The Composition of Essential Oils from Different Parts of Gilia capitata Sims

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Article

The Composition of Essential Oils from Different Parts of *Gilia capitata* Sims

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Abstract: Bluehead gilia or bluefield gilia (*Gilia capitata* Sims) from the family *Polemoniaceae* is an annual herbaceous plant widely distributed in the western regions of North America, but cultivated as an ornamental flower in various regions to support pollinators. The chemical composition of the plant has not been studied before. For the first time, essential oil (EO) was obtained by hydrodistillation from the different parts of gilia, harvested in Estonia. The yield of EOs was from 0.42 to 1.97 mL/kg, with the greatest yields from seeds, flowers, fruits, and leaves. Its component composition was studied using the GC-MS method. 118 compounds have been identified. The EO of flowers was dominated by the hexahydrofarnesyl acetone (19.1%), followed by palmitic acid (12.2%), γ-decalactone (7.1%), *(Z)*-2-*p*-menthen-1-ol (3.6%). Hexahydrofarnesyl acetone was also dominant in most parts of the *G. capitata*. The predominant compounds in the EO of leaves were diterpene alcohols: phytol (23.3%), isomanool (12.1%) and sclareol (4.5%), apocarotenoids, C13-norisoprenoid *(E)*-β-ionone (4.5%). The most dominant compounds in EO of stems are isomanool (8.3 %), sclareol (6.7%) and *(E,E)*-2,4-decadienal (5.3%). The dominant in the fruits were hexahydrofarnesyl acetone (18.2%), palmitic acid (8.0%), heptacosane (5.3%) and γ-decalactone (4.6 %). The dominant in the shell were (+)-*epi*-bicyclosesquiphellandrene (15.4%), β-elemene (8.5%) and pentadecanal (6.3%). The dominant in the seeds were hexahydrofarnesyl acetone (15.2%), palmitic acid (11.1%), 1,3-d'dimethylbenzene (10.3%) and heptacosane (5.0%). The dominant in the root were (-)-myrtenol (25.7%), *(E)*-myrtanol (16.4%), palmitic acid (8.1%) and 2-pentylfuran (2.9%). The results hint at further study options on the antimicrobial and anti-inflammatory effects of *G. capitata*.

Keywords: *Gilia capitata*; essential oil; ornamental flower; volatile compounds

1. Introduction

Gilia capitata Sims, with the common name bluehead gilia or blue field gilia (bule gilia), belongs to the family *Polemoniaceae*, and is a close relative to floxes and polemonium [1]. *G. capitata* Sims belongs to the subgenus *Gilia* and the *Eugilia* section. The plants that make up this section are herbaceous annuals with blue and purple flowers gathered in loose false umbrellas, corymbs or heads. The section consists of 9 species, among which are *G. achilleaefolia*, *G. capitata*, *G. millefoliata*, *G. clivorum*, *G. laciniata*, *G. tricolor*, *G. angelensis*, *G. nevinii*, and *G. valdiviensis* [2,3].

G. capitata is native to all western states of the USA [4,5]. The native habitats of *G. capitata* are sunny rocky hillslopes and open fields with well-drained soils at an elevation range of up to 2000 m [6,7]. It is introduced widely throughout western North America, Alaska, northern Mexico, and Europe as an ornamental flower [8].

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G. capitata is a polytypic species. It is phenotypically plastic in response to environmental conditions [9,10]. It has a wide morphological diversity because of the ecotypic and genotypic variability [6]. Eight defined subspecies form a morphological gradation throughout the Pacific coast of North America [6]. Chromosomes: 2n=18. The flagship sub-species, *G. capitata* subsp. *capitata*, is an herbaceous annual plant with a slender 20-100 cm erect stem. Stem can be simple or branched in the upper third, glabrous, glandular or slightly floccose. The root system consists of a relatively shallow main root. On base and stem, cauline leaves are bipinnately dissected, usually glabrous, 4–10 cm long, and with 5–20 mm lobes; upper leaves are more straightforward linear. Blue (or blue-violet) campanulate flowers are clustered into globose to conoidal inflorescences with (25) 50–100 flowers at the terminal position of each stem or branch. Inflorescence diameter varies between 14–40 mm. Individual flowers therein are 0.6-2.5 mm [9] with acute lobes 0.6–1 mm wide and 2 mm long, straight-tipped and with a 6-8 mm corolla. Pollen has a light blue colour. The flowers of the gilia are protandrous, i.e. the anthers mature first, and stigmas rise a few days later [2,11]. Gilia is mostly self-compatible; only some populations are facultatively outcrossing [2,11], though [9] reports that gilia is self-incompatible. The fruit is a three-celled globose or obovoid capsule, which splits at maturity only partly as three valves (i.e. it has an indehiscent capsule)). The capsule contains 1-10(25) seeds, one or two in each cell. The capsule remains indehiscent in dry weather and splits only partly open with the rain. When dry, capsules break off easily by touch. Seeds are hard, brown, ovoid or ovoid-angled, 1–2.3 mm long. When wet, the verrucose seed coat becomes a sticky, mucilaginous coat; this feature probably serves to stick seeds to animals for dispersal and later to substrate [9].

G. capitata is easily grown from seed. No stratification or scarification is required (though two weeks of cold stratification has been suggested to speed up germination). Seeds can be sown directly into the garden in spring. Still, we observed that they reseed reasonably well in autumn and overwinter in the Estonian winter to germinate in early spring. Minimal maintenance is required except for weeding. Soil should be moist when seeds are planted, but adult plants are drought-tolerant. Cutting deadhead flowers will encourage reflowering. In nature, gilia profits from wildfires, removing mature vegetation and opening the ground for light [12]. Its germination probably reacts to the signals from fire residues [13]. It grows in gardens alone or with other low-competition annuals in sunny open locations. Grows well in well-drained medium to coarse soil with a neutral pH (6.0-7.0). In Estonia, *G. capitata* is cultivated as an ornamental plant.

The gilia is declared one of the pollinator magnets (e.g., Blog of Oregon Native Plants for Pollinators [14]), and it is included in many wildflower seed mixes for bees. The flowering can be long-term continuous depending on water and temperature conditions. *G. capitata* needs an insect vector for pollination; flowers are visited by a wide range of insects, including small-sized pollinators and wild bees, bumblebees, long-tongued flies, and butterflies [15,16]. The attractiveness has been partly explained by its tight capitate inflorescence structure, composed of up to 80 flowers and forms a convenient landing pad for all insects [15]. Some of its essential oils could also be one of the causes of flower visit attraction of pollinators [17].

The chemical composition of *G. capitata* has not been studied before. Therefore, this work aimed to study the component composition of essential oil (EO) of different morphological groups of raw materials of *G. capitata*.

2. Materials and Methods

2.1. Plant Material

Seeds, obtained from different sources, were mixed and sown in spring. Plants were grown in field conditions at three sites with different soil conditions around Tartu, Estonia. Later, all the collected plant material was mixed in relatively equal proportions before analysis. During the growth, plant growth was supported with complex fertilizers. Plant material was collected twice. The main collection of plant material was done at the time of mass-flowering. We observed two waves of flowering – the first inflorescence formed at the top of the main stem and, several weeks later, on

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lateral stems – the material was collected in both rounds and later mixed. Depending on the site phenology, the first forage was done at the end of June 2023 and early weeks of July. Plant parts (flowers, leaves, roots, fruits) were collected separately in the field. Later, after drying, the leaves and stems were separated. The second collection was done in late summer in August 2023 (the date depended on the site and weather), at the time of fruit and seed ripening – the heads and clusters of fruit capsules were collected and dried. Later, fruit capsules were crushed, and seeds were separated. Capsule residues containing mainly fruit valves and walls were kept as a separate fraction as shells of the fruit wall (hereafter shells). The plant material was dried for 14 days at room temperature in a well-ventilated room. It was stored at room temperature in paper bags before distillation of essential oil. The voucher sample specimens (No Polemon/Gil1-7) are available at the Institute of Pharmacy, University of Tartu, Estonia.

2.2. *Hydrodistillation of Essential Oil*

The EO hydrodistilled from the different dried parts of *G. capitata* using the method described in the European Pharmacopoeia [18]. The plant materials (20 g) with 400 mL of purified water were hydrodistilled in a 1000 mL round-bottom flask for 2 hours (3–4 ml/min). Hexane (0.5 mL) was added to a graduated tube to remove the distilled oil [19,20]. The yield of EO was measured using European Pharmacopoeia with xylol [18]. Due to the content of saponins, intense foam was produced during the distillation of most plant parts, to reduce which 30 g of potassium chloride was added to the flask (except for the roots and stems).

2.3. *Gas chromatography/Mass Spectrometry*

The samples of EO were analysed by gas chromatography-mass spectrometry (GC/MS), using an Agilent 6890/5973 GCMS system controlled by MSD Chemstation. 1 µL of the sample was injected at an injector temperature of 280 °C in split mode (10:1), using He as the carrier gas onto Agilent HP-5MSI column (30 m length, 0.25 mm inner diameter, 0.25 µm film thickness). The carrier gas was held at the constant flow rate of 1 mL/min. The oven was held at 50 °C for 2 min, followed by a ramp of 4 °C/min to a final temperature of 280 °C and held at 280 °C for 5 minutes. The MSD was operated in EI mode at 70 eV. After a delay time of 4 min mass spectra were recorded in the range of 29 – 400 m/z at a rate of 3.8 scans per second. The data were analysed by Agilent Masshunter Data Analysis Software using a deconvolution algorithm with different window size factors. Obtained compounds were identified by using NIST23 library with Match Factor ≥ 90 and by retention indexes (relative to n-alkanes C8 – C30) or obtained by the analysis of the reference compounds. The area percentages of each peak were calculated from the total areas in the chromatograms without using correction factors [19,20].

2.4. *Data Analysis*

The similarity of plant parts in their composition of EO was analysed using the cluster analysis, implemented in PC-ord v7 [21]. The Sorensen (Bray-Curtis) distance measure of similarity was used to build the cluster tree by applying the Flexible beta linkage method with parameter -0.25 (a default value). The log-transformed proportion of oils was used, and only components with at least 1% were included in the data set to reduce noise.

3. Results

As a result of the study, it was found that different parts of *G. capitata* accumulated from 0.42 ml/kg (shells) to 1.97 ml/kg (seeds) of EO (Figure 1). It should be noted that the flowers contain less essential oil than the seeds. According to the content of EO, raw materials are arranged in the following order: seeds > flowers > fruits > leaves > stems > roots > shells. Seeds contain a bit less than twice as many essential oils as flowers and leaves.

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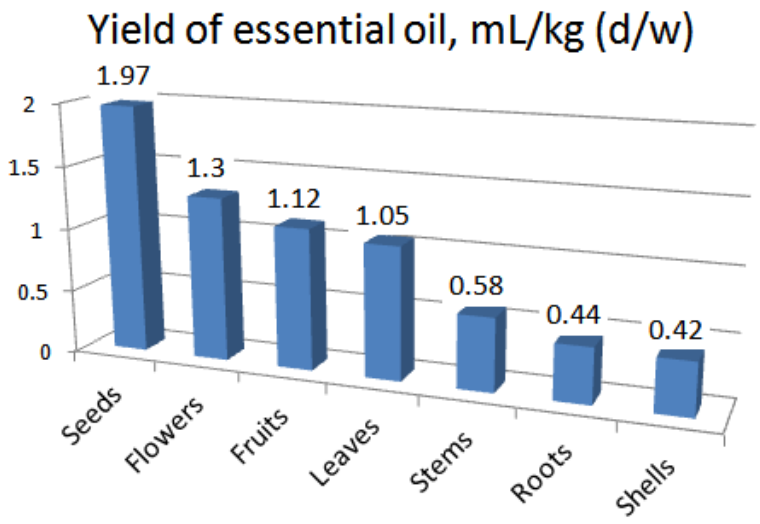

Figure 1. Yield of essential oil (mL/kg (d/w)) in different parts of *G. capitata*.

The composition of hydrodistillates was studied by GC-MS (Table 1). In total, 118 compounds were identified, representing 81.31-93.74 % in the oil (Table 1). All parts of the plant contain benzeneacetaldehyde, nonanal, *(E)*-2-nonenal, (-)-myrtenol, *(E,E)*-2,4-decadienal, tetradecanal, pentadecanal, hexahydrofarnesyl acetone, and di-2-methylpropylphtalate.

Table 1. The content (%) of volatile compounds (>0.1%) in different parts of *G. capitata*.

Compound	RI	Library NIST 23	Content (%)						
			Flowers	Leaves	Stems	Fruits	Shells	Seeds	Roots
Hexanal	799	798	3.35	1.42	3.20	nd	4.49	0.20	2.31
(E)-2-Hexenal	848	848	0.88	2.09	0.43	nd	nd	nd	nd
1-Hexanol	864	864	2.69	0.28	nd	0.19	0.93	0.04	0.08
1,3-d´Dimethyl-benzene,	866	866	nd	nd	nd	1.11	0.44	10.27	nd
(E,Z)-4-Ethylidenecyclohexene	876	877	0.36	nd	0.07	nd	nd	nd	nd
2-Heptanone	890	889	0.29	0.07	0.13	nd	0.74	nd	0.08
Nonane	900	900	0.28	nd	0.19	nd	nd	nd	nd
Heptanal	902	901	0.26	0.17	nd	nd	0.50	nd	0.28
(E)-2-Heptenal	954	954	0.17	0.23	3.23	nd	0.46	nd	0.15
Benzaldehyde	958	958	0.28	0.41	0.99	nd	0.41	nd	1.03
1-Heptanol	968	968	0.05	nd	nd	nd	0.14	nd	nd
1-Octen-3-ol	978	978	0.14	nd	1.65	0.21	0.46	0.19	0.22
2,3-Octanedione	983	983	0.26	nd	0.34	nd	nd	nd	0.14
6-Methyl-5-hepten-2-one	986	986	0.11	nd	0.10	nd	nd	nd	0.09
2-Pentylfuran	991	991	2.90	0.76	1.37	nd	1.20	nd	2.89
(Z)-2-(2-Pentenyl)furan	1001	1001	0.18	nd	0.21	nd	nd	nd	0.20
Octanal	1003	1002	0.37	0.53	0.30	nd	nd	nd	0.26
(E,E)-2,4-Heptadienal,	1010	1010	0.17	0.34	0.74	nd	nd	nd	nd

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α-Terpinene	1016	1016	0.40	nd	nd	nd	nd	nd	nd
p-Cymene	1023	1023	0.12	nd	nd	nd	nd	nd	nd
2-Ethyl-1-hexanol	1028	1027	nd	nd	nd	nd	nd	nd	0.49
β-Phellandrene	1028	1028	0.67	nd	nd	nd	nd	nd	nd
3-Octen-2-one	1038	1038	0.13	nd	1.22	nd	nd	nd	0.09
Benzeneacetaldehyde	1042	1042	0.65	1.27	0.98	0.39	2.45	0.31	1.43
(E)-2-Octenal	1057	1056	0.80	nd	2.11	nd	0.62	nd	1.04
γ-Terpinene	1057	1057	0.47	nd	nd	nd	nd	nd	nd
Acetophenone	1065	1064	nd	nd	nd	nd	0.12	nd	0.10
(Z)-2-Octen-1-ol	1066	1067	nd	nd	0.51	nd	nd	nd	nd
1-Octanol	1069	1069	2.89	2.02	nd	2.53	0.88	2.26	0.37
(E)-β-Terpinolene	1087	1087	0.16	nd	nd	nd	nd	nd	nd
3,5-Octadien-2-one	1092	1093	0.25	nd	0.49	nd	nd	nd	0.12
Linalool	1098	1098	0.34	0.50	0.28	nd	0.58	0.29	nd
Nonanal	1103	1102	2.17	1.25	1.49	1.96	1.18	1.78	1.38
(Z)-2-*p*-Menthen-1-ol	1119	1120	3.62	1.43	3.82	3.28	1.98	2.70	nd
(E)-*p*-2-Menthen-1-ol	1138	1138	2.07	0.81	2.14	2.36	1.32	1.91	nd
(E)-Verbenol	1143	1143	0.20	nd	nd	nd	nd	nd	nd
(R,S)-5-Ethyl-6-methyl-3E-hepten-2-one	1145	1145	nd	nd	0.41	nd	nd	nd	0.19
(E,Z)-2,6-Nonadienal	1152	1152	0.27	0.35	0.47	nd	nd	nd	0.18
(*E*)-2-Nonenal	1158	1158	0.94	0.44	0.92	0.46	0.57	0.42	0.95
α-Phellandren-8-ol	1165	1165	0.08	0.03	nd	0.03	0.09	nd	0.05
1-Nonanol	1170	1170	nd	0.15	0.56	0.32	0.70	0.29	0.22
L-α-Terpineol	1189	1189	0.39	nd	nd	nd	nd	nd	nd
(-)-Myrtenol	1195	1195	1.94	0.67	2.12	1.73	0.97	1.44	25.72
Decanal	1204	1204	1.06	1.16	2.21	1.34	nd	1.03	1.89
(E)-Piperitol	1206	1206	1.21	nd	1.05	1.63	1.39	1.31	nd
(E,E)-2,4-Nonadienal	1212	1212	nd	nd	0.74	0.25	nd	0.23	0.39
Bicyclo[3.3.0]octan-2-one, 7-methylene-6(or 8)-methyl-	1220	1220	nd	nd	nd	nd	nd	nd	2.20
Carvone	1244	1243	nd	nd	nd	nd	nd	nd	1.47
p-Mentha-1(7),8(10)-dien-9-ol	1245	1246	nd	nd	nd	nd	nd	nd	1.19
Geraniol	1253	1254	nd	nd	nd	nd	nd	nd	1.01
(E)-Myrtanol	1258	1258	0.70	nd	0.47	0.54	0.34	0.43	16.44
1-Decanol	1270	1271	0.46	0.19	nd	0.64	0.88	0.53	nd
Nonanoic acid	1271	1272	1.04	nd	nd	nd	nd	nd	nd

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(E)-Bornyl acetate	1285	1285	nd	nd	nd	nd	0.73	nd	nd
Thymol	1289	1290	nd	nd	nd	nd	nd	nd	0.55
(E,Z)-2,4-Decadienal	1292	1292	0.77	nd	1.61	0.87	nd	0.71	0.32
(E)-Undec-4-enal	1298	1296	nd	nd	0.33	nd	nd	nd	nd
Undecanal	1306	1305	0.19	0.25	0.33	0.43	nd	0.39	0.32
2-Methoxy-4-vinylphenol	1312	1312	0.41	0.51	nd	nd	0.53	nd	nd
(E,E)-2,4-Decadienal	1315	1315	2.71	1.10	5.29	3.36	1.43	2.85	1.18
Eugenol	1357	1357	nd	0.97	nd	nd	nd	nd	nd
Dihydro-5-pentyl-2(3H)-furanone	1362	1362	nd	nd	nd	nd	nd	nd	0.25
2-Undecenal	1363	1363	nd	nd	3.89	1.26	0.83	1.12	nd
n-Decanoic acid	1373	1372	nd	nd	nd	nd	nd	nd	1.32
2-Butyl-2-octenal	1372	1373	0.34	nd	nd	0.32	nd	0.26	nd
(E)-β-Damascenone	1385	1385	0.27	nd	nd	0.58	0.72	0.45	nd
β-Elemene	1393	1393	nd	nd	nd	nd	8.46	nd	nd
6,10-Dimethyl-2-undecanone,	1404	1404	nd	nd	0.25	nd	nd	nd	nd
Dodecanal	1408	1408	0.29	0.26	0.28	0.36	nd	0.30	0.50
7-*epi*-α-Cedrene	1416	1417	nd	nd	nd	nd	nd	nd	0.56
Copaene	1421	1420	1.28	nd	nd	nd	2.87	nd	nd
Caryophyllene	1421	1421	1.34	0.54	nd	nd	2.77	nd	nd
(E)-Geranylacetone	1453	1453	0.54	0.85	0.52	0.72	nd	0.63	0.86
Humulene	1455	1456	nd	nd	nd	nd	1.52	nd	nd
γ-Decalactone	1469	1469	7.09	1.50	1.04	4.62	1.66	4.23	nd
1-Dodecanol	1474	1474	nd	0.20	0.13	nd	0.43	nd	0.94
(+)-*epi*-Bicyclosesquiphellandrene	1484	1484	0.48	nd	nd	nd	15.41	nd	nd
(E)-β-Ionone	1488	1488	1.14	4.54	3.24	1.30	nd	0.97	nd
β-Selinene	1488	1489	nd	nd	nd	nd	0.41	nd	nd
α-(3-Methylbutylidene)-benzeneacetaldehyde	1492	1492	nd	nd	0.21	nd	nd	nd	nd
(+)-Cuparene	1510	1508	nd	nd	nd	nd	nd	nd	0.29
α-Farnesene	1510	1510	1.01	nd	nd	nd	nd	nd	nd
Tridecanal	1511	1511	nd	0.53	0.34	0.53	nd	0.44	0.29
(Z)-γ-Bisabolene	1517	1518	0.57	nd	nd	nd	nd	nd	nd
n-Tridecan-1-ol	1575	1575	nd	nd	nd	nd	nd	nd	0.25
Caryophyllene oxide	1587	1587	0.89	nd	nd	nd	nd	nd	nd

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2,2,4-Trimethyl-1,3-pentanediol diisobutyrate	1600	1599	0.38	nd	nd	nd	nd	nd	0.92
Tetradecanal	1613	1613	0.24	0.76	0.54	1.03	1.55	0.88	0.50
Benzophenone	1629	1629	nd	0.20	0.14	nd	nd	nd	nd
τ-Muurolol	1644	1646	0.62	nd	nd	nd	nd	nd	nd
α-Cadinol	1658	1658	0.41	nd	nd	nd	nd	nd	nd
1-Tetradecanol	1677	1677	nd	nd	0.49	1.01	1.81	0.97	1.52
Pentadecanal	1715	1715	0.37	4.01	2.99	4.38	6.25	3.65	2.06
1-Tetradecene	1736	1736	nd	nd	0.65	0.54	nd	0.50	nd
Myristic acid	2765	1764	nd	nd	nd	nd	nd	nd	0.85
n-Pentadecanol	1779	1778	nd	nd	nd	0.43	1.63	0.44	0.38
Ambrial	1804	1804	nd	nd	0.48	nd	nd	nd	nd
Farnesyl acetaldehyde	1845	1845	nd	nd	0.25	nd	nd	nd	nd
Hexahydrofarnesyl acetone	1851	1851	19.09	3.10	4.94	18.16	3.24	15.21	1.27
Di-2-methylpropyl phthalate	1878	1878	1.58	0.64	0.72	0.55	0.81	0.42	2.61
1-Hexadecanol	1889	1889	nd	1.05	0.78	1.47	0.83	1.55	0.74
Manoyl oxide	1896	1897	nd	2.28	2.96	0.62	nd	0.51	nd
Roughanic acid	1904	1904	nd	nd	0.70	nd	nd	nd	nd
Farnesyl acetone	1928	1928	0.50	nd	nd	nd	nd	nd	nd
Cembrene A	1969	1969	0.82	nd	nd	nd	nd	nd	nd
Palmitic acid	1976	1974	12.24	nd	nd	7.95	nd	11.13	8.05
13-*epi*-Manoyl oxide	2018	2018	nd	1.15	0.51	nd	nd	nd	nd
Epi-13-Manool	2061	2061	nd	1.01	0.77	nd	nd	nd	nd
Kolavelool	2070	2070	nd	1.67	0.97	nd	nd	nd	nd
Isomanool	2093	2094	0.39	12.07	8.29	3.23	nd	2.48	nd
γ-Palmitolactone	2103	2104	nd	nd	0.41	nd	nd	nd	nd
Phytol	2116	2114	1.72	23.26	2.63	3.51	nd	2.97	nd
Sclareol	2225	2227	nd	4.45	6.70	nd	nd	nd	nd
Nonadecane	2300	2300	0.29	0.53	0.17	1.95	nd	1.71	nd
Pentacosane	2500	2500	nd	0.99	0.64	3.34	nd	3.10	nd
Bis(2-ethylhexyl) phthalate	2551	2550	nd	nd	0.38	nd	nd	nd	nd
Heptacosane	2700	2701	nd	1.74	2.84	5.34	2.07	4.95	nd
Octacosane	2800	2800	nd	nd	0.52	1.47	1.51	1.47	nd
TOTAL			93.74	86.73	92.87	88.30	81.31	89.92	91.18

Note. “nd” – not detected

The composition of essential oils in different parts of *G. capitata* was illustrated with a cluster tree (Figure 2). Fruits and seeds were most similar in composition; flowers were next similar ones. Leaves and stems formed another narrow cluster. The most distant were shells of the fruit. The composition of roots was the most distinct from all other parts of a plant (Figure 2).

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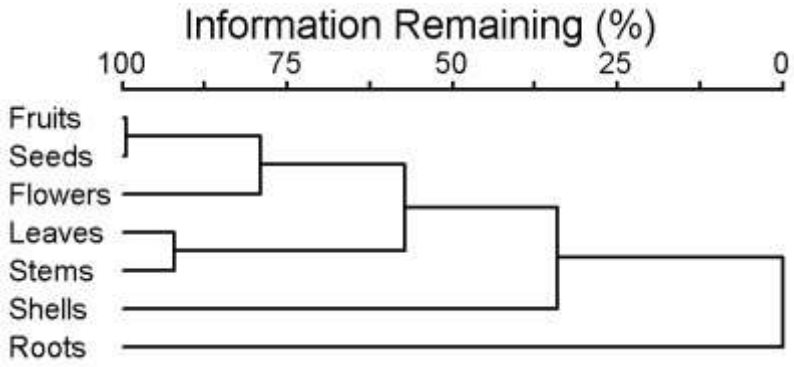

Figure 2. Cluster tree characterizing the essential oil composition between different parts of *G. capitata*.

4. Discussion

As mentioned above, the yield of EO in different parts of *G. capitata* was 0.42-1.97 ml/kg (Figure 1). We compare that with results obtained in studies of some well-known medicinal plants studied. The aerial parts of *Origanum vulgare* from different countries contained 2-11 ml/kg of EO [22], in *Thymus vulgaris* herb the yield of EO was 3-28 ml/kg [23], in commercial samples of *Valeriana officinalis* roots from various countries different origin 2-10 ml/kg [24], and in the herb of *Artemisia absinthium* from different origin 2-4 ml/kg [25]. The branches of *Juniperus communis* shrubs were collected from 27 different habitats in Estonia and contained 0.3-6 ml/kg of EO [26]. Therefore, the oil content in *G. capitata* is modest compared to classic EO plants.

The essential oil of flowers was dominated by hexahydrofarnesyl acetone (19.1%), followed by palmitic acid (12.2%), γ-decalactone (7.1%) and *(Z)*-2-*p*-menthen-1-ol (3.6%) (Figure 3). In addition to the flowers, hexahydrofarnesyl acetone is also the dominant component in fruits (18.2%) and seeds (15.2%), and it is found in significant quantities in the stems (4.9%) of the *G. capitata* (Figure 3). Hexahydrofarnesyl acetone has been proven to exhibit a potent antimicrobial, anti-inflammatory, and cytotoxic activity and is used in pain relief research [27–30]. Palmitic acid, present also in seeds (11.1%) and fruits (8.0%), has antioxidant and antibacterial activity [31,32].

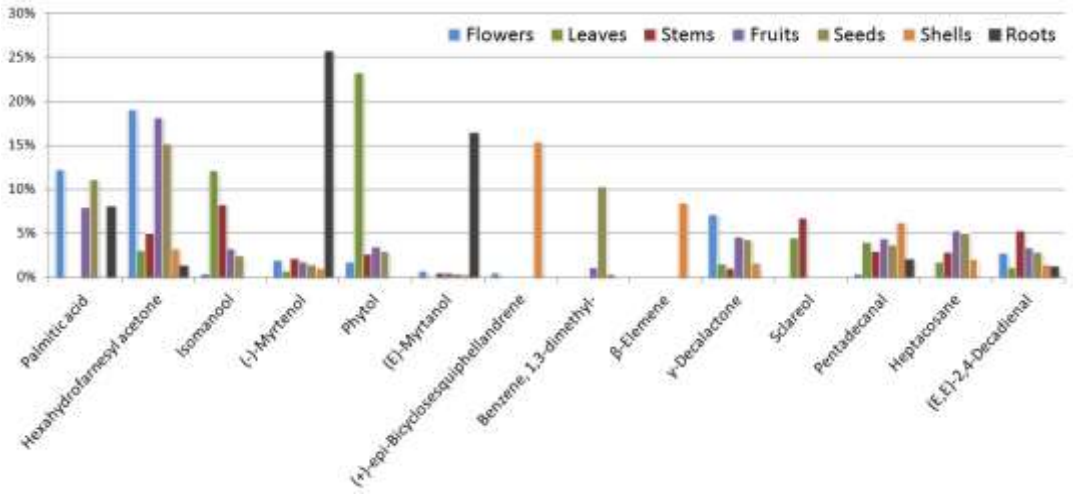

Figure 3. Dominant substances (%) in different part of *G. capitata*. Compounds with at least 5% are presented.

Lactones, including γ-decalactone, constitute an essential group of fatty acid-derived volatile organic compounds conferring peach-like aroma to a few essential oils and fruits including peach, plum, pineapple and strawberry [33]. γ-Decalactone inhibits strawberry pathogen growth and achene germination [34].

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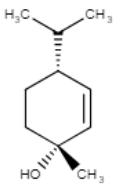
Menthane monoterpenoids *(Z)-2-p*-menthen-1-ol and *(E)-p-2*-menthen-1-ol are found in all organs of the aboveground part of the plant. They make up 5.7% of flowers, 2.2% of leaves, 6.0% of stems, 5.6% of fruits, 3.3% of shells and 4.6% of seeds. Menthenol derivatives have potentially different biological properties. 1-Methyl-4-(1-methylethenyl)-2-cyclohexen-1-ol is an acetal reagent used in the synthesis of desoxy cannabidiols and THC related psychoactive compounds. It is formed from (+)-Limonene using a photosynthesized O_2 transfer [35].

In addition to the dominant compounds in the flowers, *(Z)*-γ-bisabolene was also found (though, it is similarly abundant in stems and fruits). The antitumor activity of γ-bisabolene in human neuroblastoma cells has been proven through the induction of p53-mediated mitochondrial apoptosis [36]. γ-Bisabolene has demonstrated antiproliferative activities against several human cancer cell lines. Another study [29] disclosed the antiproliferative and apoptosis induction activities of γ-bisabolene to human neuroblastoma TE671 cells, and a CC50 value of γ-bisabolene was 8.2 μM to TE671 cells [37].

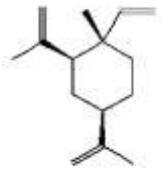
Caryophyllene oxide is found in flowers (0.9%), while caryophyllene was distributed more widely in flowers, leaves, fruits and shells (1.3, 0.5, 2.8%, respectively). Its anticancer, antioxidant and antimicrobial properties have been proven [38].

Linalool is found in flowers (0.3%), leaves (0.5%), stems (0.3%), shells (0.6%) and seeds (0.3%). Linalool and *(E)*-caryophyllene exhibited high cytotoxic activity against the amelanotic melanoma and renal adenocarcinoma cells [39].

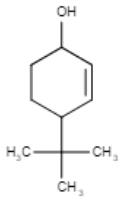
The characteristic terpenoids of *G. capitata* are shown in Figure 4.



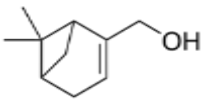
(E)-p-Menth-2-en-1-ol



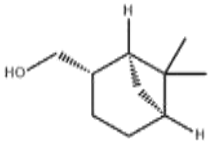
β-Elemene



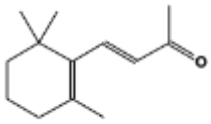
(Z)-2-*p*-Menthen-1-ol



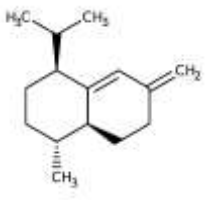
Myrtenol, (-)-



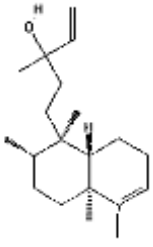
(E)-Myrtanol



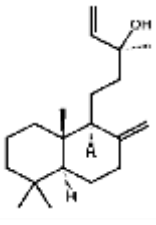
(E)-β-Ionone



(+)-*epi*-Bicyclosesquiphellandrene



(+)-Kolavelool



13-*epi*-Manool

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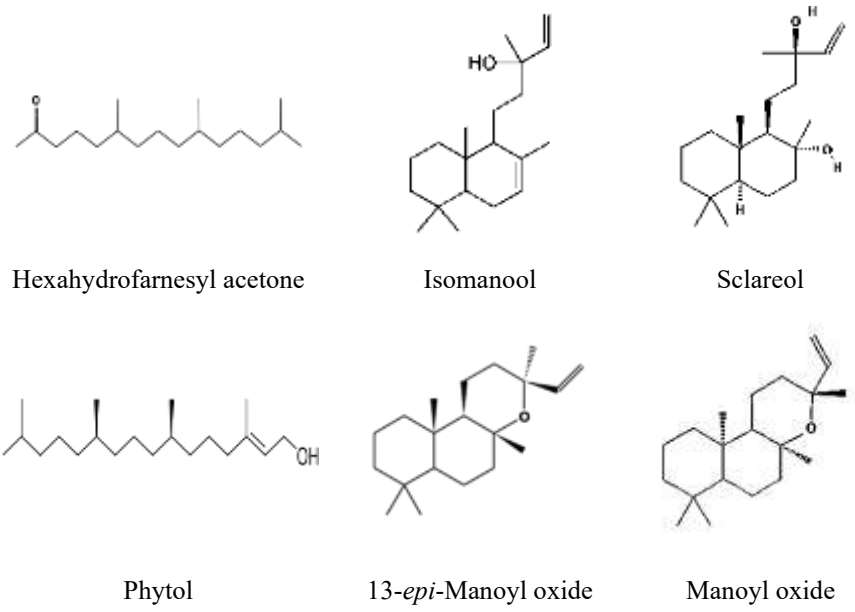

Hexahydrofarnesyl acetone | Isomanool | Sclareol

Phytol | 13-*epi*-Manoyl oxide | Manoyl oxide

Figure 4. Characteristics terpenoids of *Gilia capitata* Sims.

The predominant compounds in the EOs of the leaves were phytol (23.3%) and diterpene alcohols isomanool (12.1%) and sclareol (4.5%), (E)-β-ionone (4.5%).

Phytol has antibacterial and antioxidant activity, inhibiting the growth of *Staphylococcus aureus* [40,41]. Phytol is used in fragrance and cosmetics to produce shampoos, toilet cleaners, household cleaners and detergents [42].

Labdane diterpenoids are the most common types of diterpenoids isolated in minute amounts from higher plants [43]. Labdane diterpenoids are interesting for their cytotoxic, antifungal, anti-inflammatory, antiparasitic and analgesic properties [44–46]. Labdane diterpenoid sclareol has a wide range of bioactivity, including anti-tumor, anti-inflammation and anti-pathogenic microbes, and even anti-diabetes and hypertension [47]. Sclareol also can kill human leukemic cells and colon cancer cells in vitro by apoptosis [48,49]. Labdanum-type diterpenoids are usually found in the plant as a mixture of components. Therefore, we found it necessary to provide all the structural formulas of labdanum diterpenoids contained in *G. capitata* raw materials (Figure 4). Labdan-type diterpenes, such as manoyl oxide, 13-*epi*-manoyl oxide, *epi*-13-manool, kolavelool, isomanool, sclareol make up a significant part of leaves and stems oils – 22.63% and 20.2%, respectively. Fruits and seeds essential oils contain less– 3.85% and 2.99%, respectively. The main component among labdan diterpenes is isomanool (labda-8,14-diene-13β-ol), it is found in flowers 0.39%, leaves 12.07%, stems 8.29%, fruits 3.23% and seeds 2.48%. It is followed by manoyl oxide, found in leaves 2.28%, stems 2.96%, fruits 0.62%, seeds 0.51%. They are absent in shells and roots. Nor-labdane diterpenoids ambrial is found in trace amounts only in stems.

C-13-isoprenoid, apocarotenoid β-ionone had fungicidal activities against *Aspergillus fumigatus.* It also ameliorated fungal keratitis in mice by reducing inflammation, which LOX-1, p-p38MAPK and p-JNK regulated [50]. Literature data indicate that β-ionone and its derivatives have a lot of important pharmacological activities, including antibacterial, antifungal, antioxidant, anti-inflammatory, antiproliferative, and anti-cancer [51].

The most dominant compounds in EO of stems are isomanool (8.3 %), sclareol (6.7%) and 2,4-decadienal, (E,E)- (2.9%). Known about nematicidal activity 2,4-decadienal [52] and insecticidal against the barn bug [53].

In addition to hexahydrofarnesyl acetone, the dominant in the fruits were palmitic acid (8.0%), heptacosane (5.3%) and γ-decalactone (4.6%). The dominant in the shell were (+)-*epi*-bicyclosesquiphellandrene (15.4%), β-elemene (8.5%) and pentadecanal- (6.3%). β-Elemene exhibits anti-tumour properties, and anti-inflammatory and antioxidant effects [54,55]. β-Elemene and *β*-

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elemene piperazine derivatives have been shown to inhibit tumour cell growth *in vitro* and *in vivo* [56]. The anti-bacterial authorities of the pentadekanal were established [57,58].

In addition to hexahydrofarnesyl acetone, the dominant in the seeds were palmitic acid (11.1%), 1,3-dimethylbenzene (10.3%) and heptacosane (5.0%). Heptacosan can improve P-glycoprotein-mediated drug transport, demonstrating the ability to retain the substrate doxorubicin inside the cell and enhancing its cytotoxic effects [59].

The dominant in the root were (-)-myrtenol (25.7%), *(E)*-myrtanol (16.4%), palmitic acid (8.1%) and 2-pentylfuran (2.9%). Several reports have demonstrated the pharmacological properties of myrtenol, including its antioxidant, antibacterial, antifungal, antidiabetic, anxiolytic, and gastroprotective activities [60,61]. (-)-*(E)*-Myrtanol is an antimicrobial and acaricide agent [62,63]. 2-Pentylfuran has been suggested as a repellent for spotted-wing drosophila, as it can significantly reduce fruit infestations under field conditions [64]. In the roots, cuparene (0.3%) was found. Cuparene derivatives show moderate to high activity levels on lung cancer cell lines NSCLC-N6 and A549 [65].

A significant number of volatile compounds are aliphatic (24.37 – 48.56%). They are the dominant compounds in flowers, stems, fruits, and seeds (Figure 5).

At the same time, diterpenoids are the dominant group in the composition of volatile compounds in leaves (45.89%), sesquiterpenoids in shells (34.68%), and monoterpenoids in roots (46.43%).

It should also be noted that the content of mono- and sesquiterpenoids is quite high in flowers (12.78% and 26.73%, respectively), stems (9.88% and 5.71%), fruits (9.57% and 18.88%), seeds (8.08% and 15.84%), monoterpenoids in shells (7.93%).

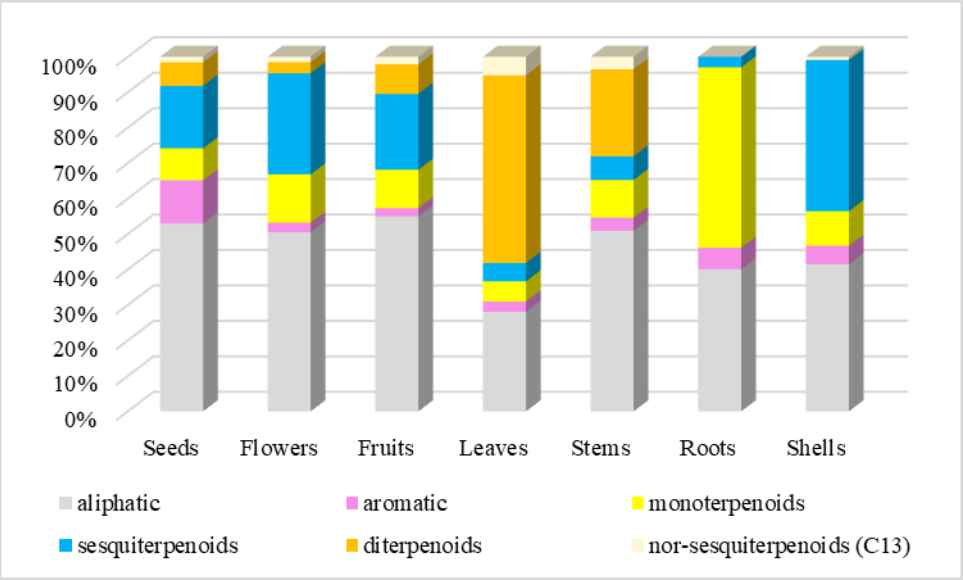

Figure 5. The content (%) group compounds in volatile components of different parts of *G. capitata.* The total % from Table 1 has been rescaled to 100%.

Sesquiterpenoids are represented by derivatives of the naphthalene, such as copaene, humulene, (+)-epi-bicyclosesquiphellandrene, β-selinene, τ-muurolol, *α*-cadinol and azulene, such as 7-*epi*-*α*-cedrene series. Antiviral activity against dengue virus (VDEN) was established for a few sesquiterpenoids, including isomers of copaene, β-caryophillene, caryophillene oxide and (+)-*epi*-bicyclosquiphellandrene [66]. Norsesquiterpenoids or apocarotenoids are represented by two compounds such as (E)-β-ionone and *(E)*-β-damascenone. They are absent in the roots. *β*-Damascenone inhibits the expression of pro-inflammatory cytokines and leukocyte adhesion molecules [67]. *β*-Damascenol has been shown to be effective in preventing skin sunburn [68].

Aromatic compounds represent an insignificant part of the composition of volatile compounds, are found in all parts of the plant and accumulate in fruits to the maximum extent (11.0%).

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5. Conclusions

The composition of volatile compounds of various parts of *G. capitata* was studied for the first time. The results of the analysis of *Gilia* essential oil made it possible to detect and identify important potentially active compounds with various biological properties: antioxidant, anti-cancer, antidepressant and others, which indicates the prospects for further phytochemical and pharmacological studies of the genus *Gilia*. Future studies should focus on *Gilia* saponins and polyphenolic substances and their biological activity.

6. Patents

No patents.

Author Contributions: Conceptualization, A.R., J.L. and O.K.; methodology, A.R., M.L., T.I., A.K., and O.K.; software, T.I., A.K., and A.R.; validation, A.R., M.L., T.I. and A.K.; formal analysis, A.R., M.L., P.S. and O.K.; investigation, A.R., M.L., P.S. and O.K.; resources, A.R. and J.L.; data curation, A.R., M.L., P.S. and O.K.; writing—original draft preparation, A.R., J.L., T.I., A.K. and O.K.; writing—review and editing, A.R., J.L., M.L., T.I., A.K. and O.K.; visualization, J.L., T.I. and A.K.; supervision, A.R.; project administration, A.R.; funding acquisition, A.R. and O.K. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The data supporting the results of this study can be obtained from the corresponding authors upon reasonable request.

Conflicts of Interest: The authors declare no conflicts of interest.

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