield	Chemical Composition	Region	Reference
200 g of aerial part	Hydrodistillation (Dean–Stark apparatus)	VB5 30 m × 0.25 mm 0.25 μm	1.06 mL/100 g dry material	Sabinene hydrate (14.08%), *α*-terpineol (13.95%), (-)-terpinen-4-ol (13.07%), (+)-sabinene (5.67%)	Morocco	[61]
-	-	HP-5 30 m× 0.32 mm× 0.25 mm	-	1,8-cineole (20.9%), terpinen-4-ol (20.4%), p-cymene (7.0%), sabinene (6.7%)	Commercial sample Egypt	[64]
Dried leaves	Hydrodistillation (clevenger apparatus)	DB-5 30 m × 0.25 mm 0.25 mm	1.20 mL/100 g dry material	terpinen-4-ol (30.41%), γ-terpinene (13.94%), *cis*-sabinene hydrate (9.64%), *α*-terpinene (7.70%)	Egypt	[52]
-	-	Restek 30 m × 0.32 mm, 0.50 μm	-	terpinen-4-ol (21.3%), *trans*-sabinene hydrate (15.5%), γ-terpinene (14.0%) and *α*-terpinene (8.9%)	Commercial product Albania	[53]
Aerial parts of plant material collected in different regions	Hydrodistillation (clevenger apparatus)	FSC 60 m × 0.25 mm, 0.25 μm	-	terpinen-4-ol (8–14%), linalyl acetate (7–10%), *trans*-sabinene hydrate (6–7%)	Turkey	[41]
100 g of air-dried aerial parts	Hydrodistillation (Dean–Stark apparatus)	HP-101 25 m × 0.32 mm	1.40 mL/100 g dry material	terpinen-4-ol (32.8%), γ-terpinene (9.9%), *cis*-sabinene hydrate (8.6%)	Tunisia	[54]
Dried leaves	Hydrodistillation (clevenger apparatus)	TR-5MS 30 m × 0.25 mm, 0.25 μm	2.5 mL/100 g dry material	terpinen-4-ol (33.0%), caryophyllene oxide (11.9%), p-cymene (6.8%), *α*-terpineol (6.7%) spathulenol (6.0%)	Commercial sample China	[42]

Plant Material	Extraction Method	Column Used for the GC Analysis	% Yield	Chemical Composition	Region	Reference
200 g dried flowers 200 g dried leaves	Hydrodistillation (clevenger apparatus)	Supelcowax 10 30 m × 0.32 mm, 0.5 pm	12.8 mL/100 g dry material (flowers) 8% ml/100 g dry material (leaves)	Leaves: *cis*-sabinene hydrate (33.3%), terpinen-4-ol (21.6%), γ-terpinene (8.3%), *α*-terpineol (7.3%), *trans*-sabinene hydrate (4.7%) Flowers: *cis*-sabinene hydrate (24%), terpinen-4-ol (16.6%), *α*-terpineol (12.4%), γ-terpinene (10.6%) Stems: terpinen-4-ol (19%), *α*-terpineol (14.25%), γ-terpinene (11.1%), *cis*-sabinene hydrate (7.4%)	Cyprus	[69]
Flowers	Steam distillation	DB-1 60 m × 0.25 mm, 0.25 pm	0.3 mL/100 g dry material	linalyl acetate (26.1%), sabinene (12%), γ-terpinene (8.8%), *cis*-sabinene hydrate (8.7%)	Iran	[66]
-	-	-	-	-	Egypt	[43]
-	-	DB-1 30 m × 0.25 mm, 0.25 μm	-	terpinen-4-ol (20.8%), γ-Terpinene (14.1%), cis-sabinene hydrate (10.8%) sabinene (9.3%), *α*-terpinene (9.2%)	Commercial sample UK	[44]
300 g of aerial parts	Hydrodistillation (clevenger apparatus)	-	1.72 mL/100 g dry material	terpinen-4-ol (26.7%), γ-terpinene (16.96%), p-menthenol (11.85%), *α*-terpinen (9.22%), *α*-terpineol (5.76%), p-cymene (5.27%)	Tunisia	[45]
Dried leaves	Hydrodistillation (clevenger apparatus)	Durabond-DB5 30 m × 0.25 mm × 0.25 μm	-	γ-terpinene (25.73%), α-terpinene (17.35%), terpinen-4-ol (17.24%), sabinene (10.8%), β-phellandrene	Egypt	[67]

Plant Material	Extraction Method	Column Used for the GC Analysis	% Yield	Chemical Composition	Region	Reference
200 g aerial part	(a) Microwave-assisted hydrodistillation (b) Hydrodistillation	**HP-5 ms capillary 30 m × 0.25 mm, 0.25 μm**	**5 mL/100 g of dry material**	(a) carvacrol (41.3%), linalool (12.2%), terpinen-4-ol (6.6%), linalyl acetate (6.8%), *γ*-terpinene (5.1%) (b) carvacrol (39.1%), linalool (7.2%), terpinen-4-ol (10.1%), linalyl acetate γ-terpinene (6.8%), (3.2%)	**Greece**	[70]
-	**Hydrodistillation (clevenger apparatus)**	**-**	**0.2 mL/100 g of dry material**	**carvacrol (43.7%), thymol (18.3%), γ-terpinene (14.1%), *o*-cymene (8.1%), α-terpinene (2.0%)**	**Greece**	[75]

The concentration of *cis*- and *trans*-sabinene hydrate ranges from 0.95% to 46.27%. This difference can be explained by taking into account the influence of abiotic components on the production of essential oils. As reported in the study of Novak et al. (2002) [71], increased temperature resulted in increased production of sabinene hydrate. In addition, apart from the effect of temperature, a longer period of sunlight had a positive influence on the production of *cis*- and *trans*-isomers, while the opposite was observed regarding the terpinene content [76]. Furthermore, row planting arrangement seems to be important. Single-row planting yielded essential oils richer in sabinene than binate rows. This effect was explained by the fact that single rows receive more sunlight [77]. On the other hand, the cyclic monoterpenes α- and *γ*-terpinene are frequently stated as components of the essential oil. Terpinen-4-ol, α-terpinene and *γ*-terpinene are typical products derived from a rearrangement reaction that follows the distillation process due to elevated temperature [78][79].

References

1. Ramos da Silva, L.R.; Ferreira, O.O.; Cruz, J.N.; de Jesus Pereira Franco, C.; Oliveira Dos Anjos, T.; Cascaes, M.M.; Almeida da Costa, W.; Helena de Aguiar Andrade, E.; Santana de Oliveira, M; Lamiaceae Essential Oils, Phytochemical Profile, Antioxidant, and Biological Activities.. *Evid.-Based Complement. Altern. Med* **2021**, *2021*, 18, https://doi.org/10.1155/2021/6748052.
2. Oald¯e Pavlovic´, M.; Kolarevic´, S.; Đord¯evic´, J.; Jovanovic´ Maric´, J.; Lunic´, T.; Mandic´, M.; Krac˘un Kolarevic´, M.; Živkovic´, J.; Alimpi´c Aradski, A.; Marin, P.D.; et al. A Study of Phytochemistry, Genoprotective Activity, and Antitumor Effects of Extracts of the Selected Lamiaceae Species.. *Plants* **2021**, *10*, 2306, https://doi.org/10.3390/plants10112306.

3. Tamokou, J.D.D.; Mbaveng, A.T.; Kuete, V.. Antimicrobial Activities of African Medicinal Spices and Vegetables in Medicinal Spices and Vegetables from Africa.; Kuete, V., Eds.; Elsevier Academic Press: Cambridge, MA, USA , 2017; pp. 207–237.
4. Singla, P.; Vasudeva, N.; Origanum majorana L.-Phyto-pharmacological review. *Indian J. Nat. Prod. Resour.* **2015**, *6*, 261–267, .
5. Bina, F.; Rahimi, R.; Sweet Marjoram: A Review of Ethnopharmacology, Phytochemistry, and Biological Activities.. *Evid. Based Complement. Altern. Med.* **2017**, *22*, 175–185, https://doi.org/10.1177/2156587216650793.
6. Hossain, M.B.; Camphuis, G.; Aguiló-Aguayo, I.; Gangopadhyay, N.; Rai, D.K.; Antioxidant activity guided separation of major polyphenols of marjoram (Origanum majorana L.) using flash chromatography and their identification by liquid chromatography coupled with electrospray ionization tandem mass spectrometry.. *J. Sep. Sci.* **2014**, *37*, 3205–3213, https://doi.org/10.1002/jssc.201400597.
7. Sahranavard, S.; Ghafari, S.; Mosaddegh, M.; Medicinal plants used in Iranian traditional medicine to treat epilepsy. *Seizure* **2014**, *23*, 328–332, https://doi.org/10.1016/j.seizure.2014.01.013.
8. Amaghnouje, A.; Mechchate, H.; Es-safi, I.; Alotaibi, A.A.; Noman, O.M.; Nasr, F.A.; Al-zharani, M.; Cerruti, P.; Calarco, A.; EL Fatemi, H.; et al. Anxiolytic, Antidepressant-Like Proprieties and Impact on the Memory of the Hydro-Ethanolic Extract of Origanum majorana L. on Mice.. *Appl. Sci.* **2020**, *10*, 8420, https://doi.org/10.3390/app10238420.
9. Soliman, A.M.; Desouky, S.; Marzouk, M.; Sayed, A.A.; Origanum majorana Attenuates Nephrotoxicity of Cisplatin Anticancer Drug through Ameliorating Oxidative Stress.. *Nutrients* **2016**, *8*, 264, https://doi.org/10.3390%2Fnu8050264.
10. Ouedrhiri, W.; Mechchate, H.; Moja, S.; Mothana, R.A.; Noman, O.M.; Grafov, A.; Greche, H.; Boosted Antioxidant Effect Using a Combinatory Approach with Essential Oils from Origanum compactum, Origanum majorana, Thymus serpyllum, Mentha spicata, Myrtus communis, and Artemisia herba-alba: Mixture Design Optimization. *Plants* **2021**, *10*, 2817, https://doi.org/10.3390/plants10122817.
11. Della Pepa, T.; Elshafie, H.S.; Capasso, R.; De Feo, V.; Camele, I.; Nazzaro, F.; Scognamiglio, M.R.; Caputo, L.; Antimicrobial and Phytotoxic Activity of Origanum heracleoticum and O. majorana Essential Oils Growing in Cilento (Southern Italy).. *Molecules* **2019**, *24*, 2576, https://doi.org/10.3390/molecules24142576.
12. Arranz, E.; Jaime, L.; Lopez, M.C.; Reglero, G.; Santoyo, S.; Supercritical fluid extraction as an alternative process to obtain essential oils with anti-inflammatory properties from marjoram and sweet basil.. *Ind. Crop. Prod.* **2015**, *67*, 121–129, https://doi.org/10.1016/j.indcrop.2015.01.012.
13. Mossa, A.T.; Nawwar, G.A.; Free radical scavenging and antiacetylcholinesterase activities of Origanum majorana L. essential oil.. *Hum. Exp. Toxicol* **2011**, *30*, 1501–1513, https://doi.org/10.1177/0960327110391686.
14. Athamneh, K.; Alneyadi, A.; Alsamri, H.; Alrashedi, A.; Palakott, A.; El-Tarabily, K.A.; Eid, A.H.; Al Dhaheri, Y.; Iratni, R.; Origanum majorana Essential Oil Triggers p38 MAPK-Mediated Protective Autophagy, Apoptosis, and Caspase-Dependent Cleavage of P70S6K in Colorectal Cancer Cells. *Biomolecules* **2020**, *10*, 412, https://doi.org/10.3390/biom10030412.
15. Abbasi-Maleki, S.; Kadkhoda, Z.; Taghizad-Farid, R; The antidepressant-like effects of Origanum majorana essential oil on mice through monoaminergic modulation using the forced swimming test. *J. Tradit. Complement. Med.* **2019**, *10*, 327–335, https://doi.org/10.1016/j.jtcme.2019.01.003.
16. Ou, M.C.; Hsu, T.F.; Lai, A.C.; Lin, Y.T.; Lin, C.C.; Pain relief assessment by aromatic essential oil massage on outpatients with primary dysmenorrhea: A randomized, double-blind clinical trial.. *J. Obstet. Gynaecol. Res* **2012**, *38*, 817–822, https://doi.org/10.1111/j.1447-0756.2011.01802.x.
17. Aboelhadid, S.M.; Abdel-Tawab, H.; Mahran, H.A.; Daferera, D.; Sokmen, A.; Al-Quraishy, S.; Abdel-Baki, A.S.; Synergistic larvicidal and repellent effects of essential oils of three Origanum species on Rhipicephalus annulatus tick.. *Exp. Appl. Acarol* **2022**, *87*, 273–287, https://doi.org/10.1007/s10493-022-00737-4.
18. Giatropoulos, A.; Kimbaris, A.; Michaelakis, A.; Papachristos, D.P.; Polissiou, M.G.; Emmanouel, N.; Chemical composition and assessment of larvicidal and repellent capacity of 14 Lamiaceae essential oils against Aedes albopictus.. *Parasitol. Res.* **2018**, *117*, 1953–1964, https://doi.org/10.1007/s00436-018-5892-9.
19. Prabu, S.; Jing, D.; Chandran, V.; Mathew, P.; Insecticidal activity of Origanum majorana L. essential oil as anti-cholinergic agent.. *Entomol. Res.* **2020**, *50*, 402–413, https://doi.org/10.1111/1748-5967.12459.
20. Nicolopoulou-Stamati, P.; Maipas, S.; Kotampasi, C.; Stamatis, P.; Hens, L.; Chemical Pesticides and Human Health: The Urgent Need for a New Concept in Agriculture.. *Front. Public Health* **2016**, *4*, 148, https://doi.org/10.3389%2Ffpubh.2016.00148.
21. Fierascu, R.C.; Fierascu, I.C.; Dinu-Pirvu, C.E.; Fierascu, I.; Paunescu, A.; The application of essential oils as a next-generation of pesticides: Recent developments and future perspectives.. *Z. Naturforsch. C J. Biosci.* **2020**, *75*, 183–

204, https://doi.org/10.1515/znc-2019-0160.

22. Caballero-Gallardo, K.; Olivero-Verbel, J.; Stashenko, E.E.; Repellent activity of essential oils and some of their individual constituents against Tribolium castaneum herbst.. *J. Agric. Food Chem.* **2011**, *59*, 1690–1696, https://doi.org/10.1021/jf103937p.
23. Kim, S.W.; Lee, H.R.; Jang, M.J.; Jung, C.S.; Park, I.K.; Fumigant Toxicity of Lamiaceae Plant Essential Oils and Blends of Their Constituents against Adult Rice Weevil Sitophilus oryzae. *Molecules* **2016**, *21*, 361, https://doi.org/10.3390/molecules21030361.
24. Kordali, ¸S.; Usanmaz, A.; Bayrak, N.; Çakır, A.; Fumigation of volatile monoterpenes and aromatic compounds against adults of Sitophilus granarius (L.) (Coleoptera: Curculionidae).. *Rec. Nat. Prod.* **2017**, *11*, 362 - 380, .
25. Abbassy, M.A.; Abdelgaleil, S.A.M.; Rabie, R.Y.A.; Insecticidal and synergistic effects of Majorana hortensis essential oil and some of its major constituents.. *Entomol. Exp. Appl.* **2009**, *131*, 225–232, https://doi.org/10.1111/j.1570-7458.2009.00854.x.
26. El-Akhal, F.; El Ouali Lalami, A.; Ez Zoubi, Y.; Greche, H.; Guemmouh, R.; Chemical composition and larvicidal activity of essential oil of Origanum majorana (Lamiaceae) cultivated in Morocco against Culex pipiens (Diptera: Culicidae).. *Asian Pac. J. Trop. Biomed.* **2014**, *4*, 746–750, https://doi.org/10.12980/APJTB.4.2014APJTB-2014-0392.
27. Pavela, K.R.; Stepanycheva, E.; Shchenikova, A.; Chermenskaya, T.; Petrova, M.; Essential oils as prospective fumigants against Tetranychus urticae.. *Ind. Crops Prod.* **2016**, *94*, 755–761, https://doi.org/10.1016/j.indcrop.2016.09.050.
28. Ayvaz, A.; Karaborklu, S.; Sagdic, O.; Fumigant toxicity of five essential oils against the eggs of Ephestia kuehniella zeller and Plodia interpunctella (Hübner) (Lepidoptera: Pyralidae).. *Asian J. Chem.* **2009**, *21*, 596–604, .
29. Pavela, R.; Insecticidal activity of some essential oils against larvae of Spodoptera littoralis. *Fitoterapia* **2005**, *76*, 691–696, https://doi.org/10.1016/j.fitote.2005.06.001.
30. Sharma, N.; Dubey, N.K.; Sharma, K.; Screening of Insecticidal Activity of Origanum majorana Oil Against Tribolium Castenium. *Biosci. Biotechnol. Res. Asia* **2008**, *6*, 203–208, .
31. Yang, Y.; Isman, M.B.; Tak, J.H.; Insecticidal Activity of 28 Essential Oils and a Commercial Product Containing Cinnamomum cassia Bark Essential Oil against Sitophilus zeamais Motschulsky. *Insects* **2020**, *11*, 474, https://doi.org/10.3390/insects11080474.
32. Werker, E.; Function of essential oil-secreting glandular hairs in aromatic plans of Lamiaceae: A review. *lavour Fragr. J.* **1993** , *8*, 249–255, https://doi.org/10.1002/ffj.2730080503.
33. alakhutdinov, N.; Volcho, K.; Yarovaya, O.; Monoterpenes as a renewable source of biologically active compounds.. *Pure Appl. Chem.* **2017**, *89*, 1105–1117, https://doi.org/10.1515/pac-2017-0109.
34. Jelali, N.; Dhifi, W.; Chahed, T.; Marzouk, B.; Salinity effects on growth, essential oil yield and composition and phenolic compounds content of marjoram (Origanum majorana L.) leaves.. *J. Food Biochem.* **2011**, *35*, 1443–1450, https://doi.org/10.1111/j.1745-4514.2010.00465.x.
35. Raina, A.P.; Negi, K.S.; Essential oil composition of Origanum majorana and Origanum vulgare spp. hirtum growing in India.. *Chem. Nat. Compd.* **2012** , *47*, 1015–1017, https://doi.org/10.1007/s10600-012-0133-4.
36. Sellami, I.H.; Maamouri, E.; Chahed, T.; Wannes, W.A.; Kchouk, M.E.; Marzouk, B.; Effect of growth stage on the content and composition of the essential oil and phenolic fraction of sweet marjoram (Origanum majorana L.).. *Ind. Crops Prod.* **2009**, *30*, 395–402, https://doi.org/10.1016/j.indcrop.2009.07.010.
37. Vagi, E.; Simandi, B.; Suhajda, A.; Hethelyi, E.; Essential oil composition and antimicrobial activity of Origanum majorana L. extracts obtained with ethyl alcohol and supercritical carbon dioxide. *Food Res. Int.* **2005**, *38* , 51–57, https://doi.org/10.1016/j.foodres.2004.07.006.
38. Vera, R.R.; Chane-Ming, J.; Chemical composition of the essential oil of marjoram (Origanum majorana L.) from Reunion Island.. *Food Chem.* **1999**, *66*, 143–145, https://doi.org/10.1016/S0308-8146(98)00018-1.
39. Hussain, A.I.; Anwar, F.; Rasheed, S.; Nigam, P.S.; Janneh, O.; Sarker, S.D.; Composition, antioxidant and chemotherapeutic properties of the essential oils from two Origanum species growing in Pakistan.. *Rev. Bras. Farmacogn.* **2011** , *21*, 943–952, .
40. Da Cunha, J.A.; de Ávila Scheeren, C.; Fausto, V.P.; de Melo, L.; Henneman, B.; Frizzo, C.P.; de Almeida Vaucher, R.; Castagna de Vargas, A.; Baldisserotto, B.; The antibacterial and physiological effects of pure and nanoencapsulated Origanum majorana essential oil on fish infected with Aeromonas hydrophila.. *Microb. Pathog.* **2018**, *124*, 116–121, https://doi.org/10.1016/j.micpath.2018.08.040.

41. Tabanca, N.; Özek, T.; Baser, K.H.C.; Tümen, G.; Comparison of the Essential Oils of Origanum majorana L. and Origanum x majoricum Cambess.. *J. Essent. Oil Res.* **2004**, *16*, 248–252, https://doi.org/10.1080/10412905.2004.9698713.

42. Jiang, Z.T.; Li, R.; Wang, Y.; Chen, S.H.; Guan,W.Q.; Volatile Oil Composition of Natural Spice, Origanum majorana L. Grown in China. . *J. Essent. Oil-Bear. Plants* **2011**, *14*, 458–462, https://doi.org/10.1080/0972060X.2011.10643601.

43. Edris, A.E.; Shalaby, A.S.; Fadel, H.H.; Effect of organic agriculture practices on the volatile aroma components of some essential oil plants growing in Egypt II: Sweet Marjoram (Origanum marjorana L.) essential oil. *Flavour Fragr. J.* **2003**, *18*, 345–351, https://doi.org/10.1002/ffj.1235.

44. Baratta, M.T.; Dorman, H.J.D.; Deans, S.G.; Figueiredo, A.C.; Barroso, J.G.; Ruberto, G.; Antimicrobial and antioxidant properties of some commercial essential oils.. *Flavour Fragr. J.* **1998** , *13*, 235–244, https://doi.org/10.1002/(SICI)1099-1026(1998070)13:4%3C235::AID-FFJ733%3E3.0.CO;2-T.

45. Raouafi, K.; Nefzi, H.; Esghaier, B.; Sadfi, N.; Abderrabba, M.; Sameh Ayadi, S.; Biological activity and characterization of essential oil of areal part from Origanum majorana L.: First report of antifungal activity against Fusarium oxysporum and against his biofilm. *J. Mater. Environ. Sci.* **2021**, *12*, 746–756, .

46. Khadhri, A.; Bouali, I.; Aouadhi, C.; Lagel, M.C.; Masson, E.; Pizzi, A.; Determination of phenolic compounds by MALDI-TOF and essential oil composition by GC-MS during three development stages of Origanum majorana L. *Biomed. Chromatogr.* **2019**, *33*, e4665, https://doi.org/10.1002/bmc.4665.

47. Ragab, T.I.; El Gendy, A.N.G.; Saleh, I.A.; Esawy, M.A.; Chemical composition and evaluation of antimicrobial activity of the Origanum majorana essential oil extracted by microwave-assisted extraction, conventional hydro-distillation and steam distillation.. *J. Essent. Oil-Bear. Plants* **2019**, *22*, 563–573, https://doi.org/10.1080/0972060X.2019.1611486.

48. Partovi, R.; Talebi, F.; Sharifzadeh, A.; Antimicrobial Efficacy and Chemical Properties of Caryophyllus aromaticus and Origanum majorana Essential Oils Against Foodborne Bacteria Alone and in Combination. *Int. J. Enteric. Pathog.* **2018**, *6*, 95–103, .

49. Verma, R.S.; Padalia, R.C.; Chauhan, A.; Verma, R.K.; Rahman, L.; Singh, A.; Changes in the Essential Oil Composition of Origanum majorana L. During Post Harvest Drying.. *J. Essent. Oil-Bear. Plants* **2016**, *19*, 1547–1552, https://doi.org/10.1080/0972060X.2014.935039.

50. Erdogan, A.; Ozkan, A.; Investigatıon of Antioxıdative, Cytotoxic, Membrane-Damaging and Membrane-Protective Effects of The Essentıal Oil of Origanum majorana and its Oxygenated Monoterpene Component Linalool in Human-Derived Hep G2 Cell Line.. *Iran. J. Pharm. Sci.* **2017**, *16*, 24–34, .

51. Salha, G.B.; Díaz, R.H.; Labidi, J.; Abderrabba, M.; Deterpenation of Origanum majorana L. essential oil by reduced pressure steam distillation.. *Ind. Crops Prod.* **2017** , *109*, 116–122, https://doi.org/10.1016/j.indcrop.2017.08.016.

52. Busatta, C.; Vidal, R.S.; Popiolski, A.S.; Mossi, A.J.; Dariva, C.; Rodrigues, M.R.; Corazza, F.C.; Corazza, M.L.; Vladimir Oliveira, J.; Cansian, R.L.; et al. Application of Origanum majorana L. essential oil as an antimicrobial agent in sausage.. *Food Microbiol. .* **2008**, *25*, 207–211, https://doi.org/10.1016/j.fm.2007.07.003.

53. Schmidt, E.; Bail, S.; Buchbauer, G.; Stoilova, I.; Krastanov, A.; Stoyanova, A.; Jirovetz, L.; Chemical Composition, Olfactory Evaluation and Antioxidant Effects of the Essential oil of Origanum majorana L. from Albania. *Nat. Prod. Commun.* **2008**, *3*, -, https://doi.org/10.1177/1934578X0800300704.

54. Ezzeddine, N.B.H.B.; Abdelkefi, M.M.; Aissa, R.B.; Chaabouni, M.M.; Antibacterial screening of Origanum majorana L. oil from Tunisia.. *J. Essent. Oil Res.* **2001**, *13*, 295–297, https://doi.org/10.1080/10412905.2001.9699698.

55. Baser, K.H.C.; Kirimer, N.; Tümen, G.; Composition of the Essential Oil of Origanum majorana L. from Turkey. *J. Essent. Oil Res.* **1993**, *5*, 577–579, https://doi.org/10.1080/10412905.1993.9698283.

56. Daferera, D.J.; Ziogas, B.N.; Polissiou, M.G.; GC-MS analysis of essential oils from some Greek aromatic plants and their fungitoxicity on Penicillium digitatum.. *J. Agric. Food Chem.* **2000**, *48*, 2576–2581, https://doi.org/10.1021/jf990835x.

57. Hajlaoui, H.; Mighri, H.; Aouni, M.; Gharsallah, N.; Kadri, A.; Chemical composition and in vitro evaluation of antioxidant, antimicrobial, cytotoxicity and anti-acetylcholinesterase properties of Tunisian Origanum majorana L. essential oil. *Microb. Pathog.* **2016**, *95* , 86–94, https://doi.org/10.1016/j.micpath.2016.03.003.

58. Chaves, R.D.S.B.; Martins, R.L.; Rodrigues, A.B.L.; Rabelo, É.M.; Farias, A.L.F.; Brandão, L.B.; Santos, L.L.; Galardo, A.K.R.; de Almeida, S.S.M.D.S.; Evaluation of larvicidal potential against larvae of Aedes aegypti (Linnaeus, 1762) and of the antimicrobial activity of essential oil obtained from the leaves of Origanum majorana L.. *PLoS ONE* **2020** , *15* , e0235740, https://doi.org/10.1371/journal.pone.0235740.

59. Amor, G.; Caputo, L.; La Storia, A.; De Feo, V.; Mauriello, G.; Fechtali, T.; Chemical Composition and Antimicrobial Activity of Artemisia herba-alba and Origanum majorana Essential Oils from Morocco.. *Molecules* **2019**, *24*, 4021, http

s://doi.org/10.3390%2Fmolecules24224021.

60. Charai, M.; Mosaddak, M.; Faid, M.; Chemical Composition and Antimicrobial Activities of Two Aromatic Plants: Origanum majorana L. and O. compactum Benth.. *J. Essent. Oil Res.* **1996**, *8*, 657–664, https://doi.org/10.1080/10412905.1996.9701036.
61. Makrane, H.; Aziz, M.; Berrabah, M.; Mekhfi, H.; Ziyyat, A.; Bnouham, M.; Legssyer, A.; Elombo, F.K.; Gressier, B.; Eto, B.; et al. Myorelaxant Activity of essential oil from Origanum majorana L. on rat and rabbit. *J. Ethnopharmacol.* **2019**, *228*, 40–49, https://doi.org/10.1016/j.jep.2018.08.036.
62. Al-Fatimi, M.; Volatile constituents, antimicrobial and antioxidant activities of the aerial parts of Origanum majorana L. from Yemen.. *J. Pharm. Res. Int.* **2018**, *23*, 10, https://doi.org/10.9734/JPRI/2018/35932.
63. Yang, Y.C.; Lee, S.H.; Clark, J.M.; Ahn, Y.J.; Ovicidal and adulticidal activities of Origanum majorana essential oil constituents against insecticide-susceptible and pyrethroid/malathion-resistant Pediculus humanus capitis (Anoplura: Pediculidae).. *J. Agric. Food Chem.* **2009** , *57*, 2282–2287, https://doi.org/10.1021/jf803738z.
64. Waller, S.B.; Madrid, I.M.; Ferraz, V.; Picoli, T.; Cleff, M.B.; de Faria, R.O.; Meireles, M.C.A.; de Mello, J.R.B.; and anti-Sporothrix brasiliensis activity of the Origanum majorana Linn. Oil. *Braz. J. Microbiol.* **2016**, *47*, 896–901, https://doi.org/10.1016/j.bjm.2016.07.017.
65. Baj, T.; Baryluk, A.; Sieniawska, E.; Application of mixture design for optimum antioxidant activity of mixtures of essential oils from Ocimum basilicum L., Origanum majorana L. and Rosmarinus officinalis L. *Ind. Crops Prod.* **2018**, *115*, 52–61, https://doi.org/10.1016/j.indcrop.2018.02.006.
66. Barazandeh, M.M.; Essential Oil Composition of Origanum majorana L. from Iran. J.. *Essent. Oil Res.* **2001**, *13*, 76–77, https://doi.org/10.1080/10412905.2001.9699616.
67. Dantas, A.D.S.; Klein-Júnior, L.C.; Machado, M.S.; Guecheva, T.N.; Dos Santos, L.D.; Zanette, R.A.; de Mello, F.B.; Pêgas Henriques, J.A.; de Mello, J.R.; Origanum majorana Essential Oil Lacks Mutagenic Activity in the Salmonella/Microsome and Micronucleus Assays.. *Sci. World J.* **2016**, *2016*, -, https://doi.org/10.1155/2016/3694901.
68. Komaitis, M.E.; Ifanti-Papatragianni, N.; Melissari-Panagiotou, E.; Composition of the essential oil of marjoram (Origanum majorana L.).. *Food Chem.* **1992**, *45*, 117–118, https://doi.org/10.1016/0308-8146(92)90020-3.
69. Arnold, N.; Bellomaria, B.; Valentini, G.; Arnold, H.J.; Comparative Study of the Essential Oils from Three Species of Origanum GrowingWild in the Eastern Mediterranean Region. *J. Essent. Oil Res.* **1993**, *5*, 71–77, https://doi.org/10.1080/10412905.1993.9698172.
70. Petrakis, E.A.; Kimbaris, A.C.; Perdikis, D.C.; Lykouressis, D.P.; Tarantilis, P.A.; Polissiou, M.G.; Responses of Myzus persicae (Sulzer) to three Lamiaceae essential oils obtained by microwave-assisted and conventional hydrodistillation. *Ind. Crops Prod.* **2014** , *62* , 272–279, https://doi.org/10.1016/j.indcrop.2014.08.041.
71. Novak, J.; Langbehn, J.; Pank, F.; Franz, C.M.; Essential oil compounds in a historical sample of marjoram (Origanum majorana L., Lamiaceae). . *Flavour Fragr. J.* **2002**, *17*, 175–180, https://doi.org/10.1002/ffj.1077.
72. Ramos, S.; Rojas, L.B.; Lucena, M.E.; Meccia, G.; Usubillaga, A.; Chemical Composition and Antibacterial Activity of Origanum majorana L. Essential Oil from the Venezuelan Andes.. *J. Essent. Oil Res* **2011** , *23* , 45–49, https://doi.org/10.1080/10412905.2011.9700481.
73. Pavela, K.R.; Stepanycheva, E.; Shchenikova, A.; Chermenskaya, T.; Petrova, M.; Essential oils as prospective fumigants against Tetranychus urticae.. *Ind. Crops Prod.* **2016**, *94*, 755–761, https://doi.org/10.1016/j.indcrop.2016.09.050.
74. Prabu, S.; Jing, D.; Chandran, V.; Mathew, P.; Insecticidal activity of Origanum majorana L. essential oil as anti-cholinergic agent.. *Entomol. Res.* **2020**, *50*, 402–413, https://doi.org/10.1111/1748-5967.12459.
75. Papanikolaou, N.E.; Kavallieratos, N.G.; Iliopoulos, V.; Evergetis, E.; Skourti, A.; Nika, E.P.; Haroutounian, S.A.; Essential Oil Coating: Mediterranean Culinary Plants as Grain Protectants against Larvae and Adults of Tribolium castaneum and Trogoderma granarium.. *Insects* **2022** , *13*, 165, https://doi.org/10.3390/insects13020165.
76. Circella, G.; Franz, C.; Novak, J.; Resch, H.; Influence of day length and leaf insertion on the composition of marjoram essential oil.. *Flavour Fragr. J.* **1995**, *10*, 371–374, https://doi.org/10.1002/ffj.2730100607.
77. De Falco, E.; Mancini, E.; Roscigno, G.; Mignola, E.; Taglialatela-Scafati, O.; Senatore, F.; Chemical composition and biological activity of essential oils of Origanum vulgare L. subsp. vulgare L. under different growth conditions. *Molecules* **2013**, *18*, 14948–14960, molecules181214948.
78. Wesolowska, A.; Jadczak, D.; Grzeszczuk, M.; Influence of distillation time on the content and composition of essential oil isolated from lavender (Lavandula angustifolia Mill.).. *Herba Pol.* **2010**, *56*, -, .

79. Turek, C.; Stintzing, F.C.; Stability of essential oils: A review. *Compr. Rev. Food Sci.* **2013**, *12*, 40–53, https://doi.org/10.1111/1541-4337.12006.