

GC-MS Characterization and Biomedical Prospects of Essential Oils from Three *Salvia* spp.

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This study aimed to analyze the volatile compound compositions of three cultivars of *Salvia* spp. (*Salvia officinalis* 'Maxima', *Salvia farinacea* 'Victoria Blue', and *Salvia yangii* 'Blue Steel') grown in Ukraine, with a focus on their chemotaxonomic features. To the best of our knowledge, the essential oil compositions of the above-mentioned *Salvia* cultivars are presented herein for the first time. Based on their gas chromatography-mass spectrometry (GC-MS) profiles, 49 volatile compounds were identified in the essential oil of *Salvia officinalis* 'Maxima', 41 in *Salvia farinacea* 'Victoria Blue', and 32 in *Salvia yangii* 'Blue Steel'. The essential oils of all three species were represented predominantly by monoterpenoids. Among the oxygenated monoterpenoids, 1,8-cineole was the major compound found in the essential oils of *Salvia yangii* 'Blue Steel' (16.34%) and *Salvia officinalis* 'Maxima' (14.26%). *Cis*-salvene, an acyclic monoterpene hydrocarbon, was the major component of *Salvia farinacea* 'Victoria Blue' (12.68%) and *Salvia yangii* 'Blue Steel' (11.51%). The monocyclic monoterpene D-limonene was exclusively identified in the essential oil of *Salvia farinacea* 'Victoria Blue' (12.01%). Among the bicyclic monoterpenoids, α -thujone and borneol were prominent constituents in both *Salvia farinacea* 'Victoria Blue' and *Salvia officinalis* 'Maxima'. Meanwhile, the bicyclic monoterpenes α - and β -pinene were found in significant quantities across all three studied cultivars. It was found that the studied taxa exhibit substantial differences in the qualitative composition of their minor components. Based on the ratio of the predominant compounds in the essential oils, the certain chemotypes of the analyzed cultivars were determined. Considering the proven therapeutic properties of the dominant components of essential oils, the studied taxa could serve as valuable sources of phytosubstances for the development of new medicinal herbal products.

Keywords: Chemotaxonomic peculiarities, Essential oil, Gas chromatography-mass spectrometry, Sage, Terpenoids, Volatile compounds.

The Mint (*Lamiaceae* Martinov) family is one of the largest families of flowering plants, encompassing over 7,000 species distributed

worldwide.¹ Its largest subfamily is *Nepetoideae*, which includes 105 genera and 3,600 species. Some of the best-known genera are *Salvia* L.,

Thymus L., *Satureja* L., *Ocimum* L., *Mentha* L., and *Lavandula* L.¹⁻³

The genus *Salvia* (sage) includes approximately 1,000 species of herbaceous and semi-woody plants distributed around the globe.⁴⁻⁸ Species within this genus are recognized for their diverse morphological characteristics, particularly their distinctive inflorescences. As it was summarized recently, some *Salvia* species are economically significant as sources of medicine, spices, and flavorings, while others are cultivated for ornamental purposes.^{8,9} Various studies have shown that *Salvia* species possess significant health benefits, including antioxidant, anti-inflammatory, astringent, antimicrobial, anticancer, and antidiabetic activities.¹⁰⁻¹² Ornamental *Salvia* varieties and cultivars are particularly prized for their diverse fragrances and vibrant colors, making them popular choices for gardens and flower beds.¹³ They are also attracting the attention of scientists in terms of their chemical composition and potential medicinal properties.

Plants of the genus *Salvia* accumulate various secondary metabolites, such as terpenoids, flavonoids, and phenolic acids.¹⁴ These compounds exhibit a wide range of biological activities and are used in the pharmaceutical industry due to their therapeutic properties, as well as in the food industry as natural preservatives and additives. However, only a few *Salvia* spp. have been investigated comprehensively from the phytochemical point of view. The primary challenge researchers face is selecting suitable phytochemical markers for the quality control of herbal medicinal products.^{15,16}

Terpenoids, especially the volatile compounds, are important secondary metabolites in *Salvia* species and play a crucial role in their biological activities.^{8,17-19} While some studies have focused on specific *Salvia* species, the majority have concentrated on those with established medicinal uses or commercially available raw materials. Certain species of the genus *Salvia* are known to be valuable sources of essential oils used in medicine, cosmetics, and perfumery. It is estimated that the production volume of essential oil from pharmacopoeial species (*Salvia officinalis*, *S. sclarea*, and *S. lavandulifolia*) reaches several tons per year.^{20,21}

As it is known, the production and

accumulation of bioactive secondary metabolites in plants are influenced by both genetic and environmental factors. Essential oils are mixtures of secondary metabolites that plants produce as part of their defense mechanisms in response to various biotic and abiotic stressors. Therefore, any change in the environment causes essential oil-bearing plants to change their chemical composition.²³ Thus, it is important to compare the essential oil content and composition of different sage taxa under the same cultivation conditions. To obtain essential oils with a consistent chemical composition and stable medicinal properties from a particular *Salvia* cultivar, it is not sufficient to select an appropriate variety (genotype); it is also necessary to strictly control the geographical area and cultivation condition and harvest the plants at a clearly defined phenophase.²⁴

Nowadays, it is important to highlight the lack of comparative chromatographic analyses of various *Salvia* cultivars grown under uniform environmental conditions. This gap in research underscores the need for more comprehensive studies in this area. In our ongoing comparative research on phytochemicals from medicinal and aromatic plants, we selected three taxa of *Salvia* to examine the essential oil compositions of their leaves using the GC-MS method. The studied taxa include *Salvia officinalis* 'Maxima', *Salvia yangii* 'Blue Steel', and *Salvia farinacea* 'Victoria Blue'; additionally, we established the chemotypes of the studied cultivars. In this context, the abovementioned cultivars were investigated for the first time.

MATERIALS AND METHODS

Plant raw material

The plants (*Salvia officinalis* 'Maxima', *Salvia yangii* 'Blue Steel', and *Salvia farinacea* 'Victoria Blue') were grown in experimental plots located in the Ternopil region of Ukraine. Voucher specimens of these plants are stored at the Department of Pharmacognosy and Medical Botany at I. Horbachevsky Ternopil National Medical University (Ternopil, Ukraine). The leaves were collected during the flowering period in June 2026 and then were dried in the shade at temperatures not exceeding 35°C.

Table 1. Volatile components of the studied *Salvia* cultivars revealed by GC-MS

Compound	Retention time,min	<i>Salvia</i> <i>farinacea</i> ‘Victoria Blue’	Content (%) <i>Salvia</i> <i>yangii</i> ‘Blue Steel’	<i>Salvia</i> <i>officinalis</i> ‘Maxima’
1	2	3	4	5
Cyclene	6.5	-	-	1.34
Tricyclene	6.6	-	0.27	-
α -Thujene	6.8	0.44	-	0.99
α -Pinene	6.9	6.92	17.23	7.14
1-octene-3-ol	7.4	9.75	tr	-
Camphene	7.4	0.11	6.04	8.65
β -Thujene	7.6	tr	-	0.29
β -Pinene	8.2	8.17	3.43	7.30
β -Myrcene	8.6	2.42	1.78	3.44
α -Phellandrene	8.9	0.10	0.33	0.37
(+)-3-Carene	9.1	-	4.57	-
2-Carene	9.3	0.29	1.96	0.78
p-Cymene	9.5	0.38	-	-
D-Limonene	9.7	12.01	-	-
1,8-Cineole	9.8	tr	16.34	14.26
β -Ocimene	9.9	0.73	0.39	1.16
γ -Terpinene	10.5	-	5.82	1.24
<i>cis</i> -Sabinene hydroxide	10.7	0.16	-	0.16
Linalool oxide	10.8	-	-	tr
α -Terpinolenå	11.2	0.47	0.66	0.84
α -Thujone	11.8	10.58	0.27	8.77
β -Thujone	12.0	1.51	-	2.06
<i>Cis</i> -Salvene	12.6	12.68	11.51	-
Camphor	12.8	0.18	0.29	9.20
Isoborneol	12.9	-	-	0.18
<i>trans</i> -Pinocamphone	13.0	0.73	-	1.10
Borneol	13.2	6.44	1.59	8.28
Terpinen-4-ol	13.4	0.27	-	-
α -Terpineol	13.7	tr	-	0.15
Myrtenol	13.9	0.50	-	0.52
Verbenone	14.2	tr	-	tr
Cyclofenchene	15.1	-	-	0.61
Bornyl acetate	15.8	3.10	1.72	-
p-Thymol	15.9	-	0.56	-
Tridecane	16.0	Inner standard		
α -Terpinene	17.1	-	0.87	0.40
Ylangene	17.5	-	-	0.78
α -Copaene	17.6	0.44	0.53	1.30
<i>cis</i> -Muurolo-3.5-diene	17.8	tr	-	0.11
1H-Cyclopropazulene	18.1	0.19	-	0.15
α -Gurjunene	18.3	-	tr	0.32
Caryophyllene	18.5	-	4.20	2.03
β -Copaene	18.7	0.45	-	0.80
Maaliene	18.8	-	-	0.39
Aromandendrene	18.9	3.12	-	2.15
Selinene	19.0	0.26	-	0.31
γ -Cadinene	19.1	5.05	-	0.14
Humulene	19.2	-	2.34	3.98

Alloaromadendrene	19.3	0.22	tr	0.25
γ -Muurolene	19.5	0.87	0.12	1.11
Germacrene D	19.6	1.30	0.62	-
β -Selinene	19.7	-	tr	0.12
β -Maaliene	19.8	-	0.22	0.92
α -Muurolene	19.9	0.22	-	0.19
δ -Cadinene	20.1	-	0.42	0.11
γ -Cadinene	20.2	0.30	-	0.34
Cadina-1(6),4-diene	20.3	1.09	-	1.19
β -Panasinsene	20.7	-	0.54	-
Spatulenol	21.3	-	-	0.13
Caryophyllene oxide	21.6	1.41	1.31	1.09
β -Elemene	25.1	0.64	-	-
Manool	28.5	-	-	0.69
Total amount		93.50	86.29	97.83

Note: 'tr' – the concentration of the component in the sample was less than 0.10%; '-' – the component was not detected

GC-MS analysis

For the analysis of volatile compounds in the studied raw materials, we employed gas chromatography-mass spectrometry (GC-MS). An Agilent Technologies 6890 gas chromatograph, equipped with an HP-5ms capillary column and a mass spectrometric detector, was used for this analysis.⁶ Tridecane served as the internal standard.

RESULTS

Based on their mass spectra and retention times, 41 volatile compounds were identified in the essential oil of *Salvia farinacea* 'Victoria Blue', 32 in *Salvia yangii* 'Blue Steel' and 49 in *Salvia officinalis* 'Maxima' (Table 1, Figures 1-3).

The total content of the identified components was in the range of 86.29-97.83%, depending on the species. As it can be seen from Table 1, the volatiles of the studied cultivars were represented mainly by monoterpene hydrocarbons, oxygen-containing monoterpenoids, sesquiterpene hydrocarbons, and oxygen-containing sesquiterpenoids. The major volatile components of the studied taxa are presented in Figures 4-6.

Among the oxygenated monoterpenoids, 1,8-cineole was the predominant compound found in the essential oils of *Salvia officinalis* 'Maxima' and *Salvia yangii* 'Blue Steel'. *Cis*-Salvene, an acyclic monoterpene hydrocarbon, was the key component of *Salvia farinacea* 'Victoria Blue' and *Salvia yangii* 'Blue Steel'.

The monocyclic monoterpene D-limonene was exclusively identified in the essential oil of *Salvia farinacea* 'Victoria Blue'. Among the bicyclic monoterpenoids, α -thujone and borneol were prominent constituents in both *Salvia farinacea* 'Victoria Blue' and *Salvia officinalis* 'Maxima'. Meanwhile, α -pinene and β -pinene were found in significant quantities across all three studied cultivars. Regarding sesquiterpenoids, the moderate humulene content was found in *Salvia farinacea* 'Victoria Blue' (5.05%) and *Salvia officinalis* 'Maxima' (3.98%), and caryophyllene in *Salvia yangii* 'Blue Steel' (4.20%). Thus, the essential oils of all three taxa are represented mainly by monoterpenoids. It is important to note that the cultivars examined exhibit substantial differences in the qualitative composition of their minor components.

Based on the qualitative composition of major components in the essential oils, the chemotypes of the studied taxa were determined. Thus, the chemotype of the *Salvia farinacea* 'Victoria Blue' is *cis*-salvene/D-limonene/ α -thujone/1-octene-3-ol/ β -pinene. *Salvia yangii* 'Blue Steel' is represented by the chemotype α -pinene/1,8-cineole/*cis*-salvene/camphene, and *Salvia officinalis* 'Maxima' by 1,8-cineole/camphor/ α -thujone/camphene/borneol.

DISCUSSION

As has been established by a large number

of studies, the content and qualitative composition of essential oils of the *Nepetoideae* taxa depend on many factors: the place of growth, altitude, climatic conditions (temperature, amount of precipitation), soil composition, genetic features, the phase of vegetation and the plant organ chosen

for analysis.^{24,25} The production of terpenoids is also determined by the influence of the ecological factors, since these compounds serve as a protective mechanism for plants against microorganisms, insects, and herbivorous animals. Therefore, various chemotypes of *Salvia* spp. reflect the

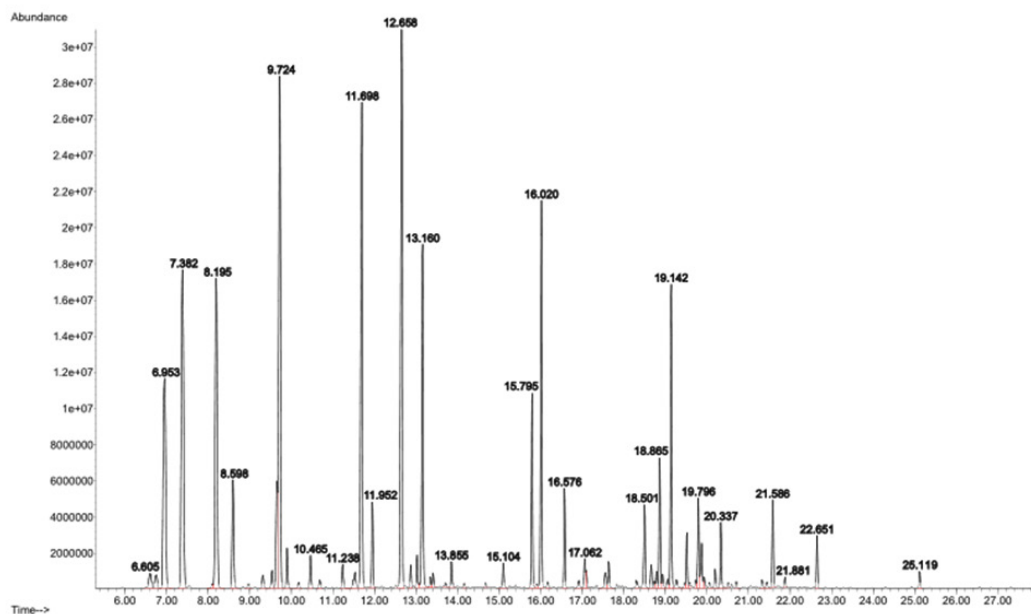


Fig. 1. GC-MS chromatogram of the *Salvia farinacea* 'Victoria Blue' essential oil

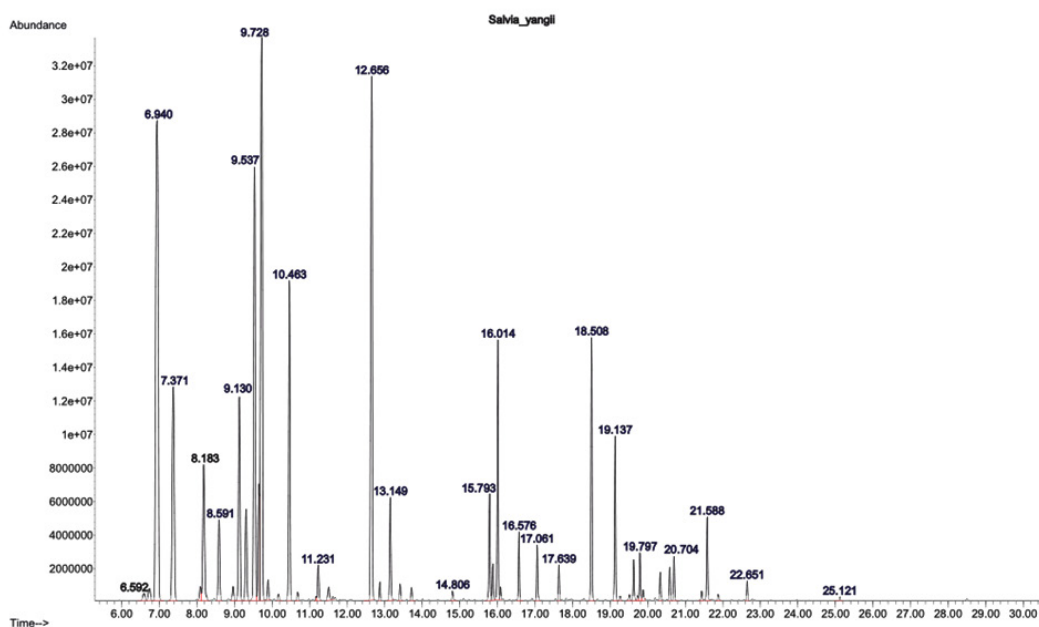


Fig. 2. GC-MS chromatogram of the *Salvia yangii* 'Blue Steel' essential oil

natural chemical variability of essential oils, driven by genetic and environmental factors. Their determination is important for the standardization of raw materials in pharmacy, aromatherapy, and cosmetology, since the qualitative composition of the essential oil directly affects its aromatic,

therapeutic, and toxicological properties. Thus, Craft *et al.* in their studies of *Salvia officinalis* identified several chemotypes, among which the dominant one was α -thujone/camphor/1,8-cineole.²⁶ Other studies of European populations of *Salvia officinalis* have described three basic

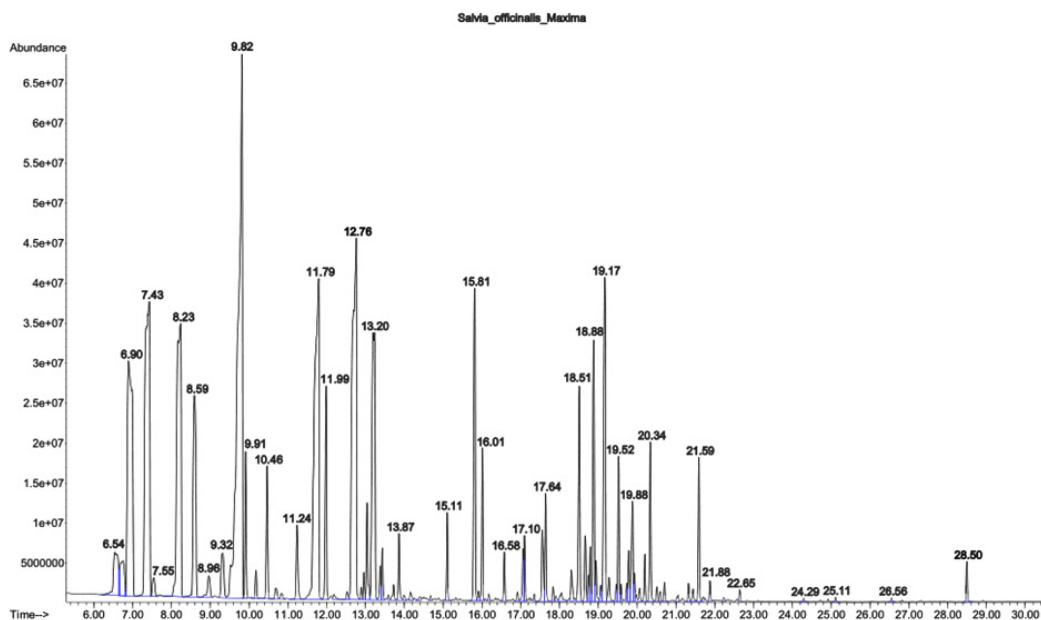


Fig. 3. GC-MS chromatogram of the *Salvia officinalis* 'Maxima' essential oil

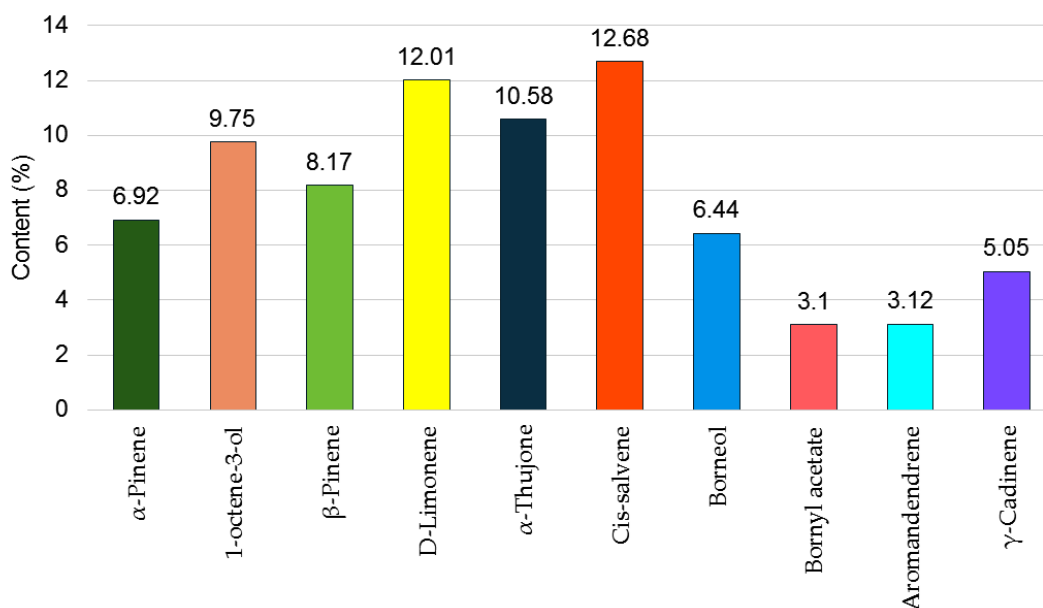


Fig. 4. Ratio of dominant volatile components of the *Salvia farinacea* 'Victoria Blue' leaves

chemotypes: α -pinene/camphor/ β -thujone, α -thujone/camphor/1,8-cineole, and β -thujone/camphor.²⁷

It should be noted that, according to the European Pharmacopoeia, 1,8-cineole, α -thujone, and β -thujone are the key markers for quality identification of *Salvia officinalis* leaves.²¹

Generally, our studies showed results for the cultivar 'Maxima' of *Salvia officinalis* that are largely consistent with the Pharmacopoeia data.

The main volatile constituents of *Salvia officinalis* collected in Uzbekistan were *cis*-thujone (18.6%), camphor (12.2%), 1,8-cineole (8.9%), and α -humulene (6.1%).²⁸ Tundis *et al.*²⁹ announced that

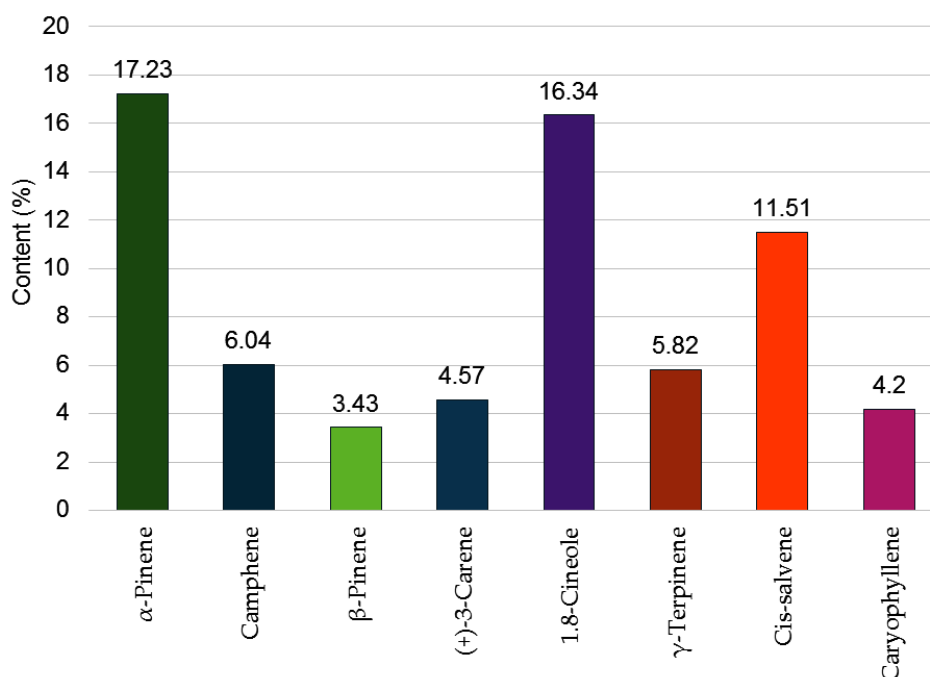


Fig. 5. Ratio of dominant volatile components of the *Salvia yangii* 'Blue Steel' leaves

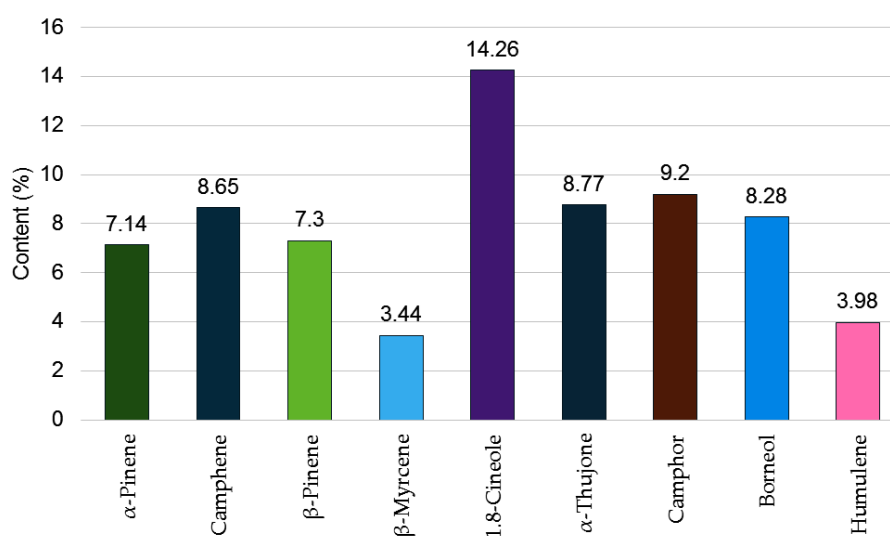


Fig. 6. Ratio of dominant volatile components of the *Salvia officinalis* 'Maxima' leaves

the Southern Italian populations of *Salvia officinalis* may represent distinct varieties within the species' variability, located at the southwestern edge of its native distribution area. Chromatographic analyses of the essential oils showed that oxygenated monoterpenes are the predominant class of constituents across all studied populations, with camphor and 1,8-cineole being the most abundant compounds.²⁹ The essential oils isolated from the *Salvia officinalis* aerial part collected in Croatia were mixtures of terpene compounds, among which dominated α -thujone, β -thujone, 1,8-cineol and camphor.³⁰

Seven populations of *Salvia officinalis* native to Greece were evaluated using modern metabolomic tools to identify the most promising genotypes.³¹ Based on the composition of their essential oils, the detected populations were classified into two chemotypes: 1,8 cineole/ α -thujone and α -thujone/1,8 cineole. Mot *et al.*³² identified two distinct chemotypes of *Salvia officinalis* from Romania based on chemical composition of the essential oils. The first chemotype was characterized by a high dominance of terpenoids, with their content decreasing in the following order: α -thujone, camphor, 1,8-cineole, and β -thujone. In contrast, the second chemotype had a greater abundance of 1,8-cineole, followed by borneol and α -thujone. In samples of *Salvia officinalis* 'La Marsa' leaves collected in the North of Tunisia, the camphor content was 33.61%, and 1,8-cineole was 22.22%.³³ Among several *Salvia* spp. from Greece, *Salvia officinalis* and *Salvia tomentosa* exhibited the highest percentages of thujones.⁷

Generally, the content of thujone among the members of the genus *Salvia* varies significantly. In particular, 18.83% of α -thujone and 4.46% of β -thujone were found in the essential oil of *Salvia officinalis* from Tunisia,³⁴ while in samples of the same species from other regions its content was 7.2-27.4%.^{26, 33} In commercial samples of the *Salvia officinalis* leaves from several European regions, the content of α -thujone ranged from 3.0 to 34.0%, and β -thujone from 1.5 to 12.9%.³⁵ At the same time, α -thujone was the main compound in all commercial *Salvia officinalis* essential oil samples from Romania, where its concentration was 31.23-52.86%.³⁶

It is worth noting that the bioactive

components of such representatives of the sage genus as *Salvia farinacea* and *Salvia yangii* have been studied scientifically an order of magnitude less than those of *Salvia officinalis*. The volatile oil components of *Salvia farinacea* grown in various Turkish regions with distinct climatic conditions and soil types showed significant variation.³⁷ The primary constituents included caryophyllene, which was found at levels ranging from 4.50% to 18.92% in Çanakkale and from 10.64% to 15.97% in Balýkesir during the first and second years of study. Additionally, β -bisabolene was present in Çanakkale at concentrations of up to 11.74% in both the first and second years.

The aerial part of *Salvia farinacea* collected from the Dallas Arboretum and Botanical Garden (Texas, USA) was characterized by dominating 1-octen-3-ol (30%) and (Z)-3-hexenal (23%) in the essential oil.¹³ The flowers of Italian *Salvia farinacea* were characterized by the highest soluble sugars among phytonutritional compounds investigated in the edible flowers of different plant species.³⁸ Afonso *et al.* found that the decoction from the aerial parts of *Salvia farinacea* 'Victoria Blue', collected in Portugal, was rich in polyphenols and exhibited significant antioxidant, anti-inflammatory, cytotoxic, and antimicrobial activities.³⁹

Recent findings indicate that mycorrhizal colonization modulates the essential oil profile and antioxidant properties of *Salvia yangii* and *Salvia abrotanoides*, which formerly were classified under the genus *Perovskia*, harvested in Iran. It was due to the adverse effects of water deficit.²² Root colonization showed a positive correlation with relative water content and leaf phosphorus concentration. When considering essential oil compositions, colonization by arbuscular mycorrhizal fungi increased the levels of certain essential oil components, including oxygenated monoterpenes such as camphor, 1,8-cineol, and borneol. In contrast, the main sesquiterpenes, such as α -humulene and E- β -caryophyllene, significantly decreased.²²

The revealed predominant volatile compounds of the studied *Salvia* representatives (see Table 1) has been shown to exhibit prominent biomedical potential. Many of them possess the antioxidant, anti-inflammatory, and antimicrobial effects against various bacteria and fungi.⁴⁰ The

oxygen-containing monoterpene 1,8-cineole also exhibits bronchodilating, analgesic, and proapoptotic effects. 1,8-cineole is used for such conditions as depression, epilepsy, peptic ulcer disease, diarrhea, heart diseases related to the cardiovascular system, and diabetes mellitus.⁴¹ Limonene has healing properties that help prevent various chronic and degenerative diseases, including anti-inflammatory, antioxidant, antidiabetic, anticancer, cardioprotective, hepatoprotective, immune modulatory, and anti-genotoxic effects.⁴² Limonene and α -pinene have shown antioxidant, antidiabetic, and skin-protective properties.⁴³ In general, antioxidant activity of various substances is a key mechanism in suppressing a variety of health disorders.⁴⁴

Camphor demonstrates an antibacterial/antifungal effect that may be indirectly related to its anti-inflammatory properties (reduction of the inflammatory microenvironment), and the synergism between camphor and 1,8-cineole enhances the antimicrobial effect.⁴⁵ Camphene exhibits anti-inflammatory and analgesic effects.⁴⁶

Lee *et al.*⁴⁷ investigated the anticancer properties of α -thujone and β -thujone, finding that both compounds inhibited the proliferation of cancer cells and induced cell death through caspase-dependent intrinsic apoptotic pathways. Their research demonstrated the therapeutic potential of α -thujone and β -thujone in treating human ovarian cancer. However, these monoterpene ketones have neurotoxic properties which somewhat limits the scope of their application.⁴⁸ Borneol possesses various pharmacological properties and is especially beneficial for treating cardio-cerebrovascular disorders.⁴⁵ Its important role in enhancing drug delivery and increasing bioavailability has garnered significant attention. Moreover, borneol is also widely used in the industries for daily chemicals, fragrances, and flavors.⁴⁹

CONCLUSIONS

The chemical profiles of volatile compounds in the leaves of three *Salvia* cultivars (*Salvia officinalis* 'Maxima', *Salvia farinacea* 'Victoria Blue', and *Salvia yangii* 'Blue Steel') cultivated under uniform conditions in western Ukraine are reported here for the first time. Based

on the ratio of the predominant compounds in the essential oils, certain chemotypes of the studied taxa were determined. Thus, the chemotype of the *Salvia farinacea* 'Victoria Blue' is *cis*-salvene/D-limonene/ α -thujone/1-octene-3-ol/ β -pinene. *Salvia yangii* 'Blue Steel' is represented by the chemotype α -pinene/1,8-cineole/*cis*-salvene/camphene, and *Salvia officinalis* 'Maxima' by 1,8-cineole/camphor/ α -thujone/camphene/borneol chemotyp. The distinct traits of the studied taxa highlight their considerable potential for further research into their bioactivities.

This study highlights the unique chemotaxonomic characteristics of the examined *Salvia* taxa. Future research on these cultivars should focus on analyzing their polyphenolic compounds and pharmacological properties. Such research will contribute to establishing a scientific basis for the standardization of raw materials derived from these cultivars.

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Conflict of interest

The authors declare no conflict of interest.

Data Availability

This statement does not apply to this article.

Ethics Statement

This research did not involve animal subjects, human participants, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Permission to reproduce material from other sources

Not Applicable.

Clinical trials

This research does not involve any clinical trials.

Author Contributions

Mariia Shanaida: conceptualization, methodology, resources, analyses, writing (original draft); Tetiana Gontova: reference search, interpretation of the data, writing (original draft); Mariana Chubka: interpretation of the data, writing – review & editing; Iryna Krut: reference search, interpretation of the data; Mariia Svyshch: reference search, interpretation of the data; Yurii Shanaida: software (visualization), writing – review & editing.

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