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ORIGINAL ARTICLE

GC-MS characterization of the essential oil from *Teucrium kotschyanum* Poech (Lamiaceae) and its antimicrobial assessment

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Abstract: The genus *Teucrium* L., a member of the Lamiaceae family, is represented by approximately 36 species in Türkiye. In this study, the essential oil composition of the aerial parts of *Teucrium kotschyanum* Poech collected from İzmir (Ödemiş) was investigated by gas chromatography (GC) and gas chromatography-mass spectrometry (GC-MS) for the first time. The major compounds were identified as germacrene D (20.0%), α-cadinol (6.9%), β-bourbonene (6.6%), hexadecanoic acid (6.6%), δ-cadinene (5.9%) and manool (4.1%). The antibacterial and antifungal activities of the essential oil were evaluated against six bacteria and six fungi using the microdilution broth method. The essential oil exhibited limited antimicrobial activity, with the highest efficacy observed against *Candida utilis* (MIC: 125 μg/mL) and the lowest against *Staphylococcus epidermidis* and *Salmonella typhimurium* (MIC: 2000 μg/mL).

Keywords: *Teucrium kotschyanum* Poech, Lamiaceae, essential oil, GC-MS, antimicrobial activity

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1 Introduction

Türkiye is a significant gene center for the Lamiaceae family, which is known for its rich diversity of secondary metabolites. Many Lamiaceae species are widely used in traditional medicine for the treatment of various ailments (El Guiche et al., 2015). Within this family, the genus *Teucrium* L. is represented in Türkiye by 36 species (48 taxa), 17 of which are endemic (Govaerts, 1999; Duman, 2000; Dönmez, 2006; Parolly and Eren, 2007; Dönmez et al., 2010; Dinç et al., 2011a; 2011b; Dirmenci, 2012; Özcan et al., 2015; Vural et al., 2015). *Teucrium* species have been utilized as medicinal plants for over 2000 years due to their antioxidant, antimicrobial, and anti-inflammatory properties (Vukovic et al., 2011; Rehman et al., 2016). They are commonly employed in folk medicine to treat diabetes, gastric ulcers, and intestinal inflammation, as well as for their diuretic, antiseptic, and antihelminthic effects (Menichini et al., 2009; Rehman et al., 2016). In Greek folk medicine, an infusion of the aerial parts of *Teucrium flavum* L. has been traditionally consumed orally for its antidiabetic properties and applied externally as an astringent to promote wound healing and alleviate skin eruptions (Bellomaria et al., 1998). Among the most widely distributed *Teucrium* species in Türkiye, *T. chamaedrys* L. and *T. polium* L. hold great medicinal significance. In the Bilecik region, infusions made from the aerial parts of *T. chamaedrys* L. subsp. *chamaedrys* are consumed as a remedy for mouth ulcers and kidney infections, while *T. polium* L. is traditionally used as an appetite stimulant and carminative, as well as for stomach pain and wound healing (Ünsal et al., 2010). Additionally, in the Aydıncık district of Mersin, *T. polium* infusions are used to relieve stomachaches and as an analgesic (Sargın, 2015).

Phytochemical studies have revealed that *Teucrium* species are abundant sources of diterpenoids and contain monoterpenes, sesquiterpenes, triterpenes, iridoids, flavonoids, and essential oils (Çalış, 2025). Notably, this genus is one of the richest sources of neo-clerodane diterpenes. The aerial parts of *Teucrium* L. species are well-known for producing essential oils, which have been the subject of extensive research due to their biological properties. Many species of this genus are utilized in the food industry for their antimicrobial, antioxidant, and antifungal activities, making them valuable as natural preservatives (Ulubelen et al., 2000).

In Türkiye, *Teucrium* species are classified into eight sections in the Flora of Turkey (Ekim, 1982). *Teucrium kotschyanum* Poech, a member of sect. Scorodonia (Hill.) Schreber, is a perennial rhizomatous herb that can grow up to 80 cm in height. It produces yellow-green flowers and

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blooms between May and July. Though it is rarely used in traditional medicine, it has been reported to possess antipyretic and antidiabetic properties (Arnold, 1985). Phytochemical analyses of the aerial parts of *T. kotschyanum* Poech have identified three neo-clerodane diterpenoids (12-epiteucvidin, 12-epiteuflin, and teukotschyn), along with ursolic acid, the flavones cirsimaritin and cirsiliol, and six previously known neo-clerodane diterpenoids (Simões et al., 1989). A comparative study on the essential oils of *T. cyprium* subsp. *cyprium* Boiss., *T. micropodioides* Rouy, *T. divaricatum* subsp. *canescens* Sieber, and *T. kotschyanum* Poech, which grow in Cyprus, revealed that caryophyllene, humulene, cubebene, and bourbonene were present in high concentrations, comprising up to 60% of the total essential oil content of *T. kotschyanum* (Arnold et al., 1991).

The medicinal potential of *Teucrium* species extends to their broad-spectrum antimicrobial properties (Jakovljević & Stanković, 2020). Previous studies indicate that these species exhibit greater activity against Gram-positive bacteria than Gram-negative bacteria and fungi, with their essential oils demonstrating stronger antimicrobial effects than their extracts. The essential oils of *T. orientale* L., *T. africanum* Thunb., *T. ramosissimum* Desf., *T. mascatence* Boiss., *T. yemense* Deflers, *T. massiliense* L., and *T. scorodonia* L. have been investigated for their antimicrobial activity, with *T. polium* L. emerging as one of the most extensively studied species due to its significant bioactivity (Jakovljević & Stanković, 2020).

In this study, the essential oil composition of the aerial parts of *Teucrium kotschyanum* Poech, collected from Türkiye (Ödemiş-İzmir) during the flowering stage, was analyzed using gas chromatography (GC) and gas chromatography-mass spectrometry (GC-MS). Additionally, the antibacterial and antifungal activities of the essential oil were evaluated against six bacterial and six fungal strains using the microdilution broth method.

2 Materials and Methods

2.1 Plant Material

Teucrium kotschyanum Poech was collected from Ödemiş-İzmir in June 2014, at full flowering stage. The aerial parts and roots of the plant were dried at room temperature. The plant material was identified by Assoc. Prof. Yeter Yeşil Cantürk and voucher specimens were deposited at the Herbarium of the Faculty of the Pharmacy, Istanbul University, Istanbul (ISTE 109573).

2.2 Isolation of Essential Oil (EO)

The aerial parts (100 g) of *T. kotschyanum* Poech were chopped into small pieces and soaked in water (distilled, 500 mL). The essential oil from the air-dried plant materials was isolated by hydrodistillation for 3 h, using a Clevenger-type apparatus. The obtained oil was dried over anhydrous sodium sulfate and stored at +4°C in the dark until analysis and testing.

2.3 Analysis of Essential Oil

The oils were analyzed by capillary Gas Chromatography (GC) and Gas Chromatography/Mass Chromatography (GC/MS) using a Agilent GC-MSD system.

2.4 Gas Chromatography/Mass Spectrometry Analysis

The GC-MS analysis was carried out with an Agilent 5975 GC-MSD system. Innowax FSC column (60 m × 0.25 mm, 0.25 µM film thickness) was used with helium as carrier gas (0.8 mL/min). GC oven temperature was kept at 60°C for 10 min and programmed to 220°C at a rate of 4°C/min, and kept constant at 220°C for 10 min and then programmed to 240°C at a rate of 1°C/min. Split ratio was adjusted at 40:1. The injector temperature was set at 250°C. Mass spectra were recorded at 70 eV. Mass range was from *m/z* 35 to 450.

2.5 Gas Chromatography Analysis

The GC analysis was carried out using an Agilent 6890N GC system. FID detector temperature was 300°C. To obtain the same elution order with GC-MS, simultaneous autoinjection was done on a duplicate of the same column applying the same operational conditions. Relative percentage amounts of the separated compounds were calculated from FID chromatograms. The analysis results are given in Table 1.

Identification of the essential oil components were carried out by comparison of their relative retention times with those of authentic samples or by comparison of their relative retention index (RRI) to series of *n*-alkanes. Computer matching against commercial (Wiley GC/MS Library, MassFinder 4.0 Library) (McLafferty & Stauffer, 1989; Hochmuth, 2008) and in-house "Başer Library of Essential Oil Constituents" built up by genuine compounds and components of known oils.

2.6 Antimicrobial Activity Assay

Antimicrobial activity against *Staphylococcus aureus* ATCC 43300, *Staphylococcus epidermidis* ATCC 14990, *Bacillus cereus* NRRL B-3711, *Bacillus subtilis* NRRL B-4378, *Pseudomonas aeruginosa* ATCC 10145, *Salmonella typhimurium* ATCC 14028, *Candida albicans* ATCC 10231, *Candida glabrata* ATCC 2001, *Candida krusei* ATCC 6258, *Candida parapsilosis* ATCC 22019, *Candida tropicalis* ATCC 1369 and *Candida utilis* NRRL Y-900 were evaluated by using partly modified CLSI microdilution broth methods M7-A7 and M27-A2 respectively (Methods for Dilution Antimicrobial Susceptibility Tests for Bacteria Grow Aerobically, Reference Method for Broth Dilution Antifungal Susceptibility Testing of Yeasts) (CLSI (NCCLS) M7-A7, 2006; CLSI (NCCLS) M27-A2, 2002). The essential oil was serially diluted two-fold in DMSO, ranging from 4000 to 7.8 µg/mL. Chloramphenicol (Merck), Ampicillin-Na (Merck), Amphotericin-B (Sigma-Aldrich) and Ketoconazol (Sigma-Aldrich) were used as standard antimicrobial agents.

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Table 1. The composition of the essential oil of *Teucrium kotschyanum* Poech

Compound	RRI[a(1–7)]	RRI[b]	%	IM
Sabinene	1098–1140[1]	1132	0.5	t_R, MS
β-Pinene	1085–1130[1; 2]	1118	0.4	t_R, MS
Myrcene	1140–1175[1]	1174	0.1	t_R, MS
Limonene	1178–1219[1]	1203	1.2	t_R, MS
γ-Terpinene	1222–1266[1]	1255	0.2	t_R, MS
p-Cymene	1246–1291[1]	1280	0.3	t_R, MS
Terpinolene	1261–1300[1]	1290	0.2	t_R, MS
1-Octen-3-ol	1438–1465[3]	1452	1.0	MS
α-Cubebene	1438–1480[1]	1466	0.1	MS
α-Copaene	1462–1522[1]	1497	1.2	MS
α-Bourbonene	1513–1530[3]	1528	0.5	MS
β-Bourbonene	1496–1546[1]	1535	**6.6**	MS
Linalool	1507–1564[1]	1553	2.8	t_R, MS
β-Ylangene	1547–1589[1]	1589	0.1	MS
β-Copaene	1550–1603[1]	1597	0.2	MS
Terpinen-4-ol	1564–1630[1]	1611	0.9	t_R, MS
β-Caryophyllene	1569–1632[4]	1612	**2.0**	t_R, MS
Alloaromadendrene	1624–1668[1]	1661	3.0	MS
epi-Zonarene		1677	0.1	MS
α-Humulene	1637–1689[1]	1687	2.2	t_R, MS
γ-Muurolene	1655–1714[1]	1704	1.2	MS
α-Terpineol	659–1724[5]	1706	1.1	t_R, MS
Bicyclosesquiphellandrene		1722	1.3	MS
Germacrene D	1676–1726[1]	1726	**20.0**	MS
α-Muurolene	686–1753[1]	1740	2.3	MS
δ-Cadinene	1722–1774[1]	1773	5.9	MS
γ-Cadinene	1735–1782[1]	1776	3.7	MS
Methyl salicylate	1727–1809[1]	1798	0.3	t_R, MS
α-Cadinene	1734–1803[1]	1807	0.4	MS
(*E*)-β-Damascenone	1789–1842[1]	1838	0.6	MS
Calamenene	1800–1853[1]	1849	0.7	MS
epi-Cubebol	1854–1928[1]	1900	0.4	MS
α-Calacorene	1893–1941[1]	1941	0.1	MS
Cubebol	1884–1964[1]	1957	0.7	MS
1-*endo*-Bourbonanol	1969, 2050[6]	1968	0.1	MS
γ-Calacorene		1984	0.1	MS
Caryophyllene oxide	1936–2023[4]	2008	0.8	t_R, MS
Salvial-4(14)-en-1-one	2016–2043[1]	2037	0.8	MS
(*E*)-Nerolidol	1995–2055[1]	2050	0.2	MS
Humulene epoxide-II	2003–2071[1]	2071	0.9	MS
Cubenol	2019–2090[1]	2080	0.6	MS
1-*epi*-Cubenol	2026–2090[1]	2088	0.7	MS
Viridiflorol	2041–2110[1]	2104	2.7	MS
Salviadienol		2130	0.7	MS
Hexahydrofarnesyl acetone	2096–213[1]	2131	0.9	MS
Spathulenol	2074–2150[1]	2144	0.2	MS
T-Cadinol	2126–2198[7]	2187	**2.5**	MS
T-Muurolol	2148–2209[7]	2209	**2.8**	MS
δ-Cadinol (=*Torreyol*)		2219	1.0	MS
α-Cadinol	2180–2255[1]	2255	**6.9**	MS
Dodecanoic acid	2442–2524[1]	2503	1.3	t_R, MS

(Continued)

Table 1. (Continued)

Compound	RRI[a(1–7)]	RRI[b]	%	IM
Manool	2370–2628[1]	2679	4.1	MS
Hexadecanoic acid	2862–2945[1]	2931	6.6	t_R, MS
Monoterpene Hydrocarbons			2.9	
Oxygenated Monoterpenes			4.8	
SesquiterpeneHydrocarbons			51.7	
Oxygenated Sesquiterpenes			22.0	
Fatty acid+esters			7.9	
Diterpenes			4.1	
Others			2.8	
Total			**96.2**	

Note: [a]Relative retention indices reported in the literature (1–7): [1]Babushok et al. (2011); [2]Demirci et al. (2025); [3]https://www.pherobase.com/database/kovats/kovats-detail-(06.06.2026) (El-Sayed, 2014); [4]Herrera-Sanabria et al. (2024); [5]Xu et al., 2025; [6]https://pubchem.ncbi.nlm.nih.gov/compound/ (06.06.2026) (PubChem, 2026); [7]https://webbook.nist.gov/chemistry/ (06.06.2026) (Linstrom & Mallard, 2001).
[b]Relative retention indices (RRI) experimentally determined against *n*-alkanes; %: calculated from FID data; IM: Identification method; t_R: identification based on the retention times of genuine compounds on the HP Innowax column; MS: identified on the basis of computer matching of the mass spectra with those of the Wiley and MassFinder libraries and comparison with literature data.

3 Results and Discussion

3.1 Chemical Composition of Essential Oil

In this study, we aimed to investigate the composition of the essential oil obtained from the aerial parts of *Teucrium kotschyanum* Poech collected in İzmir (Ödemiş)-Türkiye at the flowering stage by the use of GC and GC-MS. The yield of essential oil from the aerial parts of the plant was found to be 0.4%.

According to the *Teucrium* species studied and the plant origin, essential oil yields ranged from 0.05% to 1.5% and the amounts of main constituents (mono- and sesquiterpene hydrocarbons and oxygenated sesquiterpenes) differed notably (Ali et al., 2008; Saraçoğlu et al., 2007). The essential oil composition from the aerial parts of the *Teucrium kotschyanum* Poech were examined in our study and 53 constituents, representing 96.2% of the total components in the oil have been identified. Their retention indices and percentage composition are given in Table 1. The major compounds were identified as germacrene D (20.0%), α-cadinol (6.9%), β-bourbonene (6.6%), hexadecanoic acid (6.6%), δ-cadinene (5.9%), manool (4.1%). Other significant compounds were found as alloaromadendrene (3.0%) linalool (2.8%), T-muurolol (2.8%) viridiflorol (2.7%), T-cadinol (2.5%) and β-caryophyllene (2.0%).

3.2 Chemotaxonomic Evaluation

The essential oil from the aerial parts of *Teucrium kotschyanum* Poech was obtained by hydrodistillation, and the composition of this oil was analyzed by GC-MS. The yield of essential oils from the aerial parts of the plant was found to be 0.4%. The relative percent-ages and retention indices of the compounds in the essential oil are listed in Table 1.

53 constituents, representing 96.2% of the total components, were identified in the essential oil. The major compounds were identified as germacrene D (20.0%), α-cadinol (6.9%), β-bourbonene (6.6%), hexadecanoic acid (6.6%), δ-cadinene (5.9%), and manool (4.1%), other significant compounds were found as alloaromadendrene (3.0%), linalool (2.8%), T-muurolol (2.8%), viridiflorol (2.7%), T-cadinol (2.5%), and β-caryophyllene (2.0%).

Teucrium L. species are rich in essential oils, and the presence of various biologically ac-tive monoterpenoids and sesquiterpenoids with several biological activities has been reported. *Teucrium polium* L., *T. chamaedrys* L., *T. flavum* L. and *T. capitatum* L. are the most studied taxa in terms of volatile oil composition (De Martino et al., 2020). Phytochemical studies on the essential oils of *Teucrium* species showed that the major components of these oils are sesquiterpene hydrocarbons, such as germacrene D and β-caryophyllene, or monoterpene hydrocarbons, such as α- and β-pinene, and the taxa can be grouped into two different classes: sesquiterpene and monoterpene chemotypes (Hanoğlu et al., 2023).

Many *Teucrium* species growing in Türkiye have been investigated for their essential oil composition and the species *T. chamaedrys* L. (Bağcı et al., 2010), *T. chamaedrys* L. ssp. *chamaedrys* (Küçük et al., 2006), *T. chamaedrys* L. ssp. *lydium* (Küçük et al., 2006), *T. chamaedrys* L. ssp. *trapezunticum* (Kaya et al., 2009), *T. cavernarum* P.H. Davis (Kaya et al., 2013), *T. paederotoides* Boiss. (Kaya et al., 2013), *T. antitauricum* Ekim (Başer et al., 1999), *T. montanum* L. (Başer et al., 1997), *T. polium* L. (Hayta et al., 2017), *T. lamiifolium* d'Urv. ssp. *lamiifolium* (Doğu et al., 2013), *T. multicaule* Montbret & Aucher ex Benth. (Polat et al., 2010), *T. orientale* L. ssp. *orientale* (Küçükbay et al., 2011), *T. orientale* L. ssp. *puberulens* (Küçükbay et al., 2011), *T. parviflorum* (Hook.f.) Kattari & Salmaki (Bağcı et al., 2011), *T. pestalozzae* Boiss. and *T. sandrasicum* O. Schwarz (Başer et al., 1997) have been shown to contain germacrene D in their EOs as a major compound. The essential oils of *T. chamaedrys* L. subsp. *chamaedrys* and subsp. *lydium* growing northeast of Türkiye were found to contain germacrene D, α-pinene, β-caryophyllene, and β-pinene (Küçük et al., 2006). *T. cavernarum* P.H. Davis and *T. paederotoides* Boiss. which are endemic to Türkiye were reported to contain β-caryophyllene, germacrene D and caryophyllene oxide as major constituents in their essential oils (Kaya et al., 2013). In a previous study by Bezić et al. (2011), it was reported that essential oils from Croation *Teucrium* species (*T. polium*, *T. flavum*, *T. montanum* and *T. chamaedrys*) were characterized by a high proportion of β-caryophyllene and germacrene D. The essential oil obtained from the flowering aerial parts of *T. scordium* L. collected from North Iran was found to contain β-caryophyllene as the major constituent (Morteza-Semnani et al., 2007). The Corsican and Sardinian oils of *T. chamaedrys* L. were qualitatively similar, but differed according to the amount of their major components, β-caryophyllene and germacrene D (Muselli et al., 2009). The composition of the essential oil of *T. polium* L. subsp. *capitatum* from Corsica was investigated and the main components of the oil were found as α-pinene (28.8%), β-pinene (7.2%) and p-cymene (7.0%) (Cozzani et al., 2005). In Greece, carvacrol (10.1%), caryophyllene (9.8%), torreyol (7.6%) and caryophyllene oxide (5.0%) were found to be the major constituents of *T. polium* L. ssp. *capitatum* essential oil (Menichini et al., 2009).

The essential oils of *Teucrium* L. species were characterized by a higher content of ses-quiterpenes, in accordance with the results reported in previous studies (Cavaleiro et al., 2002; Küçük et al., 2006; Hachicha et al., 2007; Saraçoğlu et al., 2007). In this study, it has been shown that essential oil from the aerial parts of *T. kotschyanum* Poech in İzmir-Türkiye contained germacrene D (20.0%), α-cadinol (6.9%), β-bourbonene (6.6%), hexadecanoic acid (6.6%), δ-cadinene (5.9%), and manool (4.1%) as the major constituents. Previously, the essential oil from the leaves of *T. kotschyanum* in Cyprus had a different profile, and its chemical composition was rich in β-cubebene, β-burbonene, and β-caryophyllene (Arnold et al., 1991). In this study, we have also detected β-burbonene (6.6%) in the essential oil of *T. kotschyanum*. Consequently, *T. kotschyanum* which is growing in İzmir-Türkiye could be classified among *Teucrium* species producing germacrene D as the main constituent such as other Turkish *Teucrium* species; *T. chamaedrys* L. (Bağcı et al., 2010), *T. chamaedrys* L. ssp. *chamaedrys* (Küçük et al., 2006), *T. chamaedrys* L. ssp. *lydium* (Küçük et al., 2006), *T. chamaedrys* L. ssp. *trapezunticum* (Kaya et al., 2009), *T. cavernarum* P.H.Davis (Kaya et al., 2013), *T. paederotoides* Boiss. (Kaya et al., 2013), *T. antitauricum* Ekim (Başer et al., 1999), *T. montanum* L. (Başer et al., 1997), *T. polium* L. (Hayta et al., 2017), *T. lamiifolium* d'Urv. ssp. *lamiifolium* (Doğu et al., 2013), *T. multicaule* Montbret & Aucher ex Benth (Polat et al., 2010; Ersoy et al., 2023), *T. orientale* L. ssp. *orientale* (Küçükbay et al., 2011), *T. orientale* L. ssp. *puberulens* (Küçükbay et al., 2011), *T. parviflorum* Schreb. (Bağcı et al., 2011), *T. pestalozzae* Boiss. and *T. sandrasicum* O. Schwarz (Başer et al., 1997).

3.3 Antimicrobial Activity Assay

The antimicrobial activity of the essential oil against Gram-positive and Gram-negative bacteria as well as six strains of fungus were tested by broth microdilution methods. The essential oil exhibited limited antimicrobial activity, with the highest efficacy observed against *Candida utilis* (MIC: 125 µg/mL) and the lowest against *Staphylococcus epidermidis* and *Salmonella typhimurium* (MIC: 2000 µg/mL). Overall, the antimicrobial potency was lower than that of the clinical reference standards. Results of the antimicrobial activity of the essential oil are given in Table 2.

Extracts and essential oils from the *Teucrium* L. genus contain a wide range of secondary metabolites that exhibit biological activity. The antimicrobial activity of the essential oil obtained from the aerial parts of *Teucrium kotschyanum* Poech from Türkiye (İzmir-Ödemiş) has not been previously reported. In this study, the antimicrobial activities of the essential oil were tested using the broth microdilution method on four strains of gram-positive bacteria (*S. aureus*, *S. epidermidis*, *B. cereus*, *B. subtilis*), two strains of gram-negative bacteria (*P. aeruginosa*, *S. thyphimurium*) and six strains of fungi (*C. albicans*, *C. glabrata*, *C. krusei*, *C. parapsilosis*, *C. tropicalis*, *C. utilis*). MIC values of the essential oil against the selected human pathogenic bacteria and fungus were determined to be 125–2000 µg/mL.

The essential oil from the aerial parts of *T. kotshyanum* Poech exhibited the highest antibacterial potency against *B. cereus* at 250 µg/mL. The least sensitive microorganisms to the essential oil from the aerial parts of *T. kotshyanum* were *S. epidermidis* and *S. thyphimurium* with 2000 µg/mL MIC values, respectively. The essential oil from the aerial parts of *T. kotshyanum* showed the strongest antifungal activity against *C. utilis* with an MIC value of 125 µg/mL.

In vitro antimicrobial activity of the crude extracts of *T. chamaedrys* L., *T. montanum* L., *T. arduini* L., *T. polium* L., *T. scordium* L. subsp. *scordium*, *T. scordium* L. subsp. *scordioides* and *T. botrys* L. from Serbia showed greater antibacterial potential than antifungal activity (Stanković et al., 2012).

The antimicrobial activities of the essential oils from *T. chamaedrys* L. subsp. *chamaedrys*, *T. orientale* L. var. *puberulens*, and *T. chamaedrys* L. subsp. *lydium* growing in Türkiye were tested in vitro using agar-well diffusion and the essential oils showed better antimicrobial activity against the gram-positive bacteria than against gram-negative bacteria (Küçük et al., 2006).

The antimicrobial activity of *Teucrium* essential oils varies significantly within species and strains. *Teucrium africanum*

Table 2. Minimum inhibitory concentrations (μg/mL) of essential oil of *Teucrium kotschyanum*

	Microorganisms											
	Gram (+) bacteria				Gram (−) bacteria		Fungi					
EO/Reference standard	*Sa*	*Se*	*Bc*	*Bs*	*Pa*	*St*	*Ca*	*Cg*	*Ck*	*Cp*	*Ct*	*Cu*
Essential oil	500	2000	250	500	1000	2000	1000	1000	1000	500	1000	125
Ampicillin-Na	16	0.5	1	1	32	0.5	–	–	–	–	–	–
Chloramphenicol	1	2	4	1	64	2	–	–	–	–	–	–
Amphotericin	–	–	–	–	–	–	1	1	1	0.5	1	1
Ketoconazole	–	–	–	–	–	–	0.06	0.06	1	0.06	0.06	0.12

Note: *Sa*: *Staphylococcus aureus*, *Se*: *Staphylococcus epidermidis*, *Bc: Bacillus cereus, Bs: Bacillus subtilis, Pa: Pseudomonas aeruginosa, St: Salmonella typhimurium*, *Ca: Candida albicans, Cg: Candida glabrata, Ck: Candida krusei, Cp: Candida parapsilosis, Ct: Candida tropicalis, Cu: Candida utilis, −: not tested.*

Thunb. essential oil showed noteworthy activity against *S. pyogenes* mg/mL of 0.16 mg/mL while *T. trifidum* Retz. oil showed activity against *S. aureus* with an MIC value of 2 mg/mL (Ruiters et al., 2016). The essential oil of *T. arduini* L. from Croatia which was characterized by β-caryophyllene (32.9%) and germacrene D (16.4%) showed antimicrobial activity against bacterial species with MIC values ranging from 6.25 mg/ml to 37.50 mg/mL and antifungal activities with MIC values from 7.81 mg/mL and 25.00 mg/mL (Kremer et al., 2012). The essential oil of aerial parts of *T. arduini* L. from Montenegro-Greben, which was characterized by sesquiterpene hydrocarbons (48.76%), germacrene D (16.98%), β-caryophyllene (14.98%), β-burbonene (5.59%), and α-amorphene (4.68%), displayed a maximum activity against *K. pneumonia* with an MIC value of 6.25 μg/mL (Vukovic et al., 2011). *T. divaricatum* Sieber ex Heldr. which is a medicinal plant used in Lebanon, has been shown to contain abundant (E)-caryophyllene (30.1%) and caryophyllene oxide (6.1%) in its essential oil, the oil was found to have a good activity against gram-positive bacteria (Formisano et al., 2010).

Teucrium montanum L. essential oil was analyzed and the occurrence of δ-cadinene (17.19%) and β-selinene (8.16%) were the major constituents was shown. According to the antimicrobial activity results, the highest inhibition zone was observed against *K. pneumoniae* (29 mm) (Vukovic et al., 2007). The essential oil of *T. polium* L. from western Algeria was tested for antibacterial activity, and the highest activity was determined against *S. aureus* with an MIC value of 31.25 μL/mL (Fertout-Mouri et al., 2017). The chemical composition of essential oil from Algerian *T. polium* L. was analyzed, and germacrene D (25.81%), bicyclogermacrene (13%), β-pinene (11.69%), and carvacrol (8.93%) were found as the major components, and antimicrobial activity test results of this species showed that the oil exhibited moderate inhibitory activity against *Bacillus cereus*, *Enterococcus faecalis*, *E. coli* and *S. aureus* with an MIC value of 3–5 μL/mL (Belmekki et al., 2013). The essential oil of *T. polium* L. from Iran was analyzed, and β-caryophyllene (29%), farnesene (13%), β-pinene (11%), and germacrene D (6.5%) were detected as major components, in addition *T. polium* L. essential oil has shown to have a potential for use against multidrug resistant organisms such as clinical isolates of *K. pneumoniae* (Raei et al., 2014).

In a study from Morocco, the essential oils of *T. polium* L. subsp. *polium* and *T. polium* L. subsp. *aureum* were tested against six bacteria strains responsible for nosocomial infections and oils from the species exhibited significant antimicrobial activity against *S. aureus* (MIC 0.17 mg/mL) and *K. pneumoniae* (MIC 1.4 and 0.7 mg/mL) but showed a low activity against Gram-negative *P. aeruginosa* (El Atki et al., 2020). The essential oil of *T. polium* L. from Tunisia was found to be rich in α- pinene (13.32%), β-pinene (35.97%), α-thujene (8.46%), p-cymene (5.25%), and verbenone (5.03%), and the essential oil exhibited high antimicrobial activity against *Proteus mirabilis*, *Staphylococcus aureus*, and *Citrobacter freundei* with MIC values of 0.078–0.156 mg/mL (Ben Othman et al., 2017). The main components of the essential oil of Algerian *T. polium* L. subsp. *geyrii* were identified as dl-limonene (11.18%), δ-cadinene (10.02%), and trans-β-caryophyllene (9.15%), and the data obtained from the antimicrobial tests indicated that *C. albicans* was the most sensitive microorganism tested, followed by *S. aureus* and *E. coli* (Roukia et al., 2013).

An endemic plant in Tunisia, *Teucrium sauvagei* Le Houér. was shown to have β-eudesmol, T-cadinol, α-thujone, γ-cadinene, and sabinene as the prevalent constituents in its essential oil, with the results indicating that the oil showed average inhibition against only three dermatophytes (Bel Hadj Salah et al., 2006).

4 Conclusion

This study provides the first comprehensive characterization of the essential oil composition and antimicrobial profile of *Teucrium kotschyanum* Poech collected from İzmir-Türkiye. The predominance of sesquiterpene hydrocarbons, particularly germacrene D and cadinane-type constituents, supports chemotaxonomic affinities with other eastern Mediterranean *Teucrium* taxa. Although the essential oil exhibited limited antimicrobial activity, its selective efficacy against *Candida utilis* (MIC: 125 μg/mL) highlights a potential bioactivity. Beyond biological screening, these findings contribute valuable phytochemical markers for the systematic evaluation of the genus. Overall, *T. kotschyanum* emerges not merely as

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a biologically tested species, but as a chemotaxonomically informative taxon enriching the phytochemical landscape of *Teucrium*.

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Author Contributions

Çağlayan Ünsal Gürer: Conceptualization, participated in the investigation, writing, editing. Seçil Yazıcı Tütüniş: Analysis, investigation. Gizem Gülsoy Toplan: Analysis, investigation. Gökalp İşcan: Methodology, analysis, investigation. Betül Demirci: Methodology, analysis, investigation. Nur Tan: Conceptualization, participated in the investigation, writing. All authors have read and agreed to the published version of the manuscript.

Availability of Data and Materials

The authors declare that the data supporting the findings of this study are available within the paper and its Supplementary Information files. Should any raw data files be needed in another format they are available from the corresponding author upon reasonable request. Source data are provided with this paper.

Conflicts of Interest

The authors declare no conflicts of interest.

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