RESEARCH ARTICLE **(Open Access)**

Essential Oil Composition of Wild *Satureja montana L.* Collected from Mali i Balgjajt, Burrel, Albania

ERJON MAMOÇI[1], ELTON BASHA[2,*], SANIJE ZEJNELHOXHA[1], VILMA GURAZI[1], ANISA PEÇULI[2]

[1]Department of Food Science and Biotechnology, Agricultural University of Tirana, Tirana, Albania.

[2] Department of Agri-Food Technology, Agricultural University of Tirana, Tirana, Albania.

*Corresponding author; E-mail: ebasha@ubt.edu.al

Abstract

The present study evaluates the chemical composition of the essential oil of wild *Satureja montana* L. collected from Mali i Balgjajt, Burrel, Albania, at approximately 1000 m altitude. Aerial parts were harvested during the flowering stage and subjected to hydrodistillation using a Clevenger-type apparatus. The essential oil was analyzed by Gas Chromatography–Mass Spectrometry (GC-MS) for qualitative and semi-quantitative characterization. Forty-seven compounds were identified, representing 83.18% of the total oil composition. The oil was dominated by oxygenated monoterpenes (41.18%) and monoterpene hydrocarbons (33.22%), while sesquiterpene fractions were present in lower amounts. The major constituents were thymol (15.8%), γ-terpinene (9.8%), p-cymene (8.6%), cis-sabinenehydrate (4.1%), and carvacrol (3.7%). The compositional profile indicates a thymol-dominant chemotype with moderate carvacrol content. Although the EO yield was relatively low (0.1% v/w), the high proportion of phenolic monoterpenes suggests strong antimicrobial and antioxidant potential. The results highlight the influence of ecological and geographic factors on chemotypic variability and contribute to the characterization of Albanian wild populations. These findings support the potential application of this essential oil in pharmaceutical, cosmetic, and natural food preservation industries.

Keywords: *Satureja montana*, essential oil, thymol, carvacrol, natural preservatives.

1. Introduction

Satureja montana L. (*Lamiaceae*), commonly known as winter savory, is a perennial aromatic subshrub widely distributed in the Mediterranean basin and the Balkan Peninsula. The genus *Satureja* comprises more than 30 species, many of which are characterized by high essential oil (EO) content and remarkable biological activities. Among them, *S. montana* is one of the most extensively studied due to its rich content of phenolic monoterpenes, particularly thymol and carvacrol, which are responsible for its strong antimicrobial and antioxidant properties [2,6].

EOs from *S. montana* have demonstrated significant antibacterial, antifungal, antiviral, antioxidant, anti-inflammatory, and antispasmodic activities [2,3]. These properties have stimulated growing interest in their application as natural preservatives in food systems, as alternatives to synthetic additives, and as active ingredients in phytopharmaceutical and cosmetic formulations. The phenolic compounds thymol and carvacrol are especially recognized for their ability to disrupt microbial cell membranes, alter permeability, and interfere with enzyme activity, leading to microbial inhibition or cell death [3,5].

The chemical composition of *S. montana* EO is known to vary considerably depending on geographic origin, climatic conditions, altitude, soil characteristics, phenological stage, harvesting time, and genetic background [7,8,9,13]. Several chemotypes have been described, predominantly thymol-type, carvacrol-type, or mixed thymol/carvacrol-type chemotypes [6,9]. In Balkan populations, pronounced intra- and inter-population variability has been documented, suggesting strong environmental influence combined with genetic polymorphism [7,8].

Altitude is considered a particularly influential ecological factor. Plants growing at higher elevations are often exposed to increased UV radiation, temperature fluctuations, and water stress, conditions that may stimulate the biosynthesis of secondary metabolites, including phenolic monoterpenes [9].

*Corresponding author: Elton Basha; E-mail: ebasha@ubt.edu.al
(Accepted for publication 13.01.2026)
***ISSN**: 2218-2020,*

Furthermore, the biosynthetic pathway linking γ-terpinene and p-cymene as precursors to thymol and carvacrol may be modulated by environmental stress and enzymatic regulation, resulting in distinct compositional profiles [5].

Although several studies have investigated *S. montana* populations in neighboring countries such as Greece, Serbia, Montenegro, and Kosovo [7,9,12], data concerning Albanian wild populations remain relatively limited. Previous investigations in Albania have demonstrated substantial chemical variability, particularly in thymol and carvacrol content [8,13]. However, certain mountainous regions, including Mali i Balgjajt near Burrel, remain underexplored despite their ecological particularities and potential as reservoirs of unique chemotypes.

Characterizing the chemical profile of essential oils from these wild populations is crucial not only for biodiversity valorization but also for identifying chemotypes with enhanced industrial and pharmacological potential. Therefore, the aim of the present study was to determine the essential oil composition of wild *S. montana* collected from Mali i Balgjajt, Burrel, Albania, and to evaluate its chemotypic characteristics in relation to previously reported Balkan populations.

2. Material and Methods

2.1. Plant material collection and essential oil extraction

S. montana plants were collected in August, 2023, from Mali i Balgjajt, located near Burrel, Albania, Latitude 41.3529 (N) Longitude 20.0835 (E). The sampling site is situated at approximately 1000 meters above sea level. The identification of plant material was carried out by the Genetics and Plant Breeding Laboratory, Agricultural University of Tirana, Albania, where was deposited also the herbarium specimen voucher. The plant material was dried in a well−ventilated, shaded area, at room temperature about 25 °C and relative humidity around 50%. The EO was extracted by hydrodistillation using a Clevenger apparatus. One hundred grams of dried plant material (leaves), were minced finely and put into a one-liter flask with half a liter of distilled water. Distillation went on for three hours at a rate of three millilitres per minute. The oil yield was calculated as a percentage of volume by weight (% v/w) relative to the dry weight of the plant material. The obtained EOs were stored at 4 °C prior to analysis.

2.2. Gas Chromatography-Mass Spectrometry (GC-MS) Analysis

The chemical composition of the EO was analyzed by gas chromatography-mass spectrometry (GC-MS), using a Shimadzu GC-2010 system connected to a GCMS-QP2010 mass spectrometer detector (Shimadzu Corporation, Kyoto, Japan). Chromatographic separation was performed using a HP-5MS (5% phenyl-methylpolysiloxane) capillary column with typical dimensions of 30 m × 0.25 mm (inner diameter) and a film thickness of 0.25 µm. The analyses were performed in a standard manner with an ionization energy of 70 eV. The column temperature program was with an initial temperature of 60 °C, gradually increasing by 5 °C/min, up to a final temperature of 250 °C. Helium was used as the carrier gas with a flow rate of 1.0 mL/min. The injection volume for each sample was 1 µL. Arithmetic indices (AI) for all compounds were determined using a homologous series of n-alkanes (C9–C25) as standards. The retention time of each compound was used to calculate the Arithmetic Indices (AI) and were determined according to the method described by Van den Dool and Kratz (1963) [14], using a series of n-alkane standards. Identification of compounds was based on comparison of mass spectra with the NIST21 and NIST107 databases [11], comparison of retention indices with data reported in the literature (Adams, 2007) [1] and co-chromatography, when necessary, with authentic compounds provided by Fluka and Sigma-Aldrich (Buchs SG, Switzerland). Compounds were considered identified when the matching of spectra and retention indices was consistent with the reference literature. The relative concentrations of individual components were calculated based on the chromatographic peak areas (GC peak areas), without the application of correction factors, and were expressed as relative percentages (%) of the total components.

3. Results and Discussion

The EO yield obtained from *S. montana* collected at approximately 1000 m altitude was 0.1% (v/w), and the oil presented a pale-yellow coloration. This yield is lower than those reported for several Balkan and Mediterranean populations. Čopra-Janićijević et al. (2020) [4] reported yields around 0.3%, while Navarro-Rocha et al. (2020) [12] documented approximately 0.45% in Spanish populations. However, wide variability has been described, with Hajdari et al. (2016) [7] reporting yields ranging from 0.02% to 1% across populations from Kosovo, Albania, and Montenegro. Such variability supports the hypothesis that essential oil productivity is strongly influenced by ecological conditions, including altitude, soil type, water availability, and microclimatic stress.

It is well established that the accumulation of volatile secondary metabolites may fluctuate during flowering and vegetative phases [9] and the phenological stage of plant at harvest, , flowering, was appropriate for high EO yield.

The relatively low yield observed in this study may be associated with high-altitude ecological stress, soil nutrient or water limitations. Additionally, genetic variability within wild populations may influence glandular trichome density and oil biosynthesis capacity.

The GC-MS chromatogram of the sample is shown in Figure 1.

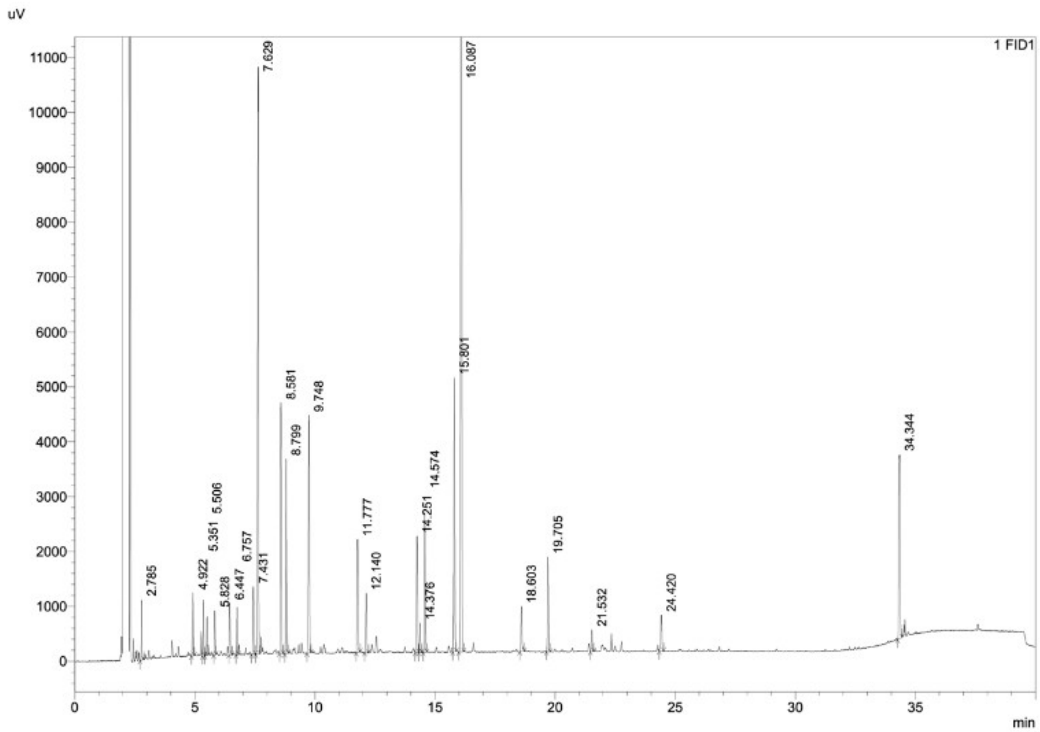

Figure 1. GC-MS chromatogram of *S. montana* from Mali i Balgjajt.

In total 47 compounds were identified representing 83.18% of the total oil composition (Table 1).

Table 1. Composition of the essential oil of S. montana (SM)

Compounds [a]	AI [b]	SM (%[c])	ID [d]
α-Thujene	926	1.7	AI, MS
α-Pinene	931	0.4	AI, MS, Co-GC
Camphene	945	0.22	AI, MS
β-Pinene	973	0.1	AI, MS, Co-GC
Octen-3-ol	983	0.1	AI, MS
β-Myrcene	992	3.0	AI, MS, Co-GC
α-Phellandrene	1003	2.8	AI, MS
δ-2-Carene	1008	0.3	AI, MS
δ-3-Carene	1015	1.4	AI, MS, Co-GC
p-Cymene	1024	8.6	AI, MS, Co-GC
Limonene	1027	0.9	AI, MS
Eucalyptol	1029	0.4	AI, MS
trans-Ocimene	1040	0.8	AI, MS
cis-Ocimene	1050	0.2	AI, MS
γ-Terpinene	1059	9.8	AI, MS, Co-GC

cis-Sabinenehydrate	1067	4.1	AI, MS
Terpinolene	1087	1.2	AI, MS
trans-Sabinenehydrate	1098	1.74	AI, MS
Linalool	1101	1.7	AI, MS, Co-GC
α-Thujone	1104	0.5	AI, MS
β-Thujone	1116	0.2	AI, MS
cis-p-Menth-2-en-1-ol	1122	0.4	AI, MS
Camphor	1143	0.2	AI, MS
Borneol	1164	3.1	AI, MS, Co-GC
δ-Terpineol	1169	0.1	AI, MS
Terpinene-4-ol	1176	3.5	AI, MS, Co-GC
p-Cymen-8-ol	1187	tr	AI, MS
α-Terpineol	1191	0.4	AI, MS
Thymol methyl ether	1236	3.5	AI, MS
Carvacrol methyl ether	1244	1.1	AI, MS
Bornyl acetate	1286	1.6	AI, MS, Co-GC
Thymol	1294	15.8	AI, MS, Co-GC
Carvacrol	1304	3.7	AI, MS
Thymyl acetate	1356	0.14	AI, MS
α-Copaene	1375	0.22	AI, MS
β-Burbonene	1384	0.2	AI, MS
β-Caryophyllene	1419	2.84	AI, MS, Co-GC
β-Copaene	1428	0.7	AI, MS
γ-Elemene	1434	0.12	AI, MS
Aromadendrene	1438	0.7	AI, MS
Myltayl-4(12)-ene	1443	0.4	AI, MS
α-Carryophyllene	1453	0.3	AI, MS, Co-GC
Allo-Aromadendrene	1460	0.1	AI, MS
Dauca-5,8-diene	1474	0.5	AI, MS
γ-Muurolene	1477	0.3	AI, MS
Spathulenol	1578	0.8	AI, MS
Carryophyllene oxide	1583	2.3	AI, MS, Co-GC
Monoterpene hydrocarbons		33.22	
Oxygenated Monoterpenes		41.18	
Sesquiterpene Hydrocarbons		7.38	
Oxygenated Sesquiterpenes		3.10	
Total		83.18	

[a]Compounds listed in order of elution from an HP-5 MS capillary column; [b] AI: Arithmetic indices as determined on a HP-5 MS capillary column using a homologous series of n-alkanes (C9-C23); [c] percentage (w/w) of the identified compound in the essential oil; and [d] Identification method: AI=Arithmetic Index, MS=mass spectrum, Co-GC=Coinjection with authentic compound.

The oil was dominated by monoterpenes, particularly oxygenated monoterpenes (41.18%) and monoterpene hydrocarbons (33.22%), followed by smaller proportions of sesquiterpene hydrocarbons (7.38%) and oxygenated sesquiterpenes (3.10%). This compositional distribution is typical for *S. montana* essential oils reported in Mediterranean regions [6,9].

Thymol (15.8%) was identified as the major constituent, followed by γ-terpinene (9.8%), p-cymene (8.6%), cis-sabinenehydrate (4.1%), and carvacrol (3.7%). The relatively high thymol content combined with moderate carvacrol levels indicates a thymol-dominant chemotype with mixed thymol/carvacrol characteristics. According to Figueiredo et al. (2008)

[6], *S. montana* populations may be classified into chemotypes depending on the predominance of thymol, carvacrol, or their precursors (γ-terpinene and p-cymene). The presence of substantial amounts of γ-terpinene and p-cymene suggests active biosynthetic pathways leading toward phenolic monoterpene formation.

The biosynthesis of thymol and carvacrol originates from γ-terpinene via p-cymene intermediates, catalyzed by specific cytochrome P450-dependent monooxygenases [5]. Environmental factors such as temperature and UV exposure may influence enzyme expression, shifting the metabolic balance toward one phenolic derivative over another. The predominance of thymol over carvacrol in the present sample may reflect such ecological modulation at higher altitudes.

Comparatively, Salihila and Nuro (2018) [13] reported carvacrol contents ranging from 2.48% to 16.49% and thymol from 2.77% to 26.11% in *S. montana* populations from Burrel, Albania, demonstrating marked variability even within a limited geographic area. Ibraliu et al. (2010) [8] reported even broader ranges (carvacrol 2.21–55.95%; thymol 0.08–27.29%), confirming strong chemotypic polymorphism in Albanian accessions. The present findings fall within these ranges but show a more balanced thymol/carvacrol ratio.

The biological significance of this chemotype is relevant. Thymol and carvacrol are known for strong antimicrobial activity against Gram-positive and Gram-negative bacteria, as well as antifungal species [2,3]. Their mechanism of action involves disruption of cytoplasmic membranes, leakage of intracellular constituents, and inhibition of ATP synthesis [3]. In addition, synergistic interactions between thymol, carvacrol, γ-terpinene, and p-cymene have been reported, enhancing antimicrobial efficacy beyond that of individual compounds [2].

The presence of other oxygenated monoterpenes such as borneol (3.1%), terpinene-4-ol (3.5%), thymol methyl ether (3.5%), and bornyl acetate (1.6%) further contributes to the bioactivity profile. Terpinene-4-ol and borneol are associated with antimicrobial and anti-inflammatory properties [2,3], while sesquiterpenes such as β-caryophyllene and caryophyllene oxide exhibit antioxidant and cytoprotective activities [10].

Overall, the chemical profile obtained for *S. montana* from Mali i Balgjajt confirms the existence of a thymol-rich chemotype with moderate carvacrol content, consistent with previously described Balkan populations. The predominance of oxygenated monoterpenes supports potential applications in food preservation, natural antimicrobial formulations, aromatherapy, and phytopharmaceutical products. Further investigations including seasonal sampling, genetic characterization, and in vitro biological assays would provide deeper insight into the functional potential of this population.

4. Conclusions

The essential oil of wild *Satureja montana* L. collected from Mali i Balgjajt, Burrel, Albania, was characterized by a relatively low yield (0.1% v/w) but a chemically rich profile dominated by oxygenated monoterpenes. A total of 47 compounds representing 83.18% of the oil were identified by GC-MS analysis. Thymol was the major component (15.8%), followed by γ-terpinene (9.8%), p-cymene (8.6%), cis-sabinenehydrate (4.1%), and carvacrol (3.7%), indicating a thymol-dominant chemotype with mixed thymol/carvacrol characteristics. The compositional pattern aligns with previously reported Balkan populations, although intra-population variability remains evident.

The predominance of phenolic monoterpenes suggests strong antimicrobial and antioxidant potential, supporting the possible application of this essential oil in food preservation, cosmetic formulations, and phytopharmaceutical products. The observed variability highlights the importance of ecological and genetic factors in shaping chemotypic diversity.

Future research should focus on seasonal and phenological variation in oil composition, genetic characterization of local populations, evaluation of the biological activity of essential oils and exploration of cultivation strategies to optimize yield and chemical quality.

The present study contributes to the valorization of Albanian wild *S. montana* populations and provides a scientific basis for their sustainable exploitation and industrial utilization.

5. References

1. Adams RP: **Identification of Essential Oil Components by Gas Chromatography/Mass Spectrometry**. 4th Edition. Allured Publishing Corporation, Carol Stream, IL 2007.
2. Bassolé IHN, Juliani HR: **Essential Oils in Combination and Their Antimicrobial**

Properties. Molecules 2012, **17**(4): 3989-4006.

3. Burt S: **Essential oils: their antibacterial properties and potential applications in foods—a review**. Int. J. Food Microbiol. 2004, **94**: 223–253.
4. Čopra-Janićijević A, Vidic D, Maksimović M: **Chemical composition of the essential oil and headspace of Satureja montana L.** Nat. Volatiles Essent. Oils 2020, **7**: 22-34.
5. Crocoll C, Asbach J, Novak J, Gershenzon J, Degenhardt J: **Terpene synthases of the thyme type monoterpene phenol pathway**. Phytochemistry 2010, **71**: 1768–1776.
6. Figueiredo AC, Barroso JG, Pedro LG, Scheffer JJC: **Factors affecting secondary metabolite production in plants: volatile components and essential oils**. Flavour Fragr. J. 2008, **23**: 213–226.
7. Hajdari A, Mustafa B, Kaçiku A, Mala X, Lukas B, Ibraliu A, Stefkov G, Novak J: **Chemical composition of the essential oil, total phenolics, total flavonoids and antioxidant activity of methanolic extracts of Satureja montana L.** Rec. Nat. Prod. 2016, **10**(6): 750–760.
8. Ibraliu A, Dhillon BS, Faslia N, Stich B: **Variability of essential oil composition in Albanian accessions of Satureja montana L**. J. Med. Plant Res. 2010, 4(14): 1359-1364.
9. Kokkini S, Karousou R, Hanlidou E: **Essential oil composition of Greek (Satureja montana L.) populations**. Biochem. Syst. Ecol. 1997, 25: 605–613.
10. Legault J, Pichette A: **Potentiating effect of β-caryophyllene on anticancer activity of α-humulene**. J. Pharm. Pharmacol. 2007, 59: 1643–1647.
11. Massada Y: **Analysis of essential oils by Gas Chromatography and Mass Spectrometry.** John Wiley & Sons, New York 1976.
12. Navarro-Rocha J, Fe Andrés M, Díaz CE, Burillo J, González-Coloma A: **Composition and biocidal properties of essential oil from pre domesticated Spanish Satureja montana.** Ind. Crops Prod. 2020, **145**: 111958.
13. Salihila J, Nuro A: **Chemical Characterisation of Essential Oil for Satureja Montana Population from Burreli Area, Albania.** Madridge J. Anal. Sci. Instrum. 2018, 4(1): 88-91. doi: 10.18689/mjai-1000117.
14. Van den Dool H, Kratz PD: **A generalization of the retention index system including linear temperature programmed gas-liquid partition chromatography.** J. Chromatogr. 1963, **11**: 463.