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Article

Volatile Compounds from *Salvia verticillata* L. – Case Study from Serbia (Kopaonik Mountain) and Comparison to Literature Data

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Abstract: The genus *Salvia* is the largest genus within the plant family Lamiaceae. However, in Serbia, only 14 species grow in nature, and *S. verticillata* L., or lilac sage, is one of them. Although this plant is rich in biologically active compounds, it is relatively rarely used. In Serbian traditional medicine, herbal tea prepared from the aerial parts of *S. verticillata* is used as an expectorant, to disinfect the oral cavity, or as a cataplasm for wound healing. The root is used to relieve gastrointestinal complaints, lower blood sugar, and treat various types of cancer. The aim of this research was to investigate the GC-MS profile of essential oil obtained by hydro distillation from plants collected in Kopaonik Mountain and compare the results with literature data collected via scientific databases. Among 63 compounds, the dominant ones were: germacrene D (27.2%) and *trans*-caryophyllene (11.5%). A literature review identified 19 papers on the chemical composition of *S. verticillata* essential oil, all of which report the dominance of sesquiterpenes as the dominant class of compounds. Sesquiterpenes have been reported to possess numerous biological activities, which supports the pharmacological potential of this plant.

Keywords: lilac sage; essential oil; germacrene D; and *trans*-caryophyllene

1. Introduction

The genus *Salvia* is the largest genus within the plant family Lamiaceae. However, in Serbia, only 14 species grow in nature, and *Salvia verticillata* L. is one of them [1]. This species, commonly known as lilac sage, is a perennial plant with a well-developed root system and semi-bushy aerial parts, with multiple branched upright stems. The entire epidermis of the plant is densely covered by glandular hairs, responsible for accumulating essential oil [2]. The leaves are elliptic or ovate-oblong, and the verticilasters are composed of dark violet-purple, two-lipped flowers [3]. It grows in grasslands, on sunny slopes, in fallow areas and along railroads in south-eastern and Central Europe, Caucasus, western Siberia and Near East [4].

The plant possesses a woody and spicy odor, derived from essential oil with sesquiterpene hydrocarbons as the prevailing group of volatile compounds [2] with germacrene D, β-caryophyllene, and its isomer α-humulene as the main compounds [5]. Additionally, *S. varticilata* is rich in

biologically active compounds. Different types of extracts from aerial parts and roots show a wide spectrum of bioactive compounds and numerous pharmacological activities [6]. For example, dichlormetane, hexane, methanol, and water extract of *S. verticillata* aerial parts contain high amounts of phenolic acids and flavonoids [7;8;9;10]. Moreover, 28 compounds were detected in the hydromethanolic leaf extract of *S. verticilata*, with phenolic acids, mainly caffeic acid derivatives, as the main ingredients [11]. Furthermore, polyphenols were also detected in methanol and ethanol extracts of *S. verticillata* roots [9;12]. Finally, a wide range of terpenoid compounds, such as diterpenoids (7α-acetoxyroyleanone and 7α-hydroxyroyleanone), tanshinones were also noted in this plant [9;13].

S. verticillata is a rarely used plant in Serbian traditional medicine. It is prepared as a herbal tea from the aerial parts, taken internally as an expectorant, for disinfecting the oral cavity, or applied externally as a cataplasm for wound healing [14]. The root is used to relieve gastrointestinal problems and lower blood sugar [15]. However, in recent decades, *S. verticillata* has been increasingly used to treat different types of cancer [16].

The aim of this study was to investigate the chemical composition of essential oil obtained by hydro distillation from plants collected in Kopaonik Mountain and to compare the results with literature data from scientific databases.

2. Materials and Methods

The arial parts of *S. verticillata* were collected in Brzeće, Kopaonik Mountain (43.278883; 20.875361) at the flowering stage (Figure 1a). Plant material was identified by Prof. Ružica Igić according to the Flora of Serbia (Figure 1b) [1], and deposited in BUNS Herbarium. For further investigations, the plant material was dried naturally to a constant weight, milled, and subjected to hydro distillation using a Clevenger-type apparatus for 3 hours. Gas chromatography coupled with mass spectrometry (GC–MS) was used to identify and quantify volatile compounds in the essential oil. The devices and conditions were previously described in detail [17].

Figure 1. *Salvia verticillata* L. – the upper part of the stem with leaves and flowers (**a**) Plant in the nature (photo M. Aćimović); (**b**) Description according to Flora of Serbia (photo M. Gajić [1])

3. Results

GC-MS analysis of the chemical composition of the aerial parts of *S. verticillata* showed the presence of 63 compounds, the dominant compounds being: germacrene D (27.2%) and *trans*-caryophyllene (11.5%), followed by: α-humulene (4.9%), spathulenol (4.4%), δ-cadinene (3.2%), α-cadinol (3.2%), germacra-4(15),5,10(14)-trien-1-α-ol (2.7%), *trans*-β-farnesene (2.6%), bicyclogermacrene (2.6%), caryophyllene oxide (2.0%), β-phellandrene (1.7%), β-copaene (1.6%), γ-muurolene (1.4%), phytol (1.3%), γ-cadinene (1.2%), β-bourbonene (1.1%), and *epi*-α-murrolol (1.0%). Other compounds were present in amounts less than 1.0% (Table 1).

A review of literature found 19 papers detailing the chemical composition of *S. verticillata* essential oil. The results are provided Table 1 (from newest to oldest), alongside the results of this study (TS).

Table 1. Chemical composition of *S. verticillata* essential oil from this study (TS) and from literature*

Peak	Compound	RI	TS	[18]	[19]	[19]	[20]	[2]	[2]	[2]	[2]	[2]	[21]
1	*α*-pinene	934	0.2	0.2	-	-	-	0.5	1.3	1.0	-	-	8.2
2	sabinene	974	0.1	0.5	-	-	2.5	0.7	0.8	0.9	tr	-	-
3	*β*-pinene	978	0.2	0.9	-	-	4.9	2.7	3.7	2.6	0.7	1.1	2.0
4	myrcene	992	0.2	0.5	-	-	2.1	0.8	1.1	1.1	-	0.2	1.4
5	*p*-mentha-1(7),8-diene	1006	0.1	-	-	-	-	-	-	-	-	-	-
6	*p*-cymene	1025	0.1	0.3	0.2	tr	3.5	tr	0.3	0.2	0.2	-	1.0
7	*β*-phellandrene	1029	1.7	0.8	-	-	-	-	4.9	4.5	2.0	-	-
8	*cis*-*β*-ocimene	1037	0.4	tr	tr	-	3.2	0.6	2.3	2.9	-	-	-
9	*trans*-*β*-ocimene	1048	0.2	-	0.4	-	-	0.4	2.6	3.7	-	-	-
10	*γ*-terpinene	1059	0.1	0.2	-	-	-	-	-	-	0.1	tr	1.1
11	linalool	1101	0.3	0.3	-	-	-	0.4	0.5	0.8	-	0.6	2.2
12	cosmene	1132	0.1	-	-	-	-	-	-	-	-	-	-
13	terpinen-4-ol	1176	0.1	tr	1.3	0.1	-	-	-	-	-	2.0	0.6
14	*α*-terpineol	1189	0.1	0.2	0.3	-	-	-	-	-	-	0.2	1.0
15	*β*-cyclocitral	1219	0.1	-	-	-	-	-	-	-	-	-	-
16	*α*-cubebene	1350	0.3	-	-	-	-	-	-	-	0.7	0.1	-
17	*α*-ylangene	1372	0.1	-	-	-	-	-	-	-	0.2	-	-
18	*α*-copaene	1377	0.4	1.1	0.5	0.1	3.0	tr	0.5	0.3	2.2	0.4	-
19	*β*-bourbonene	1386	1.1	6.1	-	-	-	2.1	3.1	1.8	5.1	0.7	-
20	*β*-cubebene	1391	0.4	-	-	-	-	-	0.3	0.3	1.5	0.3	-
21	*β*-elemene	1393	0.3	-	-	-	-	-	0.4	0.3	-	0.3	-
22	*trans*-caryophyllene	1421	11.5	17.1	3.3	3.3	13.3	11.9	7.3	7.3	21.1	15.5	0.7
23	*β*-copaene	1431	1.6	1.6	-	-	-	0.7	-	0.6	3.1	0.8	-
24	aromadendrene	1441	0.1	0.7	-	0.2	3.0	0.4	0.2	0.1	-	0.4	-
25	*α*-humulene	1456	4.9	8.3	0.3	0.2	-	5.9	2.7	2.7	-	5.5	-
26	*trans*-*β*-farnesene	1460	2.6	-	-	-	-	2.4	1.7	1.5	-	4.9	-
27	*cis*-cadina-1(6),4-diene	1465	0.6	-	-	-	-	-	-	-	-	-	-
28	*trans*-cadina-1(6),4-diene	1477	0.1	-	-	-	-	-	-	-	-	-	-
29	*γ*-muurolene	1482	1.4	0.3	-	-	-	0.4	0.3	0.2	0.7	10.0	-
30	germacrene D	1487	27.2	13.8	-	tr	7.5	39.5	40.1	40.7	38.4	-	-
31	*β*-selinene	1490	0.2	-	-	-	-	-	-	-	-	0.1	-
32	*trans*-muurola-4(14),5-diene	1495	0.4	-	-	-	-	-	-	-	-	-	-
33	bicyclogermacrene	1500	2.6	2.3	-	0.2	-	14.8	11.5	14.4	5.0	21.4	-
34	*α*-muurolene	1503	0.7	-	-	-	-	-	-	-	0.4	-	-
35	germacrene A	1508	0.2	-	-	-	-	-	-	-	-	-	-
36	*γ*-cadinene	1517	1.2	0.4	0.1	0.1	-	-	0.2	0.3	-	-	-
37	*δ*-cadinene	1526	3.2	1.4	1.6	1.3	-	1.2	0.8	0.7	1.1	0.3	-
38	*trans*-cadina-1,4-diene	1535	0.2	-	-	-	-	-	-	-	-	-	-
39	*α*-cadinene	1540	0.3	0.1	-	-	-	-	-	-	0.2	-	-
40	*trans*-nerolidol	1565	0.2	-	0.7	0.2	-	-	-	-	-	-	-
41	spathulenol	1580	4.4	5.1	9.0	19.7	8.3	6.6	3.1	4.2	0.6	0.2	31.0
42	caryophyllene oxide	1585	2.0	5.9	21.8	24.4	-	-	1.0	1.0	-	-	1.9
43	viridiflorol	1594	0.3	-	-	-	-	-	-	-	-	-	0.6
44	salvial-4(14)-en-1-one	1594	0.7	0.6	-	-	-	-	-	-	-	-	0.4
45	humulene epoxide II	1610	0.7	1.9	1.1	1.6	-	-	0.4	0.2	-	-	0.9
46	1,10-di-*epi*-cubenol	1616	0.1	0.3	-	-	-	-	-	-	-	-	-
47	junenol	1620	0.4	-	-	-	-	-	-	-	-	-	-
48	1-*epi*-cubenol	1630	0.3	-	-	-	-	-	-	-	-	-	-
49	*cis*-3-hexenyl phenyl acetate	1633	0.2	-	-	-	-	-	-	-	-	-	-
50	*α*-muurolol (=Torreyol)	1643	0.7	-	-	-	-	-	-	-	-	-	0.5
51	*epi*-*α*-murrolol (=*τ*-muurolol)	1644	1.0	0.2	-	0.3	-	-	-	-	-	-	-
52	*α*-cadinol	1657	3.2	-	tr	1.5	-	-	0.8	0.4	-	-	0.6
53	valeranone	1675	0.5	-	-	-	-	-	-	-	-	-	-
54	germacra-4(15),5,10(14)-trien-1-*α*-ol	1688	2.7	-	-	-	-	-	-	-	-	-	-
55	mint sulfide	1739	0.5	0.2	-	-	-	-	-	0.3	-	-	-
56	14-hydroxy-*δ*-cadinene	1803	0.1	-	-	-	-	-	-	-	-	-	-
57	2-pentadecanone, 6,10,14-trimethyl	1846	0.5	-	-	-	-	-	-	-	-	-	-
58	phytol	2115	1.3	0.9	11.4	0.9	-	-	-	-	-	-	-
59	pentacosane	2496	0.1	-	-	-	-	-	-	-	-	-	-
60	heptacosane	2695	0.3	-	-	-	-	-	-	-	-	-	-
61	nonacosane	2895	0.4	-	-	-	-	-	-	-	-	-	-
62	untriacontane	3095	0.3	-	-	-	-	-	-	-	-	-	-
63	tritriacontane	3296	0.1	-	-	-	-	-	-	-	-	-	-

Table 1. (continued)

Compound	[22]	[22]	[23]	[24]	[16]	[25]	[25]	[25]	[26]	[26]	[27]	[28]	[29]
α-pinene	-	1.0	2.7	-	3.0	0.1	1.0	0.5	5.7	2.3	1.0	-	3.3
sabinene	-	-	0.9	6.5	4.4	0.1	0.6	-	4.5	0.6	5.2	-	1.2
β-pinene	-	1.1	2.8	-	5.0	0.3	2.7	0.2	4.8	6.5	10.4	-	21.4
myrcene	-	0.3	0.9	1.2	1.9	0.2	0.6	0.7	3.0	1.4	0.9	-	1.2
p-mentha-1(7),8-diene	0.4	-	0.2	-	0.2	-	-	-	-	-	-	-	-
p-cymene	-	0.3	1.1	-	0.2	0.2	0.6	0.1	0.3	0.2	2.7	-	-
β-phellandrene	-	-	-	-	9.1	-	-	-	14.2	6.6	-	-	-
cis-*β*-ocimene	-	-	-	-	1.7	-	0.5	-	0.9	1.3	-	-	-
trans-*β*-ocimene	-	-	-	-	1.7	-	0.3	-	1.3	1.0	1.5	-	-
γ-terpinene	-	-	0.2	0.2	0.2	-	-	-	0.3	0.7	1.7	-	-
linalool	-	1.2	-	-	0.1	0.3	1.3	0.5	1.0	0.2	-	-	-
cosmene	-	-	-	-	-	-	-	-	-	-	-	-	-
terpinen-4-ol	-	-	-	-	0.3	0.1	0.6	-	0.3	0.2	2.0	-	-
α-terpineol	-	0.5	0.4	-	-	0.1	0.5	-	0.3	0.1	-	-	-
β-cyclocitral	-	-	-	-	-	-	-	-	-	-	-	-	-
α-cubebene	-	-	1.9	0.2	0.2	-	-	-	-	1.3	-	-	-
α-ylangene	-	0.6	0.4	-	-	-	-	-	-	-	-	-	-
α-copaene	-	0.8	1.7	0.4	0.3	0.5	0.7	0.5	0.1	0.6	0.7	-	5.4
β-bourbonene	-	0.5	2.0	0.8	0.2	0.7	0.7	0.6	1.6	0.5	-	1.0	1.7
β-cubebene	-	0.6	1.7	-	0.2	-	-	-	-	0.3	-	-	-
β-elemene	-	-	-	0.4	-	-	-	-	0.2	-	-	-	-
trans-caryophyllene	2.5	6.0	1.8	-	24.4	41.0	24.0	17.0	17.8	14.7	31.5	2.1	2.3
β-copaene	-	1.2	3.8	-	-	-	-	-	0.3	0.3	-	-	-
aromadendrene	-	0.3	0.6	2.2	0.1	-	-	2.4	-	-	-	-	5.1
α-humulene	1.1	2.5	-	-	8.6	14.0	8.1	5.4	10.2	7.7	0.6	-	-
trans-*β*-farnesene	-	-	0.8	-	-	-	0.8	-	-	-	-	-	-
cis-cadina-1(6),4-diene	-	-	-	-	-	-	-	-	-	-	-	-	-
trans-cadina-1(6),4-diene	-	-	-	-	-	-	-	-	-	-	-	-	-
γ-muurolene	-	-	-	-	-	-	-	-	-		-	1.4	1.1
germacrene D	15.8	12.1	13.8	9.5	0.2	13.0	6.4	3.5	5.2	8.7	16.2	1.2	1.2
β-selinene	-	-	0.4	-	-	-	-	-	-	-	-	-	-
trans-muurola-4(14),5-diene	-	-	-	-	-	-	-	-	-	-	-	-	-
bicyclogermacrene	1.0	2.2	3.3	2.7	6.3	13.0	1.7	21.0	4.0	6.4	1.5	-	1.6
α-muurolene	-	2.2	-	-	-	-	-	-	-	-	-	-	-
germacrene A	-	-	-	-	-	-	-	-	-	-	-	-	-
γ-cadinene	-	1.2	1.3	-	-	-	-	-	-	0.5	-	-	-
δ-cadinene	-	-	2.9	2.0	-	1.1	3.1	1.6	-	1.2	-	-	2.5
trans-cadina-1,4-diene	-	-	-	-	-	-	-	-	-	-	-	-	-
α-cadinene	-	-	0.3	-	-	-	-	-	-	-	-	-	-
trans-nerolidol	-	-	-	-	-	-	-	-	-	-	-	-	-
spathulenol	5.8	19.3	10.0	7.5	5.9	-	11.0	17.0	2.8	1.0	1.3	1.1	-
caryophyllene oxide	1.1	5.2	1.7	-	0.9	-	10.0	7.0	4.0	1.6	1.8	22.4	-
viridiflorol	-	-	-	-	0.1	-	-	-	-	0.8	-	-	-
salvial-4(14)-en-1-one	-	-	1.5	-	-	-	-	-	-	-	-	-	-
humulene epoxide II	0.9	4.7	0.2	-	-	1.6	1.7	-	-	-	-	-	-
1,10-di-*epi*-cubenol	-	-	-	-	-	-	-	-	-	-	-	-	-
junenol	-	-	-	-	-	-	-	-	-	-	-	-	-
1-*epi*-cubenol	-	-	-	-	-	-	-	-	-	-	-	-	-
cis-3-hexenyl phenyl acetate	-	-	-	-	-	-	-	-	-	-	-	-	-
α-muurolol (=Torreyol)	-	-	-	-	-	-	-	-	-	-	-	-	-
epi-*α*-murrolol (=*τ*-muurolol)	-	-	-	0.5	-	-	-	-	-	-	-	-	-
α-cadinol	-	-	-	1.8	0.2	-	-	-	-	-	-	-	2.6
valeranone	-	-	-	-	-	-	-	-	-	0.7	-	-	-
germacra-4(15),5,10(14)-trien-1-**α**-ol	-	-	-	-	-	-	-	-	-	-	-	-	-
mint sulfide	-	-	-	0.1	-	-	-	-	-	-	-	-	-
14-hydroxy-*δ*-cadinene	-	-	-	-	-	-	-	-	-	-	-	-	-
2-pentadecanone, 6,10,14-trimethyl	-	-	-	-	-	-	-	-	-	-	-	-	-
phytol	12.4	3.0	-	0.3	0.8	-	-	-	-	0.5	-	5.6	-
pentacosane	-	-	-	-	0.1	-	-	-	-	0.3	-	-	-
heptacosane	-	-	-	-	-	-	-	-	-	-	-	1.0	-
nonacosane	-	-	-	-	-	-	-	-	-	-	-	1.1	-
untriacontane	-	-	-	-	-	-	-	-	-	-	-	-	-
tritriacontane	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 1. (continued)

Compound	[30]	[30]	[30]	[30]	[30]	[30]	[30]	[31]	[31]	[31]	[32]	[33]	[34]
α-pinene	1.6	1.2	2.1	1.8	3.1	1.5	5.2	tr	tr	0.5	7.6	1.1	2.6
sabinene	0.8	0.4	0.6	0.4	1.0	0.2	4.9	tr	tr	-	-	0.4	2.7
β-pinene	1.5	0.9	4.0	2.4	8.1	1.1	29.0	tr	tr	-	30.7	0.6	5.1
myrcene	1.0	0.9	1.0	0.9	1.2	0.6	6.1	tr	tr	-	-	1.2	1.9
p-mentha-1(7),8-diene	-	-	-	-	-	-	-	-	-	-	-	-	-
p-cymene	-	-	-	-	-	-	-	-	-	-	23.0	2.2	-
β-phellandrene	-	-	-	-	-	-	-	tr	8.6	1.7	-	5.0	-
cis-*β*-ocimene	-	-	-	-	-	-	-	-	6.0	-	-	0.8	1.4
trans-*β*-ocimene	-	-	-	-	-	-	-	tr	7.5	-	-	0.7	1.4
γ-terpinene	-	-	-	-	-	-	-	-	-	-	1.9	0.4	0.2
linalool	1.7	3.3	2.8	5.0	2.6	1.6	3.7	tr	tr	-	-	1.9	-
cosmene	-	-	-	-	-	-	-	-	-	-	-		-
terpinen-4-ol	-	-	-	-	-	-	-	tr	tr	-	-	2.7	-
α-terpineol	-	-	-	-	-	-	-	tr	tr	-	-	-	-
β-cyclocitral	-	-	-	-	-	-	-	-	-	-	-	-	-
α-cubebene	-	-	-	-	-	-	-	tr	tr	0.5	-	-	0.3
α-ylangene	-	-	-	-	-	-	-	-	-	-	-	-	-
α-copaene	-	-	-	-	-	-	-	tr	tr	-	1.9	-	0.5
β-bourbonene	-	-	-	-	-	-	-	tr	tr	0.4	1.7	1.2	0.9
β-cubebene	-	-	-	-	-	-	-	-	-	8.6	-	-	0.3
β-elemene	-	-	-	-	-	-	-	tr	tr	1.1	-	-	-
trans-caryophyllene	65.3	64.5	62.2	64.0	58.3	68.5	20.2	13.4	19.0	10.2	-	13.3	24.7
β-copaene	-	-	-	-	-	-	-	-	-	-	-	-	-
aromadendrene	-	-	-	-	-	-	-	-	-	-	-	-	-
α-humulene	25.4	26.6	25.2	23.8	23.4	25.9	15.6	7.2	10.2	4.8	-	5.4	7.8
trans-*β*-farnesene	-	-	-	-	-	-	-	-	-	-	-	-	-
cis-cadina-1(6),4-diene	-	-	-	-	-	-	-	-	-	-	-	-	-
trans-cadina-1(6),4-diene	-	-	-	-	-	-	-	-	-	-	-	-	-
γ-muurolene	-	-	-	-	-	-	-	-	-	-	1.1	10.3	22.8
germacrene D	-	-	-	-	-	-	-	48.0	24.6	-	-	2.3	-
β-selinene	-	-	-	-	-	-	-	-	-	-	-	-	-
trans-muurola-4(14),5-diene	-	-	-	-	-	-	-	-	-	-	-	-	-
bicyclogermacrene	-	-	-	-	-	-	-	5.3	16.7	-	-	1.4	-
α-muurolene	-	-	-	-	-	-	-	-	-	1.0	-	-	-
germacrene A	-	-	-	-	-	-	-	-	-	-	-	-	-
γ-cadinene	-	-	-	-	-	-	-	tr	tr	1.3	-	-	-
δ-cadinene	-	-	-	-	-	-	-	6.0	tr	3.7	-	0.5	0.3
trans-cadina-1,4-diene	-	-	-	-	-	-	-	-	-	-	-	-	-
α-cadinene	-	-	-	-	-	-	-	-	-	-	-	-	-
trans-nerolidol	-	-	-	-	-	-	-	-	-	-	-	-	-
spathulenol	-	-	-	-	-	-	-	3.5	7.2	6.5	-	-	-
caryophyllene oxide	-	-	-	-	-	-	-	tr	tr	2.9	-	2.3	0.6
viridiflorol	-	-	-	-	-	-	-	-	-	-	-	-	-
salvial-4(14)-en-1-one	-	-	-	-	-	-	-	-	-	-	-	-	-
humulene epoxide II	-	-	-	-	-	-	-	-	-	-	-	0.5	-
1,10-di-*epi*-cubenol	-	-	-	-	-	-	-	-	-	-	-	-	-
junenol	-	-	-	-	-	-	-	-	-	-	-	-	-
1-*epi*-cubenol	-	-	-	-	-	-	-	-	-	-	-	-	-
cis-3-hexenyl phenyl acetate	-	-	-	-	-	-	-	-	-	-	-	-	-
α-muurolol (=Torreyol)	-	-	-	-	-	-	-	-	-	-	-	-	-
epi-*α*-murrolol (=τ-muurolol)	-	-	-	-	-	-	-	-	-	-	-	-	-
α-cadinol	-	-	-	-	-	-	-	10.4	tr	3.7	-	-	-
valeranone	-	-	-	-	-	-	-	-	-	-	-	-	-
germacra-4(15),5,10(14)-trien-1-*α*-ol	-	-	-	-	-	-	-	-	-	-	-	-	-
mint sulfide	-	-	-	-	-	-	-	-	-	-	-	-	-
14-hydroxy-δ-cadinene	-	-	-	-	-	-	-	-	-	-	-	-	-
2-pentadecanone, 6,10,14-trimethyl	-	-	-	-	-	-	-	-	-	-	-	-	-
phytol	-	-	-	-	-	-	-	-	-	-	-	-	-
pentacosane	-	-	-	-	-	-	-	-	-	-	-	-	-
heptacosane	-	-	-	-	-	-	-	-	-	-	-	-	-
nonacosane	-	-	-	-	-	-	-	-	-	-	-	-	-
untriacontane	-	-	-	-	-	-	-	-	-	-	-	-	-
tritriacontane	-	-	-	-	-	-	-	-	-	-	-	-	-

4. Discussion

According to the literature review, the chemical composition varies significantly depending on the origin of population [25;26;30;31], subspecies (i.e. ssp. *amasica* or ssp. *verticillata*) [19;20;21;23;28], plant part (aerial part, leaves, flowers) [2;19;35], sampling period [2], isolation and analysis method (simultaneous distillation and extraction by Likens-Nickerson, SFE-CO_2, headspace, etc.) [22;36].

A total of 39 different oil components were identified in three populations of *S. verticillata* from different locations in Serbia, but only 23 to 27 components were found in individual populations [31]. The dominant components in populations from Vrdnik and Rimski Sanac were germacrene D (48.0% and 24.6%, respectively) and *trans*-caryophyllene (13.4% and 19.0%, respectively), whereas the dominant components in population from Mount Tara were *trans*-caryophyllene (10.2%), β-cubebene (8.6%), and eicosane (8.5%).

In Iran, 64 constituents were identified in wild plants of *S. verticillata* with *trans*-caryophyllene (14.7%), α-gurjunene (12.8%), germacrene D (8.7%), α-humulene (7.7%), β-phellandrene (6.6%), β-pinene (6.5%) and bicyclogermacrene (6.4%) as the major constituents [26]. Furthermore, 51 components were specific for cultivated plants with *trans*-caryophyllene (17.8%), β-phellandrene (14.2%), α-humulene (10.2%), α-pinene (5.7%), germacrene D (5.2%) as the dominant constituents. In another study on *S. verticillata* conducted in Iran, 59 components were identified, with *trans*-caryophyllene (24.40%), β-phellandrene (9.08%), α-humulene (8.61%), bicyclogermacrene (6.32%), spathulenol (5.89%) and β-pinene (5.00%) as the dominant constituents [16]. Furthermore, 27 components were specific for *S. verticillata* from Iran, with β-caryophyllene (24.7%), γ-muurolene (22.8%), limonene (8.9%) and α-humulene (7.8%) as the dominant constituents [34]. In *S. verticillata* oil from Iran, sesquiterpenoids were the major compound group, including *trans*-caryophyllene (31.5%) and germacrene D (16.2%), followed by limonene (15.5%), α-pinene (10.4%) and α-humulene (9.4%) [37]. *S. verticillata* essential oil from Iran contained primarily *trans*-caryophyllene (18.8%), germacrene D (9.5%), spathulenol (7.5%), sabinene (6.5%), and bicyclo [3.1.1] heptane,6,6-dime (6.0%) among the 65 identified components, comprising 96.1% of the total elements in the oil of the herb [24].

In water-distilled essential oil was obtained from the dried aerial parts of *S. verticillata* L. subsp. *verticillata* from the southeastern region of Turkey a total 39 components were identified, with spathulenol (31.0%), α-pinene (8.2%), limonene (4.1%) and hexahydrofarnesyl acetone (3.8%) as the main constituents [21]. *S. verticillata* subsp. *amasiaca* from Turkey exhibited high levels of germacrene D (36.6%), β-caryophyllene (7.6%), hexadecanoic acid (6.7%), and β-copene (5.7%) [28].

A total of 28 components were specific for *S. verticillata* from Greece, with β-pinene (30.7%), *p*-cymene (23.0%), and isopropyl ester of lauric acid (16.8%) as the dominant constituents [32].

It was established that the chemical composition of *S. verticillata* essential oil from the Czech Republic depends on the population. In one population, the dominant compounds were *trans*-caryophyllene (57.6%) and α-humulene (23.7%); in another population β-pinene (29.0%) and limonene (14.0%) were the dominant ones [30].

5. Conclusions

Although there is a significant difference in the chemical composition of *S. verticillata* essential oil depending on many factors (origin of population, subspecies, plant part, sampling period, isolation and analysis method, etc.), almost all samples exhibit the dominance of sesquiterpenes as the dominant class of compounds. Sesquiterpenes have been reported to possess numerous pharmacological activities, therefore it can be assumed that the biological potential of *S. verticillata* originates from sesquiterpenes, primarily germacrene D, *trans*-caryophyllene, α-humulene, and others.

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