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# Essential Oil Content and Site Characteristics of *Origanum minutiflorum*

Münevver ARSLAN[a]*, Gülmira ÖZEK[b], Temel ÖZEK[bc]

[a]Research Institute for Forest, Soils and Ecology, Eskişehir, 26160 Türkiye.
arslan28@yahoo.com

[b]Anadolu University, Faculty of Pharmacy, Department of Pharmacognosy, Eskişehir, 26470 Türkiye.
gulmiraozek@gmail.com

[bc]Medicinal Plant, Drug and Scientific Research and Application Center (AUBIBAM), Anadolu University, Eskisehir, 26470 Türkiye.
tozek@anadolu.edu.tr

*Corresponding author:
arslan28@yahoo.com

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**Abstract**

Türkiye is a country rich in medicinal and aromatic plant species. Many species are threatened with extinction due to direct harvesting from the wild. To reduce the negative effects on these plants, it is crucial to determine their site factors before cultivation. *Origanum minutiflorum* O. Schwarz & P.H. Davis is an endemic species that is one of the most important medicinal and aromatic plants. Our study aimed to conduct a comprehensive investigation of the ecological requirements and essential oils of the species across all its distribution areas. The plant samples of *O. minutiflorum* were collected during the flowering period from 20 different localities. Essential oils were obtained by hydrodistillation in a Clevenger-type apparatus in accordance with the European Pharmacopoeia, and their compounds were determined by gas chromatographic methods (GC-FID and GC/MS). Data on major chemical compounds (≥3%) were transferred to the PC-ORD program and principal component analysis was applied. Relationships between essential oil and environmental factors were determined using Pearson and Kendall correlation analysis. No significant relations ship was found. Carvacrol was found as the main constituent of essential oil. The carvacrol content ranged from 78.75% to 87.15%. The essential oil yield varied between 3.30 and 5.18 mL/100g. It was found that the different habitats of the species were stable in terms of essential oil yield and chemical compounds. The habitat requirements of the species have been determined in detail in its natural range.

***Keywords:*** *Ecological factors, Chemical compounds, Soil characteristics, Sutculer thyme, Toka thyme*

**Öz**

Türkiye tıbbi ve aromatik bitki türleri açısından oldukça zengin bir ülkedir. Doğadan doğrudan toplamalar nedeniyle birçok türün nesli tehdit altındadır. Bu bitkiler üzerindeki olumsuz etkiyi azaltmak için kültüre alınmadan önce yetişme ortamı isteklerinin belirlenmesi oldukça önemlidir. *Origanum minutiflorum* O. Schwarz & P.H. Davis doğadan toplanarak ticareti yapılan ve en önemli tıbbi ve aromatik bitkilerden biridir. Bu çalışmada endemik *O. minutiflorum*'um tüm yayılış alanlarının ekolojik istekleri ve uçucu yağları hakkında kapsamlı bir çalışma yapılmıştır. Araştırmada bitki 20 farklı lokalitede örneklenmiştir. Bitki örneklerinin toprak üstü kısımları, çiçeklenme döneminde toplanmıştır. Kuru herbalarındaki uçucu yağ hidrodistilasyon tekniğiyle Avrupa Farmakopesine uygun olarak Celevenger apareyinde elde edilmiştir. İçeriğindeki bileşikler gaz kromatografik yöntemlerle (GC-FID ve GC/MS) belirlenmiştir. Başlıca bileşiklere (≥%3) ait veriler, PC-ORD programına aktarılmış ve temel bileşenler analizi (PCA) uygulanmıştır. Uçucu yağ miktarları ile çevresel faktörler arasındaki ilişkiler Pearson ve Kendall korelasyon analizi ile belirlenmiştir. Bu türün yağ miktarı ve kimyasal bileşikleri üzerinde önemli bir ilişki gösteren herhangi bir çevresel değişken bulunamamıştır. Uçuçu yağ verimi ve kimyasal içerikleri ile yapılan kümeleme analizi sonucunda üç gruba ayrılmıştır. O. minutiflorum'un tüm lokalitelerindeki başlıca kimyasal bileşiği karvakroldür. Uçucu yağ verimi 3,30–5,18 mL/100 g, karvakrol oranı %78,75-87,15 arasında değişmektedir. Türün doğal yayılış alanlarındaki yetişme ortamı istekleri detaylı olarak belirlenmiştir.

***Anahtar Kelimeler:*** *Ekolojik faktörler, Kimyasal bileşikler, Toprak özellikleri, Sütçüler kekiği, Toka kekik*

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## 1. Introduction

Plants have been used for thousands of years to meet human needs for shelter, food, heating, medicine, decoration, and cosmetics. Some plant species collected from nature over the years are now facing the threat of extinction. One such species is *Origanum minutiflorum* O. Schwarz & P.H. Davis, also known as mountain thyme or wild thyme. In Turkey, it is found only in the provinces of Antalya and Isparta (Davis, 1982; Sadıkoğlu, 2012). It is among the top 10 species in Türkiye whose future is threatened and which urgently need protection (Özhatay et al., 1997). Due to uncontrolled and severe harvesting, the density of *O. minutiflorum* is decreasing every year, making it one of the most frequently harvested species from nature (Fakir et al., 2009). In the Sütçüler district, the annual collection of up to 140 tons has decreased by 50% to 70 tons (Baydar, 2001; Baydar, 2005).

The valuable essential oil known as oregano oil is produced from *O. minutiflorum* (Başer, 2009). Its essential oils are used as pain relievers, remedies for rheumatism and colds, and as spices (Sadıkoğlu and Özhatay, 2015), as well as for flavoring foods and alcoholic beverages and in perfumery (Altundağ et al., 2011). In addition, essential oils possess antibacterial, antifungal, antioxidant, anticancer, and anti-inflammatory propeties, and, exhibit enzyme inhibitor activity. These properties have aplications in the food, leather, and pharmaceutical industries (Şarer et al., 1996; Dadalioğlu and Evrendilek, 2004; Bayramoğlu et al., 2006; Vardar-Ünlü et al., 2007; Aslım and Yücel, 2008; Altundağ et al., 2011; Sokmen et al., 2020; Veljovic et al., 2023; Yıldız et al., 2023). It has also been found to have insecticidal and parasiticidal properties (Çetin and Yanıkoğlu, 2006; Çetin et al., 2009). *O. minutiflorum* essential oils has a more effective antibacterial effect than commercial bactericides (Bayramoğlu, 2005). In addition, it has been determined that it has a high allelopathic effect on the germination of seeds of some woody and herbaceous plant species (Gülsoy et al., 2008; Cunedioğlu and Üremiş, 2018).

Understanding the characteristics and habitat requirements of the plant materials collected from nature enables more balanced use of rural areas and the conservation of hydrological resources and biodiversity (Figueiredo et al., 2008). Detailed documentation of the chemical diversity of species studied as herbal medicines, taking into account their use, is essential for rational evaluation and further cultivation (agriculture) (Trendafilova et al., 2013).

Knowledge of the factors determining chemical variability and yield for each species is crucial (Figueiredo et al., 2008). The literature contains several studies on the essential oil content of *O. minutiflorum* (Başer et al., 1993; Şarer et al., 1996; Baydar, 2005; Özkum et al., 2010; Toker et al., 2017). However, there is not available detailed study on the site characteristics and essential oils of all distribution areas of the species, the most traded endemic species in Türkiye (Gurbuz et al., 2011; Bozdemir, 2019). In this study, the site characteristics, essential oil content, and chemical compounds of the essential oils of *O. minutiflorum* have been investigated in detail. The study also determined whether environmental factors (physiographic, edaphic factors) have an effect on essential oil yield and compounds.

## 2. Materials and Methods

### 2.1. Fieldwork

*Origanum minutiflorum* (Figure 1) was sampled in 14 localities in Antalya Province and 6 localities in Isparta Province in 2015. GPS was used to determine the location (UTM coordinates) and elevation (m), and a clizimeter for slope (°) and aspect (°). Parent material samples were taken from each sample area to determine the parent material. To determine soil characteristics, disturbed soil samples were taken from depths of 0-10, 10-20, and 20-30 cm from a 30 cm deep pit dug at each location. Soil samples were collected to the depth that could be reached in karst areas. Therefore, soil data from depths of 0-10 and 10-20 cm were used in statistical analyses. To determine the essential oil content and chemical compounds of the plants, sufficient quantities of mixed plant samples were taken from randomly selected plants in each sample area. Plant samples were collected during the mid-flowering stage by cutting them 10 cm above the soil surface.



**Figure 1.** *Origanum minutiflorum* O. Schwarz & P.H. Davis

### 2.2. Laboratoryworks

The specimens collected in the field in paper bags were spread out in a shaded, clean, and well-ventilated place and air-dried at room temperature until they became air-dry. All herbarium specimens were taxonomically verified by Dr. Münevver Arslan. The herbarium specimens are preserved in the herbarium of the Research Institute for Forest Soil and Ecology Directorate.

Essential oils were extracted from the plant material using hydrodistillation on a laboratory scale, in accordance with the European Pharmacopoeia (Eur. Ph.), using a Clevenger-type apparatus. Analyses were performed in duplicate, and mean values were calculated.

**Gas Chromatography–Mass Spectrometry (GC-MS):** Gas chromatographic-mass spectrometric analysis was performed according to conditions reported previously (Özek et al., 2018).

**Gas Chromatography (GC):** Gas chromatographic analysis was performed according to conditions reported previously (Özek et al., 2018).

**Identification and Quantification of Compounds:** Identification of the compounds was performed according to the following:

-comparison of the GC-MS Relative Retention Indices (RRI) of the compounds on polar column determined relative to the retention times of a series of *n*-alkanes ($C_8$-$C_{40}$), with those of authentic compounds or literature data;

-computer matching with commercial mass spectral libraries: MassFinder software 4 (Joulain et al., 2001), Adams Library (Adams, 2007), Wiley GC-MS Library, and NIST Library (NIST, 2018), and comparison of the recorded spectra with literature data. Confirmation was also achieved using the in-house "Başer Library of Essential Oil Constituents" database, obtained from chromatographic runs of pure compounds performed with the same equipment and conditions. Percent composition was obtained for each constituent on the basis of GC-FID chromatogram without normalization.

Soil samples collected from the field and brought to the laboratory were air-dried, then ground and passed through a 2 mm sieve to prepare them for analysis. Physical soil analyses were used to determine sand (%), dust (%) and clay (%) (texture) according to Kroetsch and Wang (2008), soil type according to the In-Farm Method (MT 06), and chemical soil analyses were used to determine soil reaction (pH) according to TS ISO 10390 (TS 8332) (Anonymous, 2013), organic matter content (%) according to the Modified Walkley-Black method (TS 8336) (Anonymous, 1990a), electrical conductivity (EC X 10-3 mS/cm) according to the TS ISO 11265 method (Anonymous, 1996a) in a 1:5 soil-water solution, lime (CaCO3, %) according to the Volumetric Method (TS 8335 ISO 10693) (Anonymous, 1996b), total nitrogen according to the Kjeldahl method, and available phosphorus (ppm) according to the Olsen Method (TS 8340) (Anonymous 1990b) in basic soils. In acidic soils, the Modified Bray and Kurtz No. 1 Method (TS 8338) (Anonymous, 1990c) was used for analysis. $K^+$ determination in soils was performed using the Ammonium Acetate Method (TS 8341) (Anonymous 1990d).

The determination of exchangeable $Na^+$, $Ca^{++}$, and $Mg^{++}$ (ppm) in soil samples was performed using the "ammonium acetate method" (Jackson, 1962, Kacar, 1994). In the prepared soil solutions, the amounts of $K^+$ and $Na^+$ were measured with a "Jenway PFP 7 flame photometer," while the amounts of iron ($Fe^{++}$), manganese ($Mn^{++}$), copper ($Cu^{++}$), and zinc ($Zn^{++}$) were measured using the "double acid (HCl + H2SO4) method" (Kacar, 2009). The amounts of $Cu^{++}$, $Ca^{++}$, $Mg^{++}$, $Fe^{++}$, $Mn^{++}$, and $Zn^{++}$ were measured with a "Perkin-Elmer 3110 atomic absorption spectrometer."

### 2.3. Data Evaluation

The exposure was converted to radiation index(RI) using the following equation (1) (Moisen and Frescino, 2002; Aertsen et al., 2010) and used in numerical analysis. The radiation index takes "0" at 30 degrees (north-northeast) and "1" at 210 degrees (southwest-south).

$$RI = \frac{\left[1-COS\left(\left(\frac{\pi}{180}\right)(Q-30)\right)\right]}{2} \quad (1)$$

*RI*: Radiation index, *Q*: azimuth angle of the sample plot to the north.

The main chemical compounds of *O. minutiflorum* essential oils were used in the numerical analysis. Chemical compounds (≥3%) were transferred to the PC-ORD program as the main matrix, and environmental and soil variables as the secondary matrix (McCune and Mefford, 2011), and subjected to Principal Component Analysis (PCA) (Bro and Smilde, 2014). Eigenvalues of the axes, variance, and cumulative variance percentages were calculated according to the chemical compounds. In order to interpret the results of principal component analysis based on the axes, the eigenvalue coefficient must be >1 and the percentage variance must be >10 (Özdamar, 2002). Following principal component analysis, correlation analysis (Pearson and Kendall Correlations) was applied using the PC-ORD program to determine the correlation coefficients between the essential oil percentage, major chemical compounds, and the axis values of environmental and soil variables. This revealed whether environmental variables had an effect on the yield and chemical

composition of *O. minutiflorum* essential oils in different growing environments. Cluster analysis was applied to the chemical compounds in PC-ORD program. Ward's method was used as the linkage method and Jaccard as the distance measure. Thus, similarities between plants in different habitats were revealed based on their chemical compounds and oil content. Descriptive statistics for physiographic factors, soil properties, and oil content were calculated using SPSS (version 24) software (Özdamar, 2009).

## 3. Results and Discussion

### 3.1. Ecological characteristics of *Origanum minutiflorum*

According to current literature, *O. minutiflorum* is found on limestone rocky slopes at altitudes of 1500-1800 meters in Antalya and Isparta (Davis, 1982; Kaynak and Tarımcılar, 2001; Baydar, 2005; Sadıkoğlu, 2012). According to our findings, it is found in sparsely vegetated cedar and black pine forests, as well as in forest clearings. With increasing altitude, it is found in rocky areas at the transition to the alpine zone, in very sparse cedar and fragrant juniper areas. It also grows in subalpine areas with herbaceous vegetation. *O. minutiflorum* is generally found in rocky and stony areas throughout its distribution.The altitude of *O. minutiflorum* in the studied localities ranges from 1100 to 2000 meters. It generally prefers slopes other than north-facing slopes. It is usually found on middle and lower slopes. The parent material of the areas where it is distributed is mostly limestone and conglomerate. It grows in clay, clayey loam, dusty clay, loam, sandy clayey loam, and sandy loam soils (Table 1).

**Table 1.** Localities, physiographic features and habitats of *O. minutiflorum* collection sites

| Plot | Location | Altitude (m) | Aspect | Asp. (°) | RI | Slope (°) | Parent material | Habitat |
|---|---|---|---|---|---|---|---|---|
| 1 | A_Saklikent Kayak Centre | 1838 | E | 105 | 0.3706 | 28 | limestone | Alpine |
| 2 | A_Feslikan Plato | 1882 | SE | 135 | 0.6295 | 35 | limestone | Alpine |
| 3 | A_Finike-Akcalan Village-Sarıkaya | 1812 | S-SW | 200 | 0.9925 | 7 | limestone | Subalpine |
| 4 | A_Kumluca-Karacaören-Anbarkatrani | 1953 | SE-S | 150 | 0.7500 | 37 | limestone | Alpine |
| 5 | A_Finike-Alacadag-Ückuzluk | 1398 | E | 85 | 0.2132 | 25 | limestone | Cedar forest clearance |
| 6 | A_Demre-Cagman Plato | 1760 | W | 270 | 0.7500 | 17 | limestone | Subalpine |
| 7 | A_Demre-Cagman Plato | 1762 | NE | 45 | 0.0170 | 30 | limestone | Scattered juniper woodland |
| 8 | A_Finike-Ordibek Plato | 1586 | NW-N | 340 | 0.1786 | 15 | limestone | Cedar forest clearance |
| 9 | A_Finike-Alacadag-Ückuzluk | 1692 | NW | 308 | 0.4304 | 29 | limestone | Cedar forest clearance |
| 10 | A_Kemer-Yaylakuzdere-Cukuryayla | 1580 | NW-N | 337 | 0.1991 | 33 | limestone | Meadow area |
| 11 | A_Kemer-Yaylakuzdere folowing 9 km | 1508 | W-SW | 245 | 0.9096 | 40 | limestone | Cedar forest clearance |
| 12 | A_Manavgat-Altinkaya Village | 1181 | N-NE | 22 | 0.0049 | 21 | conglomerate | Blackpine forest |
| 13 | A_Manavgat-Altinkaya Village | 1118 | NW | 315 | 0.3706 | 35 | conglomerate | Meadow area |
| 14 | A_Manavgat-Altinkaya Village | 1126 | NW-N | 337 | 0.1991 | 28 | conglomerate | Meadow area |
| 15 | I_Sutculer-Candır Vil.-Sogut Plato | 1675 | W | 270 | 0.7500 | 27 | limestone | Meadow area |
| 16 | I_Sutculer-Candır Village-Akca Hill | 1303 | W-NW | 285 | 0.6295 | 30 | limestone | Blackpine forest clearance |
| 17 | I_Sutculer-Candır Village-Akca Hill | 1526 | N-NW | 345 | 0.1464 | 35 | limestone | Blackpine-fir forest claerance |
| 18 | I_Sutculer-Beydilli Village | 1503 | W | 267 | 0.7723 | 16 | limestone | Meadow area |
| 19 | I_Sutculer-Kuzdere Village | 1213 | W | 267 | 0.7723 | 33 | limestone | Cedar-blackpine forest claerance |
| 20 | I_Aksu-Karacahisar-Beltasi | 1127 | N-NE | 23 | 0.0037 | 31 | limestone | Stony and rocky area |

Asp: Aspect; A: Antalya; I: Isparta; RI: Radiation Index

The lowest organic matter content was found in soils developing on conglomerate and limestone bedrock, with 1.15% in the 0-10 cm (plot 13) and 1.75% in the 10-20 cm (plot 19). In general, the organic matter content of the soils was high. The organic matter content in the first 10 cm of Sutculer-Candır Village-Akca Hill (plot 17) was 37.8%, and these soils were classified as organic mineral soils. The amounts of N, P, Fe, Mn and Zn were detected as 0.07–1.31%, 4.35–268.78, 1.95–2.60, 0.20–1.96 and 0.07–3.19 ppm, respectively. Na amounts varied between 43 and 65 ppm. The amounts of Ca, K, and Mg were found to be 3578–10704, 94–979, and 73–1012 ppm, respectively (Table 2). Ünal et al., (2005) determined that *O. minutiflorum* in Antalya-Saklikent had an organic matter content of 8.2% and a total nitrogen content of 0.563% in the soil (0-30 cm) at 1800 meters. In our study, in Antalya-Saklikent, the organic matter content was 19.95% and nitrogen 0.08% in the 0-10 cm layer, and the organic matter content was 14.32% and nitrogen 0.8% in the 10-20 cm layer, with the average results falling within a similar classification.

The soil reaction pH varied between 6.83 and 7.78. It is generally slightly alkaline. All soils were non-saline. The lime content in the soils ranged from 0.04 to 73.45, and it can also grow in calcareous soils. The highest lime content was found in plot 13 (43.9-58.4%) on lime-filled conglomerate and plot 18 (52.6-73.5%) on limestone. Similar results were obtained for pH, lime, and organic matter content of *O. minutiflorum* in a study investigating the soil properties of some localities of the *Origanum* species *O. saccatum, O. hypericifolium, O. leptocladum*, and *O. husnucan-baserii* (Temel et al., 2011).

**Table 2.** Physical and chemical analysis results and descriptive statistics of soils

| Plot | ST1 | ST2 | pH1 | pH2 | Lime1 | Lime2 | OM1 | OM2 | EC1 | EC2 | P1 | P2 | N1 | N2 | K1 | K2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | % | | % | | mS/cm | | ppm | | % | | ppm | |
| 1 | SaL | L | 7.39 | 7.12 | 24.57 | 19.32 | 19.95 | 14.32 | 0.26 | 0.25 | 140.40 | 106.90 | 0.08 | 0.80 | 575 | 408 |
| 2 | L | L | 7.51 | 7.33 | 48.59 | 12.42 | 9.79 | 10.65 | 0.23 | 0.24 | 76.79 | 68.83 | 0.24 | 0.57 | 476 | 366 |
| 3 | CL | C | 7.50 | 7.46 | 15.95 | 22.03 | 7.30 | 5.63 | 0.21 | 0.19 | 91.44 | 37.14 | 0.44 | 0.36 | 656 | 472 |
| 4 | CL | CL | 6.90 | 7.06 | 0.31 | 0.35 | 14.84 | 12.14 | 0.16 | 0.17 | 62.56 | 41.01 | 0.88 | 0.80 | 979 | 852 |
| 5 | C | C | 7.24 | 7.17 | 0.04 | 0.39 | 9.94 | 9.06 | 0.17 | 0.17 | 74.32 | 46.19 | 0.47 | 0.41 | 489 | 406 |
| 6 | SiC | SiC | 7.28 | 7.13 | 0.31 | 0.40 | 6.17 | 4.58 | 0.14 | 0.13 | 118.13 | 76.04 | 0.09 | 0.26 | 875 | 305 |
| 7 | C | SiC | 7.26 | 7.23 | 0.44 | 0.84 | 9.82 | 9.63 | 0.15 | 0.16 | 139.08 | 71.73 | 0.52 | 0.49 | 596 | 798 |
| 8 | SiC | C | 7.37 | 7.25 | 2.51 | 2.64 | 11.89 | 8.92 | 0.19 | 0.16 | 216.12 | 268.78 | 0.50 | 0.40 | 599 | 420 |
| 9 | C | C | 6.87 | 6.96 | 0.17 | 0.09 | 8.61 | 6.00 | 0.13 | 0.12 | 96.07 | 41.09 | 0.41 | 0.33 | 708 | 646 |
| 10 | C | C | 7.24 | 7.17 | 0.17 | 0.61 | 8.19 | 6.98 | 0.14 | 0.14 | 103.60 | 73.83 | 0.41 | 0.36 | 759 | 656 |
| 11 | C | CL | 7.32 | 7.35 | 12.06 | 43.90 | 17.07 | 8.32 | 0.19 | 0.20 | 92.59 | 40.85 | 0.68 | 0.38 | 330 | 307 |
| 12 | CL | CL | 6.83 | 6.85 | 0.04 | 0.09 | 3.54 | 2.81 | 0.09 | 0.11 | 7.48 | 4.35 | 0.15 | 0.14 | 323 | 284 |
| 13 | SiC | SiC | 7.78 | 7.78 | 58.35 | 43.93 | 1.15 | 2.27 | 0.20 | 0.20 | 10.84 | 14.75 | 0.07 | 0.09 | 151 | 192 |
| 14 | CL | CL | 7.47 | 7.31 | 0.51 | 0.47 | 4.78 | 2.54 | 0.16 | 0.18 | 37.63 | 20.14 | 0.17 | 0.13 | 152 | 255 |
| 15 | C | C | 7.32 | 7.32 | 4.77 | 5.64 | 8.13 | 7.00 | 0.16 | 0.19 | 44.04 | 21.26 | 0.39 | 0.28 | 365 | 271 |
| 16 | CL | C | 7.00 | 7.09 | 0.17 | 0.30 | 6.39 | 5.07 | 0.15 | 0.16 | 34.68 | 30.14 | 0.25 | 0.21 | 479 | 305 |
| 17 | SaL | C | 7.23 | 7.09 | 1.14 | 6.96 | 37.81 | 12.24 | 0.22 | 0.21 | 171.97 | 170.71 | 1.31 | 0.58 | 275 | 473 |
| 18 | SaCL | SaCL | 7.28 | 7.38 | 52.62 | 73.45 | 13.09 | 4.74 | 0.24 | 0.21 | 120.53 | 57.77 | 0.74 | 0.32 | 335 | 299 |
| 19 | C | SaCL | 7.68 | 7.57 | 15.54 | 69.29 | 7.74 | 1.75 | 0.17 | 0.19 | 101.39 | 36.50 | 0.31 | 0.13 | 165 | 341 |
| 20 | L | L | 7.65 | 7.44 | 22.77 | 37.70 | 12.27 | 9.56 | 0.21 | 0.22 | 90.39 | 39.22 | 0.52 | 0.42 | 94 | 340 |
| Minimum | | | 6.83 | 6.85 | 0.04 | 0.09 | 1.15 | 1.75 | 0.09 | 0.11 | 7.48 | 4.35 | 0.07 | 0.09 | 94 | 192 |
| Maximum | | | 7.78 | 7.78 | 58.35 | 73.45 | 37.81 | 14.32 | 0.26 | 0.25 | 216.12 | 268.78 | 1.31 | 0.80 | 979 | 852 |
| Average | | | 7.31 | 7.25 | 13.05 | 17.04 | 10.924 | 7.2105 | 0.179 | 0.18 | 91.5 | 63.36 | 0.432 | 0.373 | 469.1 | 419.8 |
| Std Dev. | | | 0.26 | 0.22 | 19.09 | 23.81 | 7.7569 | 3.6128 | 0.042 | 0.038 | 52.2 | 60.87 | 0.304 | 0.201 | 250 | 182.3 |
| Variance | | | 0.07 | 0.05 | 364.3 | 566.8 | 60.169 | 13.052 | 0.002 | 0.001 | 2725 | 3705 | 0.092 | 0.041 | 62507 | 33234 |

1: 0-10 cm; 2: 10-20 cm; ST: soil type; C: Clay; CL: Clay loam; L: Loam; SaL: Sandy loam; SaCL: Sandy Clay loam; SiC: Silty clay; OM: Organic matter

**Table 2. (*continued*)** Physical and chemical analysis results and descriptive statistics of soils

| Plot | Na1 | Na2 | Ca1 | Ca2 | Mg1 | Mg2 | Fe1 | Fe2 | Cu1 | Cu2 | Zn1 | Zn2 | Mn1 | Mn2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ppm | | ppm | | ppm | | ppm | | ppm | | ppm | | ppm | |
| 1 | 46 | 49 | 8378 | 8042 | 438 | 323 | 2.31 | 2.36 | 0.488 | 0.494 | 0.327 | 0.279 | 0.95 | 1.17 |
| 2 | 45 | 45 | 5388 | 5612 | 899 | 833 | 2.32 | 2.31 | 0.462 | 0.465 | 0.296 | 0.282 | 1.04 | 1.23 |
| 3 | 49 | 49 | 6444 | 5996 | 268 | 220 | 2.33 | 2.36 | 0.505 | 0.500 | 0.342 | 0.464 | 1.20 | 0.89 |
| 4 | 49 | 51 | 6835 | 7195 | 883 | 872 | 2.42 | 2.54 | 1.242 | 0.820 | 1.518 | 1.112 | 1.70 | 1.66 |
| 5 | 59 | 61 | 6705 | 6953 | 867 | 876 | 2.56 | 2.53 | 0.967 | 0.785 | 0.967 | 0.678 | 1.28 | 1.63 |
| 6 | 58 | 65 | 7319 | 7649 | 378 | 349 | 2.60 | 2.35 | 0.727 | 0.830 | 0.844 | 0.830 | 1.04 | 1.18 |
| 7 | 58 | 57 | 7959 | 7873 | 437 | 370 | 2.30 | 2.26 | 0.558 | 0.765 | 1.605 | 0.436 | 1.09 | 1.16 |
| 8 | 53 | 53 | 8770 | 7810 | 390 | 273 | 2.29 | 2.32 | 0.733 | 0.620 | 0.377 | 0.307 | 1.28 | 1.12 |
| 9 | 52 | 51 | 6252 | 6078 | 446 | 325 | 2.32 | 2.33 | 1.853 | 0.983 | 1.607 | 1.074 | 1.42 | 1.55 |
| 10 | 49 | 50 | 6475 | 6414 | 806 | 831 | 2.33 | 2.34 | 0.998 | 0.935 | 1.377 | 1.025 | 1.21 | 1.22 |
| 11 | 46 | 44 | 5794 | 4792 | 1012 | 946 | 2.32 | 2.39 | 0.582 | 0.572 | 0.286 | 0.241 | 1.38 | 1.41 |
| 12 | 52 | 48 | 3578 | 3910 | 446 | 341 | 2.26 | 2.29 | 1.280 | 1.218 | 2.290 | 1.337 | 1.63 | 1.96 |
| 13 | 45 | 49 | 4429 | 5040 | 130 | 187 | 2.35 | 2.38 | 0.515 | 0.629 | 0.237 | 0.296 | 1.61 | 1.71 |
| 14 | 51 | 53 | 5708 | 5965 | 324 | 312 | 2.38 | 2.43 | 1.358 | 1.121 | 1.873 | 1.671 | 1.71 | 1.71 |
| 15 | 48 | 51 | 6901 | 6311 | 935 | 907 | 2.45 | 2.09 | 0.914 | 0.560 | 0.374 | 0.246 | 1.79 | 1.54 |
| 16 | 51 | 55 | 6142 | 6248 | 203 | 150 | 1.97 | 1.95 | 2.236 | 1.985 | 3.192 | 2.100 | 0.47 | 0.27 |
| 17 | 58 | 50 | 10704 | 8384 | 949 | 932 | 2.23 | 2.17 | 0.694 | 0.587 | 2.036 | 0.248 | 0.43 | 0.41 |
| 18 | 43 | 43 | 6512 | 4422 | 231 | 119 | 2.04 | 2.04 | 0.527 | 0.577 | 0.162 | 0.066 | 0.46 | 0.41 |
| 19 | 49 | 44 | 9122 | 5282 | 231 | 73 | 2.07 | 2.03 | 0.456 | 1.322 | 0.106 | 0.091 | 0.20 | 0.76 |
| 20 | 53 | 50 | 10086 | 8388 | 351 | 233 | 2.14 | 2.10 | 0.856 | 0.814 | 0.081 | 0.094 | 0.21 | 0.35 |
| Min. | 43 | 43 | 3578 | 3910 | 130 | 73 | 1.97 | 1.95 | 0.456 | 0.465 | 0.081 | 0.066 | 0.20 | 0.27 |
| Max. | 59 | 65 | 10704 | 8388 | 1012 | 946 | 2.60 | 2.54 | 2.236 | 1.985 | 3.192 | 2.100 | 1.79 | 1.96 |
| Ave. | 50.7 | 50.9 | 6975.05 | 6418.2 | 531.2 | 473.6 | 2.3 | 2.279 | 0.898 | 0.829 | 0.995 | 0.644 | 1.105 | 1.167 |
| Std_D | 4.758 | 5.515 | 1778.11 | 1340.5 | 297.8 | 320.27 | 0.157 | 0.164 | 0.487 | 0.367 | 0.891 | 0.573 | 0.508 | 0.507 |
| Var. | 22.64 | 30.41 | 3161667 | 1796824 | 88694 | 102575 | 0.025 | 0.027 | 0.237 | 0.134 | 0.793 | 0.328 | 0.258 | 0.257 |

1: 0-10 cm; 2: 10-20 cm; ST: soil type; C: Clay; CL: Clay loam; L: Loam; SaL: Sandy loam; SaCL: Sandy Clay loam; SiC: Silty clay; OM: Organic matter

### 3.2. Essential Oil and Chemical Compounds

A total of 75 different chemical compounds were identified in the essential oils of *O. minutiflorum* (Table 3). Looking at the chemical compounds, the most abundant compound was carvacrol, followed by p-cymene and γ-terpinene. The most important and abundant chemical component group is the oxygenated monoterpene group (84–91%), which includes carvacrol. The highest concentration of oxygenated monoterpene was found in Antalya, Saklikent (91%), and Feslikan Plateau (89%), while the lowest concentrations were in sample area 4 (Kumluca, Anbarkatran) (83.3%) and sample area 20 (Aksu-Karacahisar Village-Beltasi) (83.8%). Monoterpene hydrocarbons, which ranked second, were most abundant in sample areas 20 (13.5%) and 18 (12.7%).

**Table 3.** The chemical component profiles (%) of *O. minutiflorum* from different localities

| RRI | Compounds | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1032 | α-Pinene | 0.5 | 0.4 | 0.6 | 0.6 | 0.4 | 0.6 | 0.5 | 0.5 | 0.5 | 0.5 | 0.6 | 0.7 | 0.6 | 0.5 | 0.7 | 0.7 | 0.7 | 0.8 | 0.6 | 0.6 |
| 1035 | α-Thujene | 0.5 | 0.5 | 0.6 | 0.6 | 0.5 | 0.5 | 0.4 | 0.5 | 0.5 | 0.5 | 0.6 | 0.6 | 0.6 | 0.5 | 0.6 | 0.7 | 0.6 | 0.9 | 0.7 | 0.6 |
| 1076 | Camphene | 0.3 | 0.1 | 0.5 | 0.4 | 0.2 | 0.4 | 0.1 | 0.2 | 0.3 | 0.3 | 0.3 | 0.4 | 0.4 | 0.3 | 0.6 | 0.4 | 0.7 | 0.7 | 0.3 | 0.3 |
| 1118 | α-Pinene | 0.1 | 0.1 | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.1 |
| 1132 | Sabinene | tr | tr | tr | tr | tr | | | | | | tr | tr | tr | tr | | | | | tr | |
| 1159 | α-3-Carene | 0.1 | 0.1 | 0.1 | 0.1 | tr | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| 1174 | Myrcene | 1.0 | 1.2 | 1.3 | 1.3 | 1.4 | 1.4 | 1.4 | 1.5 | 1.1 | 1.3 | 1.2 | 1.5 | 1.6 | 0.3 | 1.4 | 1.5 | 1.5 | 1.6 | 1.6 | 1.5 |
| 1176 | α-Phellandrene | tr | tr | tr | tr | 0.1 | | | | tr | | 0.1 | tr | tr | 0.1 | tr | 0.1 | tr | tr | tr | tr |
| 1188 | α-Terpinene | 0.5 | 0.6 | 0.6 | 0.6 | 0.9 | 0.8 | 0.7 | 0.8 | 0.6 | 0.6 | 0.5 | 0.8 | 0.8 | 0.7 | 0.3 | 0.8 | 0.7 | 0.9 | 0.9 | 0.9 |
| 1203 | Limonene | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| 1218 | β-Phellandrene | 0.1 | 0.2 | 0.2 | 0.2 | 0.3 | 0.2 | 0.2 | 0.2 | 0.1 | 0.2 | 0.3 | 0.2 | 0.3 | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 |
| 1255 | α-Terpinene | 1.2 | 1.8 | 2.2 | 1.7 | 3.6 | 3.6 | 2.4 | 3.4 | 1.6 | 1.2 | 1.7 | 3.2 | 3.5 | 2.1 | 2.5 | 3.1 | 2.9 | 3.5 | 3.6 | 4.1 |
| 1266 | (*E*)-β-Ocimene | | | tr | tr | tr | | | tr | tr | | tr | tr | tr | 0.1 | | tr | tr | tr | tr | tr |
| 1280 | *p*-Cymene | 3.0 | 2.8 | 3.1 | 3.7 | 3.4 | 3.6 | 4.1 | 3.9 | 3.6 | 3.1 | 3.3 | 3.3 | 3.5 | 3.5 | 3.5 | 3.0 | 3.1 | 3.5 | 3.5 | 4.6 |
| 1547 | Dihydroachillene | tr | | | | | | | | | | | | | | | | | tr | | |
| 1213 | 1.8-Cineole | 0.2 | 0.5 | 0.5 | 0.4 | 0.1 | 0.3 | 0.2 | 0.2 | 0.5 | 0.2 | 0.1 | 0.3 | 0.1 | 0.2 | 0.3 | 0.2 | 0.3 | 0.4 | 0.2 | 0.2 |
| 1474 | *trans*-Sabinene hydrate | 0.8 | 1.2 | 1.2 | 1.1 | 0.8 | 1.1 | 0.9 | 0.9 | 1.0 | 0.9 | 0.9 | 1.0 | 0.7 | 0.9 | 0.9 | 0.8 | 0.9 | 1.0 | 0.7 | 1.4 |
| 1532 | Camphor | | | | | | | | | | | | | | | | | | tr | | |
| 1553 | Linalool | tr | tr | 0.1 | 0.1 | tr | 0.1 | 0.1 | 0.1 | 0.1 | tr | tr | tr | 0.1 | | 0.1 | tr | tr | 0.1 | 0.2 | 0.1 |
| 1556 | *cis*-Sabinene hydrate | 0.3 | 0.4 | 0.4 | 0.4 | 0.3 | 0.4 | 0.3 | 0.3 | 0.4 | 0.3 | 0.3 | 0.3 | 0.3 | 0.4 | 0.3 | 0.3 | 0.3 | 0.4 | 0.3 | 0.4 |
| 1571 | *trans*-*p*-Menth-2-en-1-ol | 0.2 | 0.1 | 0.1 | tr | tr | 0.1 | tr | | 0.1 | tr | tr | tr | tr | 0.1 | 0.1 | tr | tr | 0.1 | tr | tr |
| 1611 | Terpinen-4-ol | 0.3 | 0.7 | 0.8 | 0.7 | | | | | 0.1 | | 0.1 | 0.5 | 0.1 | 0.4 | tr | 0.5 | | 0.6 | 1 | 0.7 |
| 1614 | Carvacrol methyl ether (=Methyl carvacrol) | | | | 0.1 | 1.2 | 0.2 | 0.2 | 0.1 | 0.1 | tr | tr | | tr | 0.1 | tr | | | 0.1 | | tr |
| 1629 | *trans*-Dihydrocarvone | | | | | tr | | 0.1 | 0.1 | 0.1 | | 0.1 | | | 0.1 | | | | | | tr |
| 1638 | *cis*-*p*-Menth-2-en-1-ol | tr | tr | | | tr | | | | tr | | tr | tr | tr | tr | | tr | | | tr | |
| 1645 | *cis*-Isodihydrocarvone | tr | tr | tr | 0.1 | tr | 0.1 | 0.1 | 0.1 | 0.1 | tr | tr | tr | tr | tr | 0.1 | tr | | tr | tr | |
| 1670 | *trans*-Pinocarveol | tr | tr | | | tr | | | | tr | | | tr | | | | | | | | |
| 1682 | δ-Terpineol (=*p*-1(7)-*menthen*-8-ol) | | tr | tr | | | | | | tr | | | tr | 0.1 | | 0.1 | | | | | tr |
| 1688 | *trans*-Verbenol | | | | | | | | | tr | | | | | tr | | | | | | |
| 1697 | Carvotanacetone | tr | | | tr | | | | | tr | | | | | | | | | | | |
| 1703 | Salicylaldehyde | | | tr | | | | | | | | | | | | | | | | | |
| 1706 | α-Terpineol | 0.2 | 0.4 | 0.4 | 0.3 | 0.2 | 0.3 | 0.2 | 0.3 | 0.3 | 0.2 | 0.2 | 0.3 | 0.2 | 0.3 | 0.2 | 0.2 | 0.3 | 0.3 | 0.2 | 0.3 |
| 1719 | Borneol | 1.3 | 0.4 | 1.8 | 1.5 | 0.6 | 1.4 | 0.2 | 0.5 | 1.0 | 0.9 | 0.8 | 1.3 | 0.9 | 1.4 | 2.0 | 1.3 | 2.3 | 2.2 | 1.0 | 1.3 |
| 1751 | Carvone | 0.1 | | 0.1 | 0.1 | tr | 0.1 | tr | 0.1 | tr | tr | tr | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | tr |
| 1864 | *p*-Cymen-8-ol | | tr | tr | tr | tr | tr | tr | tr | tr | tr | tr | tr | tr | tr | tr | tr | tr | tr | tr | tr |
| 1880 | Myrcen-8-ol | 0.1 | | 0.1 | 0.1 | | | | 0.1 | tr | 0.1 | tr | tr | | tr | | 0.1 | 0.1 | 0.1 | | |
| 1890 | Carvacryl acetate | | | | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | tr | tr | tr | | | 0.1 | | tr | 0.1 | 0.1 | 0.1 | tr |
| 1969 | *cis*-Jasmone | | tr | | | tr | | | | | | | | | | | tr | | | | tr |
| 2198 | Thymol | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.7 |
| 2239 | Carvacrol | 87 | 86 | 82 | 83 | 82 | 79 | 84 | 83 | 83 | 86 | 85 | 82 | 82 | 84 | 82 | 83 | 81 | 79 | 82 | 79 |
| 1535 | β-Bourbonene | | | | | | | | | | | | tr | tr | | | | | | | |
| 1594 | *trans*-β-Bergamotene | | | | tr | tr | | | | | | tr | | | | | | | | | |
| 1610 | Calarene (=β-*gurjunene*) | 0.1 | | | | | | | | | | | | | | | | | | tr | |
| 1612 | β-Caryophyllene | 1.7 | 1.5 | 2 | 1 | 1.9 | 3.1 | 2.2 | 2.2 | 2.7 | 2.1 | 2.2 | 2.2 | 2 | 0.4 | 2.5 | 1.2 | 2.3 | 1.7 | 1.7 | 1.6 |
| 1628 | Aromadendrene | 0.2 | 0.4 | 0.2 | 0.4 | 0.2 | 0.3 | 0.3 | 0.3 | 0.2 | 0.2 | 0.1 | 0.4 | 0.2 | 0.2 | 0.3 | 0.2 | 0.5 | 0.3 | 0.3 | 0.2 |
| 1631 | Selina-5.11-diene | tr | tr | tr | tr | tr | | | | | | | | tr | tr | | tr | tr | | | |
| 1661 | Alloaromadendrene | tr | tr | | | tr | | | | tr | | tr | tr | tr | tr | | | | | tr | |
| 1687 | α-Humulene | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| 1708 | Ledene | | 0.2 | | | tr | | 0.1 | | 0.1 | | 0.1 | tr | 0.2 | 0.2 | | | | | | tr |
| 1726 | Germacrene D | | | | | | | | | | | | tr | | | | | | | | |
| 1741 | β-Bisabolene | | 0.1 | 0.2 | 0.5 | 0.2 | 0.6 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | tr | tr | tr | | | | tr | 0.1 | tr |

RRI:Recreative Retention Index; ***:** tentative identification; tr: trace

**Table 3. (*continued*)** The chemical component profiles (%) of *O. minutiflorum* from different localities

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1755 | Bicyclogermacrene | | tr | | | 0.1 | | | | 0.1 | | tr | | tr | | | | tr | 0.1 | | tr |
| 1773 | δ-Cadinene | tr | tr | | tr | tr | | | | tr | | tr | | tr | | | tr | tr | tr | tr | tr |
| 1779 | γ-Cadinene | | | | | | | | | tr | | tr | | | | | | tr | tr | tr | tr |
| 1784 | (*E*)-α-Bisabolene | | | | tr | | 0.2 | 0.1 | | | tr | tr | | | | | | | | | |
| 2001 | Isocaryophyllene oxide | | | | | tr | tr | tr | tr | tr | | tr | | tr | tr | | | | | | tr |
| 2008 | Caryophyllene oxide | 0.1 | 0.1 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.2 | 0.3 | 0.2 | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 | 0.1 | 0.1 | 0.2 | 0.1 | 0.3 |
| 2098 | Globulol | tr | 0.1 | tr | | | tr | | 0.1 | tr | tr | | tr | tr | tr | tr | tr | 0.1 | tr | tr | |
| 2104 | Viridiflorol | | | | | | | | | | | | | | | | tr | | | | |
| 2143 | Rosifoliol | | tr | | | | | | | | | | | | | | | | | | |
| 2144 | Spathulenol | 0.1 | 0.2 | 0.1 | 0.2 | 0.1 | 0.2 | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | 0.1 | 0.2 | 0.1 | 0.2 | 0.1 |
| 2264 | Intermedeol | | | | | | | | | tr | | | | | | | | | | | |
| 2392 | Caryophyllenol II | | | | | | | | | tr | | tr | | tr | 0.1 | | | | | | |
| 2931 | Hexadecanoic acid | | | | | tr | | | | 0.6 | | tr | | tr | 0.1 | | | | | | |
| 1225 | (Z)-3-Hexenal | | | | | tr | | | | | | tr | | tr | | | | | | tr | |
| 1051 | 2.5-Dimethyltetrahydrofuran | | tr | tr | | | tr | tr | tr | | | tr | tr | tr | | | | tr | | tr | |
| 1024 | Methyl 3-methyl-butyrate (=methyl isovalerate) | | | 0.1 | | | tr | | tr | | tr | tr | | tr | | | | tr | | tr | |
| 1391 | (Z)-3-Hexenol | | | | | | tr | | tr | | | tr | | tr | | tr | tr | tr | tr | tr | |
| 1393 | 3-Octanol | | tr | | tr | 0.1 | 0.1 | 0.1 | tr | tr | | tr | tr | tr | tr | tr | tr | 0.1 | 0.1 | tr | tr |
| 1452 | 1-Octen-3-ol | tr | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.2 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.2 | 0.3 | 0.3 | 0.3 | 0.4 |
| 1482 | (Z)-3-Hexenyl-2-methyl butyrate | | | | | | | tr | | | | tr | | | | tr | | | | | |
| 1505 | Dihydroedulane II | | | tr | | tr | | | | | | | tr | | | | tr | | tr | tr | |
| 1798 | Methyl salicylate | tr | tr | tr | tr | tr | | | | tr | | tr | tr | | | tr | tr | tr | tr | tr | tr |
| 1940 | 4-Isopropyl salicylaldehyde | | tr | tr | 0.1 | tr | tr | tr | tr | tr | | tr | tr | tr | tr | tr | tr | tr | tr | tr | tr |
| 2186 | Eugenol | tr | | | | tr | | | | tr | | | | | | | tr | | | | |
| **Total** | | 100 | 100 | 100 | 100 | 99 | 100 | 99 | 100 | 100 | 99 | 99 | 100 | 100 | 100 | 99 | 100 | 100 | 100 | 100 | 99 |
| Monoterpene hydrocarbons | | 7.2 | 7.9 | 9.6 | 9.5 | 11 | 12 | 10 | 11 | 8.6 | 8 | 8.9 | 11 | 12 | 9.6 | 10 | 11 | 11 | 13 | 12 | 13 |
| Oxygenated monoterpenes | | 91 | 89 | 87 | 88 | 86 | 83 | 86 | 85 | 87 | 88 | 88 | 86 | 85 | 88 | 86 | 87 | 86 | 85 | 86 | 84 |
| Sesquiterpene hydrocarbons | | 2 | 2.2 | 2.4 | 1.9 | 2.4 | 4.4 | 2.9 | 2.6 | 3.3 | 2.6 | 2.6 | 2.7 | 2.4 | 1.8 | 2.9 | 1.5 | 2.8 | 2.1 | 2.2 | 1.9 |
| Oxygenated sesquiterpene | | 0.2 | 0.4 | 0.3 | 0.3 | 0.4 | 0.5 | 0.4 | 0.4 | 0.4 | 0.3 | 0.4 | 0.3 | 0.4 | 0.4 | 0.3 | 0.2 | 0.4 | 0.3 | 0.3 | 0.4 |
| Others | | 0 | 0.15 | 0.2 | 0.3 | 0.2 | 0.4 | 0.4 | 0.2 | 0.8 | 0.1 | 0.2 | 0.2 | 0.2 | 0.3 | 0.2 | 0.2 | 0.4 | 0.4 | 0.2 | 0.4 |

RRI:Recreative Retention Index; ***:** tentative identification; tr: trace

According to our study results, carvacrol is the most important chemical compound in the essential oils of *O. minutiflorum*, present in the highest proportion. The highest carvacrol concentration (87.15%) was found in plot 1 (Saklikent) at 1838 m. This is followed by plot 10 (Kemer – Yaylakuzdere – Cukuryayla) at 1580 m with 85.75%, and Antalya–Feslikan Plateau (plot 2) and plot 11 at 1882 m with 85.65%. The lowest carvacrol concentrations were found in Isparta – Aksu – Karacahisar Village (1127 m) with 78.75%, Antalya-Demre-Cagman Plateau (1760 m) with 79.15%, and Beydilli Village (1503 m) with 79.30% (Table 4).

Özkum et al. (2010) determined that the essential oils of *O. minutiflorum*, collected in the same area during the flowering period, contained 78.6% carvacrol and 7.7% *p*-cymene. In our study, the carvacrol content of *O. minutiflorum* during the flowering period varied between 78.75% and 87.15%. The chemical compounds following carvacrol were γ-terpinen (1.15-4.1%), *p*-cymene (2.75-4.55%), and β-caryophyllene (0.95-3.1%).

Essential oils obtained from *O. minutiflorum* leaves in the Isparta-Sütçüler-Develi region during the spring contained γ-terpinene 6.2%, thymol 4.0%, *p*-cymene 2.1%, and carvacrol 83.9% (Gülsoy et al. 2008). In Antalya–Yaylakuzdere, during the flowering period, at altitudes of 1100 and 1500 meters, the carvacrol content in the above-ground parts of *O. minutiflorum* varied between 90.8-93.0%, α-terpineol 1.1-0.7%, terpinen-4-ol 1.2-0.5%, and *p*-cymene 1.3-1.0% (Şarer et al., 1996). From the above-ground parts of *O. minutiflorum* in Isparta–Sütçüler–Söğüt Plateau during the flowering period (September), 73.93% carvacrol, 7.2% *p*-cymene and 3.99% γ-terpinene were obtained (Aslım and Yücel, 2008). The essential oils from the above-ground parts of the plant collected in the same area and period contain 74.0% carvacrol, 7.2% *p*-cymene, and 4.0% γ-terpinene (Altundağ et al., 2011). In the natural habitat of the species, the most abundant chemical compounds in the essential oils obtained from the above-ground parts collected during the flowering period are 85.1% carvacrol, 7.1% *p*-cymene, and 2.1% borneol (Çetin et al., 2009). Furthermore, in a study examining the changes in chemical composition of *O. minutiflorum* according to different hydrodistillation times, the highest amount of carvacrol (84.35±1.71%) was obtained at 30 minutes (Toker et al., 2017). According to these results, the yield and chemical composition of essential oils show similar results to our studies. However, essential oil yields and chemical compositions can change over the years (temporal) as well as with hydrodistillation time.

**Table 4.** The percentage of main chemical compounds and essential oil yields from *O. minutiflorum* localities

| Plot | Compounds≥3% | | | | Essential oil yield |
|---|---|---|---|---|---|
| | γ-Terpinene | *p*-Cymene | β-Caryophyllene | Carvacrol | mL/100g |
| 1 | 1.15 | 2.95 | 1.65 | 87.15 | 4.21 |
| 2 | 1.80 | 2.75 | 1.50 | 85.65 | 3.74 |
| 3 | 2.15 | 3.05 | 2.00 | 81.95 | 3.82 |
| 4 | 1.65 | 3.65 | 0.95 | 83.30 | 3.62 |
| 5 | 3.60 | 3.40 | 1.90 | 82.20 | 3.82 |
| 6 | 3.60 | 3.60 | 3.10 | 79.15 | 3.76 |
| 7 | 2.40 | 4.10 | 2.20 | 83.90 | 3.30 |
| 8 | 3.35 | 3.85 | 2.15 | 82.60 | 3.55 |
| 9 | 1.55 | 3.60 | 2.65 | 83.05 | 3.94 |
| 10 | 1.15 | 3.10 | 2.10 | 85.75 | 5.18 |
| 11 | 1.70 | 3.25 | 2.15 | 85.10 | 4.52 |
| 12 | 3.15 | 3.30 | 2.20 | 81.60 | 4.08 |
| 13 | 3.45 | 3.45 | 2.00 | 82.35 | 3.69 |
| 14 | 2.05 | 3.50 | 1.35 | 84.05 | 4.26 |
| 15 | 2.50 | 3.50 | 2.45 | 81.95 | 3.85 |
| 16 | 3.10 | 3.00 | 1.20 | 83.45 | 4.27 |
| 17 | 2.85 | 3.05 | 2.25 | 81.05 | 3.81 |
| 18 | 3.50 | 3.50 | 1.65 | 79.30 | 3.66 |
| 19 | 3.60 | 3.50 | 1.70 | 81.90 | 3.95 |
| 20 | 4.10 | 4.55 | 1.60 | 78.75 | 3.82 |
| Minimum | 1.15 | 2.75 | 0.95 | 78.75 | 3.30 |
| Maximum | 4.10 | 4.55 | 3.100 | 87.15 | 5.18 |
| Average±Std D | 2.62±0.92 | 3.43±0.42 | 1.94±0.51 | 82.71±2.22 | 3.94±0.41 |
| Variance | 0.851 | 0.175 | 0.257 | 4.933 | 0.164 |

Cluster analysis performed using the PC-ORD program based on chemical compounds and essential oil yield (Figure 2) divided the *O. minutiflorum* localities into three main groups. The sample areas forming the first group are closer to each other (plots 1, 2, 10, and 11) and are distinguished from the other groups by having the highest carvacrol content and the lowest γ-terpinene and *p*-cymene content in their essential oils. In the third group, *O. minutiflorum* localities (plots 6, 18, and 20) have higher γ-terpinene and *p*-cymene content and lower carvacrol content (Figure 3).

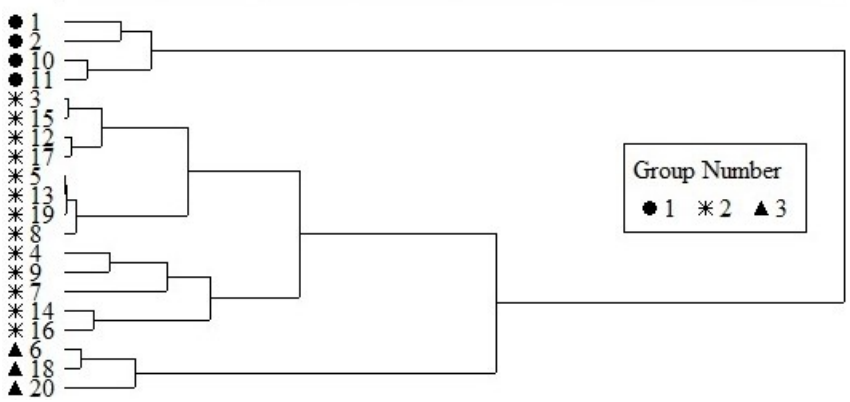



**Figure 2.** Dendrogram showing the grouping of *Origanum minutiflorum* sampling localities based on essential oil composition and yield (Ward's method, Jaccard distance).

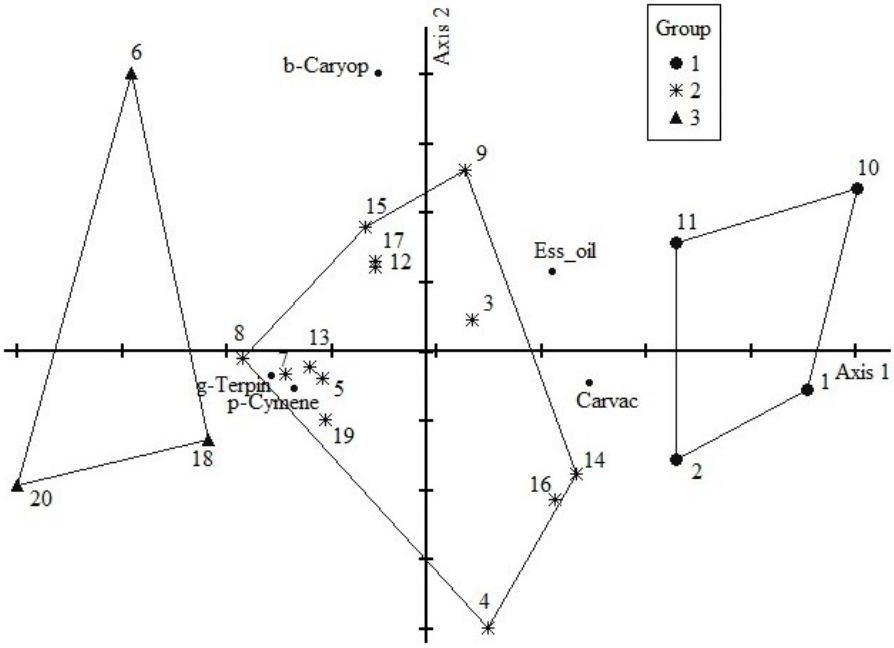



**Figure 3.** Chemical compounds and essential oil yield parameters that differentiated the cluster groups (γ-terpinene, *p*-cymene, carvacrol, β-caryophyllene)

According to the PCA analysis results, only the eigenvalue of axis 1 (2.643) was found to be greater than 1. Axis 1 was found to explain 52.87% of the variance. According to the correlation analysis results, which was carried out to determine which site characteristics could affect the major chemical compounds and essential oil yield, no environmental variable showing a high correlation (≥0.5) was found. Indeed, Başer et al. (1993) stated that *O. majorana* and *O. minutiflorum* oils contain carvacrol at rates of 78.3-79.5% and 75.1-83.6%, respectively, and are much more stable than other *Origanum* species. The results of the numerical analysis supported the stability of the chemical content of *O. minutiflorum* essential oils in their natural distribution areas.

The highest oil content of *O. minutiflorum* was 5.18 mL/100g in sample plot 10 at 1580 meters (Antalya–Kemer–Cukuryayla). This was followed by sample plot 11 with 4.52 mL/100g, sample plot 16 with 4.27 mL/100g, sample plot 14 with 4.26 mL/100g, and plot 2 with 4.21% (Table 4). Şarer et al. (1996) found the essential oil content in the above-ground parts of *O. minutiflorum* during its flowering period (Antalya–Yaylakuzdere, 1100 - 1500 m) to be 4.3-5.3% (mL/g). The lowest oil yield was 3.30 mL/100 g, which was determined in the Antalya–Demre–Cagman Plateau at 1762 m and in the Antalya–Finike–Ordibek Plateau at 1586 m (3.55 mL/100 g) (Table 4). Studies on *Origanum* species indicate an increase in plant productivity as soil nitrogen content increases (Ceylan, 1983; Ömer, 1999). However, in our study, no environmental variable showing a significant relationship between the oil yield and chemical compounds of *O. minutiflorum* was found. The essential oil yield and chemical compounds of *O. minutiflorum* can be affected by factors other than the environmental variables we examined. For example, Novak et al. (2011) determined that thymol decreased and carvacrol increased with increasing temperature in the essential oils of *Origanum vulgare* x *Origanum majorana* cultivars and *Origanum syriacum* species grown under different temperature conditions, showing that the synthesis of both similar monoterpene phenols was affected in opposite directions by temperature.

In a study comparing the essential oils of *O. minutiflorum* leaves at different stages in the Devebeli locality of Isparta–Sutculer, the highest essential oil yield (4.9%) was obtained from samples collected at the beginning of flowering and during flowering (3.8%). The highest carvacrol content (92.3%) was obtained from samples collected at the end of flowering and during flowering (86.5%) (Baydar, 2005). In our study, the lowest oil yield in the above-ground parts of the plant and during flowering was found in only one locality with 3.3%. The highest oil yield was 5.18%, which is higher than the highest oil yield (4.9%) found by Baydar (2005) before flowering. Therefore, it can be stated that essential oil yield varies according to different environmental conditions, collection time, and the developmental stage of the plant.

## 4. Conclusions

The demand for medicinal and aromatic plants is continuously increasing. Cultivation of these species is necessary to protect their populations in their natural habitats. Success in cultivation efforts depends primarily on understanding the ecological requirements of each species.

It was found that the various habitats of the species were stable in terms of essential oil yield and chemical compounds. In the cluster analysis, Antalya, Feslikan Plateau, Saklikent, Yaylakuzdere, and Cukuryayla were grouped

together. Although these values may change in subsequent years, considering the results of all other studies, Antalya–Kemer–Cukuryayla stands out in terms of both essential oil yield and the highest carvacrol yield.

In our study, the habitat requirements of the species were determined. *O. minutiflorum* prefers sloping, rocky hillsides. Generally, it grows in very slightly or high calcareous, moderately alkaline to slightly acidic soils. It is distributed in soils with medium to high organic matter content. It can grow in various soil types, ranging from clay soils to loamy soils. Its natural distribution area is above 1000 meters. The species seems to prefer higher altitudes with cold winters, far from the influence of the sea. Therefore, considering this information is crucial in cultivating this species. Further studies are needed on agronomic performance under cultivation conditions and the selection of high-yielding individuals.

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**Conflict of Interest**

The authors declare that they have no conflicts of interest.

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