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CLIMATE INFLUENCE AND ESSENTIAL OILS COMPOSITION OF SALVIA OFFICINALIS IN POPULATIONS OF SOUTHERN ALBANIA

SUMMARY

Salvia officinalis L. is an important medicinal and aromatic plant species belonging to Lamiaceae family, largely used in folk medicine and in culinary. This plant species is growing mainly wild in the mountain areas of Albania where the population's essential oils composition is affected by environmental factors and weather conditions. The aim of the present study is to provide data on the EO composition of the *S. officinalis* in Southern Albania, and on the influence of climatic conditions on foreground temperature and precipitations in a selected location on the variation of the EO components. The essential oils were extracted by hydro-distillation and analyzed by gas chromatography (GC-FID). Qualitative and quantitative variation in composition of essential oil was analyzed on yearly basis for five consecutive years. In total, 20 main compounds were identified representing 95.1% to 98.9% of the total EO. Monoterpenes were found to be the main group of components ranging from 87.8% to 95.5% of total EO with the oxygenated monoterpenes as the most abundant compounds. The chemical profile of *S. officinalis* grown wild in mountain area in Southern Albania was alpha-Thujone (29.9%) > Camphor (21.7%) > Cineole (12.1 %) > Camphene (7.9 %) > beta-Thujone (5.4%) > alpha-Pinene (4.6%) > alfa-Humulene (2.6%) > beta-Caryophyllene (2.5%). The temperature was positively correlated with, sesquiterpenes and negatively correlated with bicyclic monoterpenes, while the opposite was observed for precipitation. The ordination analysis results PCA explained 93% of total variance, camphene, camphor, alpha-pinene, cineole and beta-thujone were the most variable components among analyzed years.

Keywords: *Salvia officinalis*, essential oils, precipitation, temperature

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INTRODUCTION

Salvia officinalis L. or sage is an outstanding member of Lamiaceae family, native to Mediterranean Basin. It is widely used in folk medicine, as culinary herb, in aromatherapy and food industry. Essential oils of this species have important biological activities such as antioxidant (Abdelkader *et al*., 2014) antimicrobial (Kačániová *et al*., 2021), antiviral, anti-inflamatory, anticancer, antidementia, hypoglycemic and hypolipidemic, etc (Ghorbani and Esmaeilizade, 2017). Different chemotypes of sage show big differences in a distinct compound, there are reported about 18 sage chemotypes (Schmiderer *et al.,* 2013). The use of the EO derived from medicinal plants depends on components availability, therefore the identification of chemotypes is rather important, also considering the increased demand for unique EO producing cultivars (Rathore *et al*., 2022).

There are several factors affecting chemical variability in plants including ecological conditions, development stage of the plant, geographical and climatic variation as well as genetic diversity (Figueiredo *et al*, 2008). Earlier studies reported variation of EOs compositions of sage populations grown in different locations and ecological conditions in Albania (Schmiderer *et al.*, 2013, Nuro *et al*., 2017, Papa *et al*., 2017), in different harvesting season (Hasa *et al*., 2021).

The cultivation of medicinal and aromatic plants has a long tradition in the agro-ecological conditions of Europe and Mediterranean area (Petrović *et al*., 2022). It was proved that several ecological factors such as phosphorus, potassium, organic matter, temperature and moisture are positively correlated with herbaceous species richness and play an important role in organic sage cultivation (Solomou *et al*., 2020). In addition, it is well known that the composition of essential oils and concentration of volatile compounds in Salvia sp. depends not only on genetic and seasonal factors but also on environmental conditions (Ramezani *et al*., 2020), although with the accelerating climate change this can potentially be problematic for the future production and use of these oils in the pharmaceutical and food industry (Karalija *et al.*, 2022). There are limited reports on the variation of chemical oil composition of medicinal plants under different climatic conditions. These studies demonstrate that the temperature and precipitation variation affected the essential oil yields and essential oil chemical composition in medicinal and aromatic plants as lavandin (Liao *et al*., 2021; Acimovic *et al*., 2022), chamomile (Gosztola *et al*., 2010) and sage (Radwan *et al.*, 2017).

Sage grows mostly wild in mountain areas in Albania, but several initiatives to cultivate it have recently taken place due to the increased demand for its essential oil (EO). Thus, the knowledge on the quality of EOs of sage populations and the effect of microclimatic conditions on their chemical composition, would be relevant for the sage cultivation initiatives and other related industries in the country. Therefore, the current study aims to study chemical polymorphism of natural populations of *S. officinalis* in Southern Albania, and to investigate the influence of climatic conditions on foreground temperature and precipitation in the selected locations on the variation of the EO components.

MATERIAL AND METHODS

Sampling sites and plant material. The areal parts of *Salvia officinalis* plants were collected from four populations grown wild in mountain area in Southern Albania year to year for five consecutive years 2017-2021 in the mid-June. The plant material was air dried in the dark and used to extract essential oils. The geographical position and localities of each sampling site are given in the table 1. In addition, key meteorological data as the average temperature and precipitation of the sample collection region was obtained by the database of IGJEUM (2017-2021). The minimum, maximum and the mean values of temperatures and rainfall registered in the sampling region was given in the Table 2 and Figure 1.

The essential oil isolation. The essential oils of the sampled wild sage populations were extracted from 50g air dried plant material using hydro-distillation using Clevenger type apparatus for 4 hours. Toluene (2 ml) was then added to the balloon for isolation of the essential oils, which were then dried over anhydrous sodium-sulphate (Na_2SO_4) and stored in sealed amber glass vials at +8^oC prior further analysis.

Table 1. Sampling collection sites geographical coordinates

Code	Latitude	Longitude
Sample 1-S1	40^0 33'11.34"	$20^0$7'51.608"
Sample 2-S2	$40^0$15'7.351"	$20^0$58'8.166"
Sample 3-S3	$40^0$35'35.32"	$20^0$10'6.852"
Sample 4-S4	$40^0$17'8.375"	$20^0$35'27.8"

Analytical Gas chromatography analysis. The analytical gas chromatographic analyses of isolated essential oils of sage were carried out on GC V 450 instrument equipped with a flame ionization detector and split-splitless injector, attached to aVF-1ms capillary column (30 m x 0.33 mm x 0.25 μm). The applied injector temperature was 280^oC and FID temperature was held at 300°C. The essential oil (1 ul) diluted in Toluene was injected in split mode 1:50. The nitrogen was used as carrier (1 ml/min) and carrier gas flow rate was 25 ml/min. Hydrogen and air were flame detector gases with 30 ml/min and 300 ml/min, respectively. The oven temperature was programmed as follows: 40°C (held for 2 minutes) to 150^oC (with 4°C/min), after that to 280°C with 10°C/min and held for 7 minutes. The identification of the essential oils compounds was based on the comparison of their Kovats indices (KI), their retention times (RT) to the data already available (Adams, 1995; David *et al*., 2010, Konig *et al*., 1999). A mixture of n-alkanes from n-octane (C_8) to eicosanes (C_{20}) was used in KI calculation. The identified components were subjected to principal component analysis (PCA) to analyze the variability in each analyzed year, temperature, and rainfall levels.

RESULTS AND DISCUSSION

The analysis of *S. officinalis* essential oil composition was carried out in five successive years. There were observed a difference of +1.2°C in the mean temperatures of the analyzed years, they ranged from 15.9°C (year 2020) to 17.5°C (year 2019). While it was observed great variation in the minimal temperature values, ranging from 0°C (year 2018) to 8°C (year 2021). Comparing rainfall among years, in the years 2018 and 2021 had significantly higher mean rainfall values compared to other years with mean values of 122.2 mm and 92 mm, respectively whereas in the year 2020 are recorded the lowest mean values of rainfall with 57.5 mm. While high variation resulted for the minimal rainfall values that ranged from 0 mm in the year 2017 to 10 mm in the year 2020.

In the June, the month when the collection of samples was carried out, the temperatures varied from 17°C (year 2020) to 26°C (year 2017), while the average rainfall ranged from 10 mm to 110 mm for the years 2017 and 2018, respectively (Table 2 and Figure 1).

Table 2. Yearly mean, minimal and maximal temperatures, and rainfall values in the sampling region for the period 2017-2021

	2017	2018	2019	2020	2021
Mean Temperature (°C)	**16.3**	**16.7**	**17.5**	**15.9**	**17.1**
Min temp	3	0	3	6	8
Max temp	30	36	29	26	27
Mean temp- June	**26**	**25**	**26**	**17**	**23**
Mean rainfall (mm)	**79.3**	**122.2**	**78.2**	**57.5**	**92**
Min rainfall	0	9	4	10	0
Max rainfall	400	233	260	170	400
Mean rainfall-June	**10**	**110**	**50**	**20**	**30**

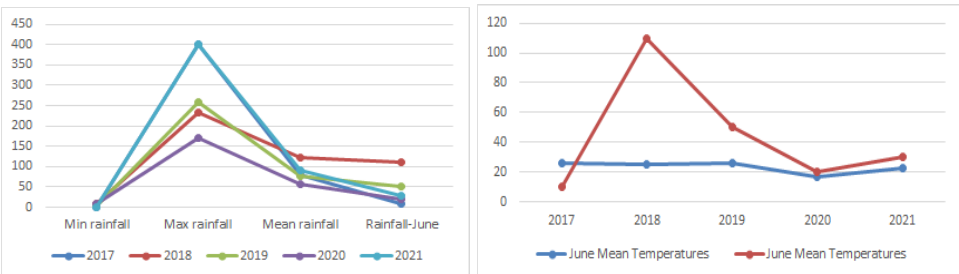

Figure 1. The mean values of temperatures and rainfall in June during five successive years, 2017-2021.

Essential oils components. The overall GC/FID analysis of EOs identified in total 120 different components. This study focused on the assessment of the variation of 20 most abundant components, which represented 95.1% to 98.9% of total yield of EOs. The peaks lower than 0.05% were not included into our analysis. The mean values (in percentage) of the main chemical components obtained from year-to-year analysis of the sampled population were given in the table 3.

Qualitative and quantitative assessment of EOs composition of all sample set calculated as the mean values of each of the components identified in five analyzed years suggested that the chemical profile of *S. officinalis* grown wild in mountain area in Southern Albania was: alpha-Thujone (29.9%) > Camphor (21.7%) > Cineole (12.1 %) > Camphene (7.9 %) > beta-Thujone (5.4%) > alpha-Pinene (4.6%) > alfa-Humulene (2.6%) > beta-Caryophyllene (2.5%) (Figure 2) Compared to the chemical profiles reported in previous studies for sage grown in other regions in Albania (Nuro *et al*., 2017), the sage populations under study had lower concentration of alpha and beta-Thujone and higher levels of Cineole and Camphor, the same was observed for other components as bicyclic monoterpenes. These differences suggests that populations in Southern Albania might be a different chemotype. In addition, the differences in chemical composition and components concentration of sage grown in Southern Albania compared to EOs composition of sage grown in other regions might be the reason of preferential and wider use on the folk medicine of sage grown in Southern region. Comparative analysis of our data with the reported chemical profiles of sage grown in other Balkan and Mediterranean countries (Khedher *et al.*, 2017; Oniga *et al*., 2010; Damyanova *et al*., 2016; Miguel *et al.*, 2011; Bernotiene *et al*., 2007; Awen *et al.*, 2011; Perry *et al.*, 1999) did not show significant differences.

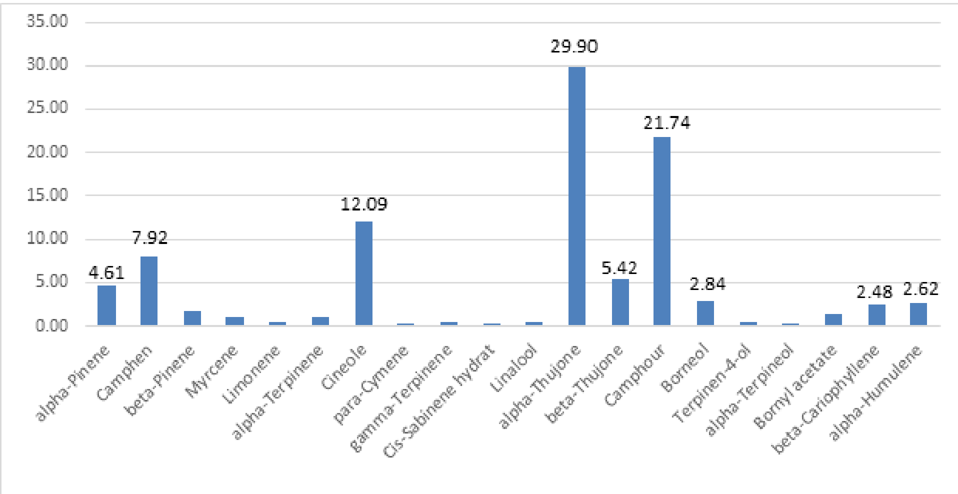

Figure 2. Profile of main compounds for *Salvia officinalis* from Southern Albania

The essential oil composition varies within a country depending on the microclimate conditions suggesting the significance of tracking the climate-related conditions and their effect on plants (Karalija *et al*., 2022). Thus, the analysis of essential oil components of four natural populations of *Salvia officinalis* was carried out for five consecutive years 2017-2021 in order to investigate the variation of Essential Oils (EOs) chemical components in relation of the temperature and precipitation variations. Some components such as: alpha-Thujone, beta-Thujone, Camphor, Cineole, and Camphene were present in all analyzed samples independently from the climate changes. As it was shown in the Figure 3, these components are found in the first line of chromatogram, due to their low boiling points. In addition, the characteristic smell of sage is attributed to the presence of these chemical components.

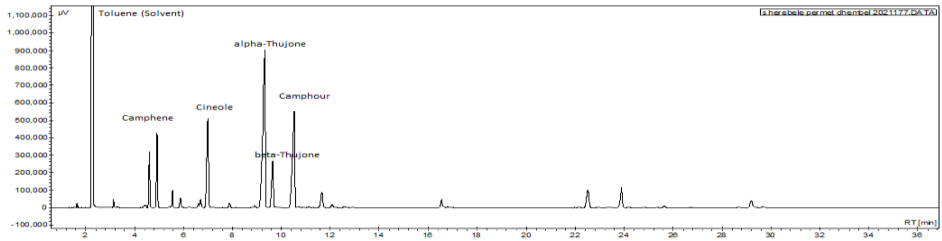

Figure 3. Chromatogram of *Salvia officinalis* essential oil (year 2021)

The results showed that the EOs of sage populations collected in mountain area of Southern Albania (Table 3) presented two major chemical groups of terpenes: monoterpenes and sesquiterpenes ranging from 87.8% (year 2018) to 95.5% (year 2019) and 3.3% (year 2019) to 7.25% (year 2018), respectively.

The monoterpenes fraction comprised the oxygenated monoterpenes (72.3 – 75.7%) > bicyclic monoterpenes (12.1 – 16.6%) > sesquiterpenes (3.3 – 7.3%) > monocyclic monoterpenes (1.3 – 2.8%) > aliphatic monoterpenes (1.0 – 1.2%) > aromatic monoterpenes (0.1 – 0.3%).

Oxygenated monoterpenes such as alpha and beta-Thujones, Camphor, Cineole, Borneol, Bornyl acetate, Linalool, Terpinen-4-ol and alpha-Terpineol were found in all samples. The highest level of these components in sage EO (75%), was observed in the EOs sampled in the years 2017, 2019 and 2021. These components were in lower concentration in the EOs of samples collected in the years 2018 and 2020, where they constitute 73.2% and 72.4%, respectively. Nevertheless, no significant variations were observed for the concentration of oxygenated monoterpenes through the analyzed samples. Similarly, other studies on lavandin reported that differences in climate conditions through years have not impacted hydrolate composition variations (Acimovic *et al*., 2022)

Bicyclic monoterpenes as alpha and beta-Pinene, Camphene and cis-Sabinene hydrate, represented the second major group of compounds identified in our sample set. This group of compounds was found in higher amount in the samples collected in the year 2019 (16.2%) and in the year 2020 (16.6%), whereas the lowest concentration of bicyclic monoterpenes was obtained in the samples collected in the years 2018 (12.1%) and 2021 (12.5%), in which the level of precipitations was higher than in the other years. Being highly volatile, the level of bicyclic monoterpenes concentration in EO is affected by both the temperature variation and level of precipitation.

Table 3. Variation of chemical composition (%) of essential oil of *Salvia officinalis* populations, average values per year

	Rt	Year 2017	Year 2018	Year 2019	Year 2020	Year 2021
alpha-Pinene	4.32	**5.52 ± 1.25**	**3.65 ± 1.66**	**4.81 ± 1.33**	**4.82 ± 0.92**	**4.23 ± 0.87**
Camphene	4.41	**7.40 ± 2.24**	**7.02 ± 1.14**	**9.58 ± 1.73**	**9.57 ± 1.37**	**6.01 ± 0.44**
beta-Pinene	5.22	2.10 ± 0.48	1.30 ± 0.43	1.65 ± 0.71	2.13 ± 0.44	1.74 ± 0.53
Myrcene	5.34	1.20 ± 0.33	0.97 ± 0.31	1.10 ± 0.40	1.06 ± 0.32	0.95 ± 0.28
Limonene	6.41	0.13 ± 0.04	0.30 ± 0.09	1.21 ± 0.49	0.28 ± 0.05	0.26 ± 0.04
α-Terpinene	6.47	**0.81 ± 0.27**	**0.73 ± 0.24**	**1.04 ± 0.31**	**1.50 ± 2.17**	**0.95 ± 0.19**
Cineole	6.73	**12.90 ± 4.26**	**11.51±3.45**	**12.42± 3.49**	**12.13 ± 2.49**	**11.48 ± 3.22**
para-Cymene	7.33	0.10 ± 0.49	0.10 ± 0.04	0.11 ± 0.03	0.33 ± 0.82	0.26 ± 0.08
gamma-Terpinene	7.98	0.32 ± 0.67	0.41 ± 0.06	0.33 ± 0.05	0.98 ± 0.04	0.07 ± 0.02
Cis-Sabinene hydrate	8.13	0.10 ± 0.03	0.11 ± 0.03	0.14 ± 0.04	0.11 ± 0.03	0.47 ± 0.09
Linalool	8.44	0.25 ± 0.06	0.25 ± 0.9	0.21 ± 0.06	0.17 ± 0.05	0.99 ± 0.04
α-Thujone	9.12	**29.92 ± 4.22**	**31.37±3.64**	**26.7 ± 3.29**	**27.27 ± 4.38**	**34.21 ± 4.37**
β-Thujone	9.21	**5.64 ± 0.93**	**5.58 ± 1.07**	**5.71 ± 1.66**	**4.28 ± 1.22**	**5.87 ± 1.64**
Camphor	10.52	**22.50 ± 2.16**	**19.53±4.36**	**25.30± 3.82**	**24.13 ± 3.47**	**17.24 ± 1.43**
Borneol	11.78	**2.10 ± 0.71**	**2.73 ± 0.84**	**3.14 ± 0.44**	**2.35 ± 0.72**	**3.86 ± 1.43**
Terpinen-4-ol	12.21	0.52 ± 0.06	0.51 ± 0.14	0.51 ± 0.14	0.48 ± 0.18	0.39 ± 0.09
α-Terpineol	14.43	0.10 ± 0.03	0.22 ± 0.06	0.12 ± 0.02	0.20 ± 0.05	0.20 ± 0.04
Bornyl acetate	16.95	**1.20 ± 0.33**	**1.52 ± 0.42**	**1.41 ± 0.37**	**1.33 ± 0.55**	**1.50 ± 0.81**
β-Caryophyllene	22.44	**2.44 ± 0.83**	**1.94 ± 0.84**	**1.61 ± 0.59**	**3.24 ± 0.70**	**2.16 ± 1.31**
α-Humulene	24.65	**2.72 ± 0.91**	**2.30 ± 0.82**	**1.71 ± 1.43**	**1.14 ± 1.53**	**3.19 ± 2.42**
Total		**97.98**	**95.07**	**98.85**	**97.51**	**96.03**
Σ Monoterpene		92.82	87.82	95.52	93.12	90.68
Σ Monocyclic monoterpenes		1.26	1.45	2.58	2.76	1.28
Σ Bicyclic monoterpenes		15.12	12.08	16.18	16.63	12.45
Σ Aliphatic monoterpenes		1.20	0.97	1.11	1.06	0.95
Σ Oxygenated monoterpenes		75.14	73.22	75.54	72.34	75.74
Σ Aromatic monoterpenes		0.11	0.12	0.11	0.33	0.26
Σ Sesquiterpenes		5.16	7.25	3.33	4.38	5.35

The maximum values of temperature variation impact was also observed in sesquiterpenes, which have high boiling points. At the year 2018, when the highest maximal temperature and mean precipitation were registered, the sesquiterpenes had high concentration. Sesquiterpenes (beta-Caryophyllene and alpha-Humulene) highest concentration was obtained from samples of the year 2018 (7.3%) and in lowest percentage was obtained in the samples collected in the 2019 (3.3%) (Table 3) The ratio of monoterpenes and sesqiuterpenes fractions in essential oils changes with the variation of the temperature (Usano-Alemany *et al.*, 2014).

Monocyclic monoterpenes (alpha and gamma-Terpinene and Limonene) showed remarkable differences concentrations in EOs which resulted higher in the years 2019 (2.6%) and 2020 (2.8%) compared to the years 2017 and 2021 (1.3%). The concentration of Aliphatic monoterpenes (Myrcene) and aromatic monoterpenes (para-Cymene) were very low (≤ 1). The total amount of alpha-Thujone and beta-Thujone in our samples varied from 31.6% (year 2020) to 40.1% (year 2021). Whereas Cineole varied from 11.5% (year 2018, 2021) to 12.9% (year 2017). Camphor lowest concentrations were observed in the years 2018 and 2021 with 19.5% and 17.2%, respectively while the highest camphor concentration was observed in samples collected in the year 2019 with a value of 25.3%. Results suggested that camphor is affected by level of precipitation, it was in higher amount in the EO collected in years with lower levels of rainfall. The results are in line with the Radwan *et al*., (2017), that reported an increase of the camphor concentration and of the total monoterpenes in sage under drought stress. However, several compounds did not correlate with the temperature and precipitation in neither their yearly mean values nor with the mean weather conditions recorded on June, period when samples were collected.

Principal Component Analysis. The twenty main identified compounds of sage EO were subjected to principal component analysis (PCA) to analyze their variability in the different analyzed years, in relation with yearly temperatures and rainfall values.

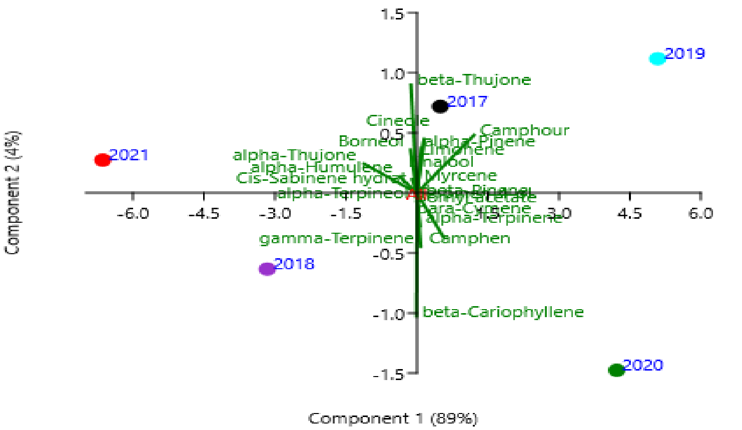

Figure 4. Principal component analysis (PCA) of the essential oil composition of S. officinalis variation in five analyzed years

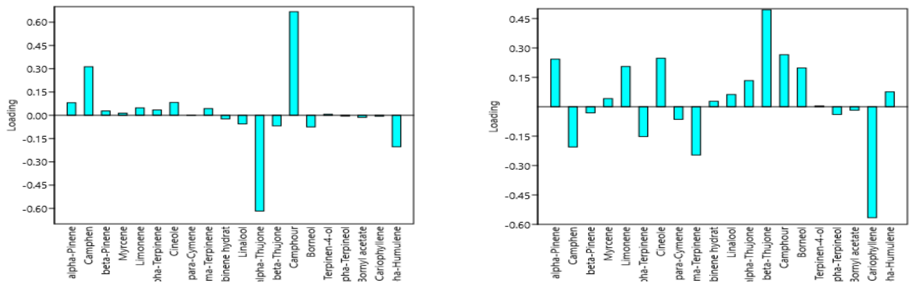

Figure 5. Loading plot of principal component analysis PC1 loading plot (left) and PC2 loading plot (right)

The ordination analysis results for two main components (PC1 and PC2) were given in the figure 4, the data points of the variables with similarities were grouped in the same cluster in PCA.

The main two principal components mutually accounted for 93% of total variance. The yearly variation of the essential oil compounds based on the first major principal component (PC1), which accounted for 89% of the total variation. The analysis demonstrated that camphene and camphor had positive loadings (values ≥0.3), whereas alpha-thujone and alpha-humulene had negative loadings (values ≤0.3). This result also is supported by the higher camphor and camphene concentration in the EO collected in the years 2017 and 2019 and 2020, positioned also in the right of the PC1 axis compared with their concentrations in the EOs of years positioned in the left side of the PC1 axis (2018 and 2021) (Table 3, Figure 4). The yearly variation of the essential oil compounds based on the second major principal component (PC2), which accounted for 4% of the total variation, showed positive loading (values ≥0.3) of alpha-pinene, cineole, beta-thujone, and negative loading (values ≤0.3) of gamma-terpinene and beta-caryophyllene (Figure 4 and Figure5). The concentration of alpha-pinene and cineole had highest concentration in the EO of the year 2017 and lowest concentrations in the EOs of the year 2018 in which the maximum values of mean precipitation were recorded (Table 1 and Table 3). The highest concentration of beta-Thujone were obtained in the EO of the year 2019 with higher level of the mean temperature and precipitation compared to the year 2020 in which lowest beta-Thujone concentration were obtained (Table 3), supporting the year differentiation from the PC2 presented in the scatterplot (Figure 4) and indicating that this compound might be influenced by both temperature and rainfall values.

CONCLUSIONS

This study shows the qualitative and quantitative differences on overall content and relative abundance of compounds of essential oil of *Salvia officinalis* grown wild in Southern Albania and their variation affected by weather conditions such as temperature and precipitation through five successive years. GC/FID analysis of the essential oil of sage in this location contains higher concentration of alpha-Thujone, beta-Thujone, Camphor, Cineole, and Camphene. The most variable components among analyzed years were camphor, alpha-pinene, cineole and beta-thujone. It was observed that bicyclic monoterpenes and sesquiterpenes were more affected by the climate variations than other groups of compounds. The study provided new insight for the quality of essential oils and the effect of microclimatic conditions on its chemical composition, relevant for the sage cultivation initiatives and industries.

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