

# A Review of the Phytochemistry, Traditional Uses and Biological Activities of the Essential Oils of Genus *Teucrium*

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## ABSTRACT

The genus *Teucrium* is a large and polymorphic genus of the Lamiaceae family distributed in mild climate zones, particularly in the Mediterranean basin and Central Asia. Studies of nonvolatile constituents of *Teucrium* species showed that they are a rich source of *neo*-clerodane diterpenoids, considered as chemotaxonomic markers of the genus. In addition to the nonvolatile metabolites, there has been a large interest in the essential oils of this genus. In this review, a complete survey of the chemical composition and biological properties of the essential oils isolated from *Teucrium* taxa is provided. In traditional medicine, since ancient times, species of this genus have been widely implemented for their biological properties, including antimicrobial, anti-inflammatory, antispasmodic, insecticidal, anti-malaria, etc. Therefore, a complete review of all of the traditional uses of *Teucrium* taxa are also reported.

## Introduction

The genus *Teucrium* L. is a large and polymorphic genus of the Lamiaceae family, represented mostly by perennial, bushy, or herbaceous plants, living commonly in sunny habitats [1]. The Plant List [2], which has been used to validate the scientific names of the species, includes more than one thousand scientific plant names of species rank for the genus *Teucrium*. Of these, 415 are accepted names, including species, subspecies, varieties, forms, and hybrids, and they have been divided into ten sections [*Teucriopsis* Benth., *Teucrium* Benth., *Chamaedrys* (Mill.) Schreb., *Polium* (Mill.) Schreb., *Isotriodon* Boiss., *Pycnobotrys* Benth., *Scorodonia* (Hill) Schreb., *Stachyobotrys* Benth., *Scordium* (Mill.) Benth., and *Spinularia* Boiss.], identifiable through the calyx shape, the inflorescence structure, and pollen morphology [1,3,4],

although different authors modified this number from eight up to fifteen and created several subsections [5,6].

The species of the genus *Teucrium* grow in mild climate zones, particularly in the Mediterranean basin and Central Asia. As the species can be found in southern, southwestern, and southeastern parts of Europe, the continent is regarded as the main center of differentiation of the genus. A significant number of species have also been observed in Southwestern Asia, Northwestern Africa, southern North America, and southwestern South America. As for Australia, the species of the genus *Teucrium* are distributed in both southern parts of the continent and certain nearby islands [7,8].

Studies of nonvolatile constituents of *Teucrium* species showed that they are a rich source of *neo*-clerodane diterpenoids, considered as chemotaxonomic markers of the genus. Up to now, 279 *neo*-clerodanes have been identified and their occurrence has

been widely reviewed [9–14]. Other metabolites isolated from species of this genus include abietane diterpenes, sesquiterpenes, triterpenes, steroids, flavonoids, iridoids, and aromatic compounds [14].

In this review, a complete survey of the chemical composition and biological properties of the EOs isolated from *Teucrium* taxa is provided. Moreover, the traditional uses of *Teucrium* taxa are also reported. The available information on these genera was collected from scientific databases and covers 1972 up to 2019. The following electronic databases were used: PubMed, SciFinder, Science Direct, Scopus, Web of Science, and Google Scholar. The search terms used for this review included *Teucrium*, all of the botanical names of the species, both accepted names or synonyms, EOs, volatile components, traditional uses, activity, pharmacology, and toxicity. No limitations were set for languages. ► **Table 1** reports the taxa of *Teucrium* investigated so far, their synonyms, the accepted botanical names, and their section.

## Traditional Uses

*Teucrium* species have been used as medicinal herbs for more than 2000 years, and many of them are also currently in use in folk medicine. A summary of their traditional uses is presented in ► **Table 2**. The first record of the medicinal properties of these species dates back to Greek mythology from ten centuries BC. The name *Teucrium* is derived from Teucer, a son of Telamon, king of Salamis, who was the first to use these plants for curative purposes [157].

By far the most utilized species of this genus in the ethnomedicine of many countries is *Teucrium polium* (felty germander). It is a wild growing, flowering species; it is a perennial, aromatic plant, 20–50 cm high, with green-grayish leaves, and white to light pink flowers that occurs from June to August and is found abundantly in Southwestern Asia, Europe (Mediterranean region), and North Africa [158].

*T. polium* is largely used in traditional Iranian medicine. Its tea is utilized to treat many diseases such as abdominal pain, indigestion, common cold, urogenital diseases, and rheumatism. The aqueous extract of the dried aerial parts of *T. polium* is used by many type-2 diabetic patients, particularly in Southern Iran, as an antidiabetic drug. Furthermore, antimutagenic, cytotoxic, antinociceptive, antioxidant, antimicrobial, antihypertensive, anti-hyperlipidemic, anti-inflammatory, antispasmodic, and analgesic properties of this plant have been reported [159].

*T. polium* is also largely utilized in North Africa. In traditional Moroccan medicine, where it is locally called “Jaada”, aerial parts from the plant are used by the Moroccan population for the treatment of various human diseases, including digestive disorders, liver problems, inflammation, hypertension, fever, diabetes, rheumatism, and parasitic diseases [103], whereas in Algeria (local name “Kheyata” or “Jaada”), the species was traditionally used in folk medicine due to its hypoglycemic, hypolipidemic, anti-inflammatory, antibacterial, and antioxidant properties [82]. It is also known in Tunisia as “Jaadah” and some biological and therapeutic effects have been reported such as anti-inflammatory, antioxidant, antimicrobial, antinociceptive, antipyretic, anti-gastric ulcer, hepatoprotective, hypolipidemic, and hypoglycemic [124].

Traditionally, the local Palestinian population has used hot water leaf extracts of *T. polium* for centuries as a treatment for intestinal and cardiac disorders and the infusion of its leaves is drunk after each meal for its antispasmodic and antidiarrheal effects. The treatment is usually prescribed by the local Arab traditional practitioner alongside other forms of treatments. Furthermore, it has been reported that *T. polium* is a traditional medicinal plant used by the Bedouins in the south of the country [107, 108]. It is also known in traditional ethnoveterinary Palestinian medicine with the name الصبيان, and used orally in sheep, cows, and goats to treat diarrhea, colic, scabies, and flatulence. The crushed leaves are applied to the skin as a poultice to treat scabies [106]. In Israel and the Golan Heights, a standard decoction is prepared from 50 g of leaves of *T. polium* and taken orally, 100 cc, three times/day to treat kidney and liver diseases, diabetes, stomach and intestine pain, and inflammation [38]. In Saudi Arabian folk medicine, germander (*T. polium*) is known under the vernacular name of “Jaada” or “Jaa’d”. Aerial parts from the plant and infusion of tender leaves are used by the local population of Bedouins for treatment of febrifuge, vermifuge, stomach, and intestinal troubles. The plant is also used in a steam bath for colds and fevers [113, 114]. Also, in Jordan, where it is known with similar names (Jada, Jadeh), *T. polium* has been used for treatment of several diseases such as inflammation, pain, diabetes, kidney stones, cancer, fever, rheumatism, etc. [97–100].

*T. polium* has also been largely employed in Turkish traditional medicine. In the area of Bayramiç (West Turkey), the infusion of the aerial part of *T. polium*, known as Mayasıl otu, is used against hemorrhoids and eczema [49], while people in Silopi (Turkey) use it as a spice in meals. It is drunk for diseases of the stomach, and it is used as a drug by applying the hard parts of it on the wounds after it is boiled [122]. Many other ethnopharmacological uses in Turkey are reviewed in ► **Table 2**.

Traditionally, in the Mediterranean countries, *T. polium* has been used for various types of pathological conditions, in fact, its utilization as a digestive aid in Albania [81], for gastrointestinal disorders in Bosnia and Herzegovina [27, 28], as tonic, anti-icteric, and antihelmintic in Spain [44], and for myalgias, stomach pains, cold, menopause disorders, toothache pains, insect bites, and skin diseases in Sardinia (Italy) [63, 64] has been reported. The phytochemistry and medicinal properties of *T. polium* have been reviewed by Bahramikia and Yazdanparast [159] and its complete ethnopharmacological uses are resumed in ► **Table 2**.

Another species largely employed in the folk medicine of several countries is *Teucrium chamaedrys*, a Mediterranean and Middle European species present throughout all of Europe except for northern Europe. It is also present in North Africa and West Asia. It is a semi-perennial plant growing mostly on rocky calcareous soil, but it can also be found in meadows, pastures, steppes, and sand. It is used for the preparation of teas, tinctures, wines, etc., due to its beneficial therapeutic effects on the digestive and immune systems, skin, and anemia. The species is an ingredient of several liquors, vermouth, and rakjas [160].

The blossoms of *T. chamaedrys* have long been used in folk medicine in the Middle East and Mediterranean region as treatment for dyspepsia, obesity, diabetes, and abdominal colic.

► **Table 1** *Teucrium* taxa studied for their EOs and their synonyms (accepted botanical name in bold).

Taxa	Synonyms	Sect. [4–6, 15–21]
<i>T. abutiloides</i> L'Her		<i>Teucriopsis</i>
<i>T. africanum</i> Thumb.		<i>Teucrium</i>
<i>T. algarbiensis</i> (Cout.) Cout.		<i>Polium</i>
<i>T. alopercus</i> Noë		<i>Polium</i>
<i>T. alyssifolium</i> Stapf		<i>Teucrium</i>
<i>T. antiatlanticum</i> (Maire) Sauvage & Vindt		<i>Polium</i>
<i>T. antitauricum</i> Ekim		<i>Isotriodon</i>
<i>T. apollinis</i> Maire & Weiller		<i>Polium</i>
<i>T. arduini</i> L.		<i>Stachybotrys</i>
<i>T. asiaticum</i> L.		<i>Scorodonia</i>
<i>T. atratum</i> Pomel		Not determined
<i>T. betonicum</i> L'Her		<i>Teucriopsis</i>
<i>T. botrys</i> L.		<i>Spinularia</i>
<i>T. brevifolium</i> Schreb.		<i>Teucrium</i>
<i>T. canadensis</i> L.		<i>Scorodonia</i>
<i>T. carolipau</i> Vicioso ex Pau		<i>Polium</i>
<i>T. cavernarum</i> P. H. Davis		<i>Isotriodon</i>
<i>T. chamaedrys</i> L.		<i>Chamaedrys</i>
<i>T. chamaedrys</i> ssp. <i>chamaedrys</i>	<b><i>T. chamaedrys</i> L.</b>	<i>Chamaedrys</i>
<i>T. chamaedrys</i> ssp. <i>lydium</i> O. Schwarz		<i>Chamaedrys</i>
<i>T. chamaedrys</i> ssp. <i>syspirense</i> (K.Koch) Rech f.		<i>Chamaedrys</i>
<i>T. chamaedrys</i> ssp. <i>trapezunticum</i> Rech f.		<i>Chamaedrys</i>
<i>T. creticum</i> L.		<i>Teucrium</i>
<i>T. cyprium</i> ssp. <i>cyprium</i> Boiss.	<b><i>T. cyprium</i> Boiss</b>	<i>Polium</i>
<i>T. divaricatum</i> ssp. <i>canescens</i> (Celak.) Holmboe		<i>Chamaedrys</i>
<i>T. divaricatum</i> ssp. <i>divaricatum</i>	<b><i>T. divaricatum</i> Sieber ex Heldr.</b>	<i>Chamaedrys</i>
<i>T. divaricatum</i> ssp. <i>villosum</i> (Celak.) Rech.f.	<b><i>T. divaricatum</i> Sieber ex Heldr.</b>	<i>Chamaedrys</i>
<i>T. flavum</i> L.		<i>Chamaedrys</i>
<i>T. flavum</i> ssp. <i>flavum</i>	<b><i>T. flavum</i> L.</b>	<i>Chamaedrys</i>
<i>T. flavum</i> ssp. <i>glaucum</i> (Jord. & Fourr.) Ronniger		<i>Chamaedrys</i>
<i>T. flavum</i> ssp. <i>hellenicum</i> Rech.f.		<i>Chamaedrys</i>
<i>T. fruticans</i> L.		<i>Teucrium</i>
<i>T. gnaphalodes</i> L'Her		<i>Polium</i>
<i>T. haenseleri</i> Boiss.		<i>Polium</i>
<i>T. hetrophyllum</i> L'Her		<i>Teucriopsis</i>
<i>T. hyrcanicum</i> L.		<i>Stachybotrys</i>
<i>T. kotschyanum</i> Poech		<i>Scorodonia</i>
<i>T. lamiiifolium</i> ssp. <i>lamiiifolium</i> d'Urv Mem		<i>Stachybotrys</i>
<i>T. lamiiifolium</i> ssp. <i>stachyophyllum</i> (P. H. Davis) Hedge & Ekim	<b><i>T. stachyophyllum</i> P. H. Davis</b>	<i>Stachybotrys</i>
<i>T. lepicephalum</i> Pau		<i>Polium</i>
<i>T. leucocladum</i> Boiss.		<i>Polium</i>
<i>T. libanitis</i> Schreb.		<i>Polium</i>
<i>T. lusitanicum</i> Schreb.		<i>Polium</i>
<i>T. lusitanicum</i> ssp. <i>aureiformis</i> (Rouy) Valdes Berm.		<i>Polium</i>
<i>T. maghrebinum</i> Greuter & Burdet		<i>Spinularia</i>
<i>T. marum</i> L.		<i>Chamaedrys</i>

continued

► **Table 1** Continued

Taxa	Synonyms	Sect. [4–6, 15–21]
<i>T. marum</i> ssp. <i>drosocalyx</i> Mus, Rossellò & Mayol	<b><i>T. marum</i> L.</b>	<i>Chamaedrys</i>
<i>T. marum</i> ssp. <i>marum</i>	<b><i>T. marum</i> L.</b>	<i>Chamaedrys</i>
<i>T. marum</i> ssp. <i>occidentale</i> Mus, Rossellò & Mayol	<b><i>T. balearicum</i> (Coss. ex Pau) Castrov. &amp; Bayon</b>	<i>Chamaedrys</i>
<b><i>T. mascatense</i> Boiss.</b>		<i>Polium</i>
<b><i>T. massiliense</i> L.</b>		<i>Scorodonia</i>
<b><i>T. melissoides</i> Boiss. &amp; Hausskn.</b>		<i>Scordium</i>
<b><i>T. micropodiodes</i> Rouy</b>		<i>Polium</i>
<b><i>T. montanum</i> L.</b>		<i>Polium</i>
<i>T. montanum</i> ssp. <i>jailae</i> (Juz.) Soó		<i>Polium</i>
<b><i>T. montbretii</i> ssp. <i>heliotropifolium</i> (Barbey) P. H. Davis</b>		<i>Isotriodon</i>
<b><i>T. multicaule</i> Montbret. &amp; Aucher ex Benth.</b>		<i>Teucrium</i>
<b><i>T. orientale</i> ssp. <i>glabrescens</i> (Hausskn. ex Bornm) Rech.f.</b>		<i>Teucrium</i>
<i>T. orientale</i> ssp. <i>orientale</i>	<b><i>T. orientale</i> L.</b>	<i>Teucrium</i>
<b><i>T. orientale</i> var. <i>puberulens</i> (T.Ekim)</b>		<i>Teucrium</i>
<b><i>T. orientale</i> ssp. <i>taylori</i> (Boiss.) Rech.f.</b>		<i>Teucrium</i>
<i>T. oxylepis</i> ssp. <i>oxylepis</i>	<b><i>T. oxylepis</i> Font Quer</b>	<i>Stachybotrys</i>
<i>T. oxylepis</i> ssp. <i>marianum</i> Ruiz Torre & Ruiz Cast.	<b><i>T. oxylepis</i> Font Quer</b>	<i>Stachybotrys</i>
<b><i>T. paederotoides</i> Boiss.</b>		<i>Isotriodon</i>
<b><i>T. parviflorum</i> Schreb.</b>		<i>Teucrium</i>
<b><i>T. persicum</i> Boiss.</b>		<i>Isotriodon</i>
<b><i>T. pestalozzae</i> Boiss.</b>		<i>Teucrium</i>
<b><i>T. polium</i> L.</b>		<i>Polium</i>
<i>T. polium</i> ssp. <i>album</i> (Poir.) Breistr.	<b><i>T. capitatum</i> L.</b>	<i>Polium</i>
<b><i>T. polium</i> ssp. <i>aurasiacum</i> (Maire) Greuter &amp; Burdet</b>		<i>Polium</i>
<i>T. polium</i> ssp. <i>aureum</i> (Schreb.) Arcang.	<b><i>T. aureum</i> Schreb.</b>	<i>Polium</i>
<i>T. polium</i> ssp. <i>capitatum</i> (L.) Arcang.	<b><i>T. capitatum</i> L.</b>	<i>Polium</i>
<i>T. polium</i> ssp. <i>gabesianum</i> Le Houer	<b><i>T. luteum</i> ssp. <i>gabesianum</i> (S.Puech) Greuter</b>	<i>Polium</i>
<i>T. polium</i> ssp. <i>geyrii</i> Maire	<b><i>T. helichrysoides</i> (Diels) Greuter &amp; Burdet</b>	<i>Polium</i>
<i>T. polium</i> ssp. <i>pilosum</i> Decne	<b><i>T. decaisnei</i> C.Presl</b>	<i>Polium</i>
<i>T. polium</i> ssp. <i>valentinum</i> (Schreber) Borja		<i>Polium</i>
<b><i>T. pruinosum</i> Boiss.</b>		<i>Teucrium</i>
<b><i>T. pseudochamaepitys</i> L.</b>		<i>Teucrium</i>
<i>T. pseudoscorodonia</i> ssp. <i>baeticum</i>	<b><i>T. pseudoscorodonia</i> Desf.</b>	<i>Scorodonia</i>
<i>T. puechiae</i> Greuter & Burdet	<b><i>T. dunense</i> Sennen</b>	<i>Polium</i>
<b><i>T. quadrifarium</i> Buch.-Ham</b>		<i>Pycnobotrys</i>
<b><i>T. ramosissimum</i> Desf.</b>		<i>Polium</i>
<b><i>T. royleanum</i> Wall. ex Benth.</b>		<i>Scorodonia</i>
<b><i>T. salviastrum</i> Schreb.</b>		<i>Scorodonia</i>
<b><i>T. sandrasicum</i> O. Schwarz</b>		<i>Teucrium</i>
<b><i>T. sauvegi</i> Le Houer</b>		<i>Polium</i>
<b><i>T. scordium</i> L.</b>		<i>Scordium</i>
<b><i>T. scordium</i> ssp. <i>scordiodes</i> (Schreb.) Arcang.</b>		<i>Scordium</i>
<b><i>T. scorodonia</i> L.</b>		<i>Scorodonia</i>
<i>T. scorodonia</i> ssp. <i>baeticum</i>	<b><i>T. pseudoscorodonia</i> Desf.</b>	<i>Scorodonia</i>
<i>T. scorodonia</i> ssp. <i>scorodonia</i>	<b><i>T. scorodonia</i> L.</b>	<i>Scorodonia</i>
<b><i>T. siculum</i> (Raf.) Guss.</b>		<i>Scorodonia</i>

continued

► Table 1 Continued

Taxa	Synonyms	Sect. [4–6, 15–21]
<i>T. stocksianum</i> Boiss.		<i>Polium</i>
<i>T. stocksianum</i> ssp. <i>gabrielae</i> (Bornm.) Rech.f.		<i>Polium</i>
<i>T. stocksianum</i> ssp. <i>stocksianum</i>	<i>T. stocksianum</i> Boiss.	<i>Polium</i>
<i>T. trifidum</i> Retz.		<i>Teucrium</i>
<i>T. turredanum</i> Losa & Rivas Goday		<i>Polium</i>
<i>T. yemense</i> Deflers		<i>Polium</i>
<i>T. zanoni</i> Pamp.		<i>Polium</i>

In traditional medicine of Balkan countries, its properties include treatment of inflammations of the skin, open wounds, joint pain, liver diseases, diarrhea, pulmonary disorders, coughs, asthma, abscesses, conjunctivitis, and as a digestive and diuretic agent [27, 36, 41, 42].

In Turkey, *T. chamaedrys* and its subspecies *lydium* are mainly utilized against hemorrhoids, although it has also been reported to treat mouth ulcers, kidney infection, heart disease, malaria, and stomachache (► Table 2). It has also been used in traditional English medicine as part of the Portland Powder for treating rheumatism and gout [37]. Several applications of *T. chamaedrys* have been reported: a decoction of the leaves and seeds is applied to inflamed eyes; a decoction prepared from leaves and stems is taken orally, three times/day to treat stomach and intestine pain and inflammation, lack of appetite, and jaundice [38].

Despite its wide use, in the early 1990 s, it was found that herbal preparations, in the form of tea or capsules, could cause significant liver injury, probably due to the presence of some *neo-clerodane* diterpenoids such as *teucrin A*. The injury is characterized by a hepatocellular pattern associated with marked jaundice in the absence of immunoallergic or autoimmune features. The latency before onset of injury is short and usually occurs within 30 days from consuming the preparation. Although fatal cases and liver transplants have been reported, the injury generally resolves after cessation of consumption of the causing agent [161].

Many other species have been used in the folk medicine of various countries, and they are grouped below according to their geographical areas.

## Europe

*Teucrium scorodonia*, common name woodland germander or wood sage, is a perennial herb, native to Western Europe and Tunisia. It is cultivated in many places as an ornamental plant in gardens, and naturalized in several regions (New Zealand, Azores, and North America). The plant resembles hops in taste and flavor. An infusion of the leaves and flowers is used as a hops substitute for flavoring beer in some areas. It is said to clear the beer more quickly than hops but imparts too much color to the brew. The herb is astringent, carminative, diaphoretic, diuretic, emmenagogue, tonic, and vulnerary. It is often used in domestic herbal practice in the treatment of skin afflictions, diseases of the blood, fevers, colds, etc. [69]. In Italian folk medicine, *T. scorodonia* L. is

known for its astringent, anti-scurvy, antiseptic, and eupeptic properties [140], whereas in Britain, Ireland, and the Isle of Man, it has been used against amebic dysentery, rheumatism, gripe, indigestion, palpitations, colds and coughs, and tuberculosis [137]. *T. scorodonia* is used in border regions of Cantabria (Spain), where it is known as “hierba lopera/hoja de lobo” to wash infected wounds caused by wolf or dog bites [141]. Furthermore, its tincture has been applied in the treatment of mastitis in ruminants [139].

*Teucrium scordium* L. (garlic germander) is a perennial plant that grows in South and Southeast Europe, the Middle East, and North Africa. In traditional medicine, the flowering branches are used for tea and tonic-based medicinal preparation for the treatment of some gastrointestinal ailments, wound healing, and as a spice plant [69]. The herb is anthelmintic, antifungal, antiseptic, and tonic, making it an excellent remedy for all inflammatory diseases [69]. It was reported to be used in Spain as an antidote for poisons and also as an antiseptic and anthelmintic, though it is scarcely used nowadays [44]. In Bosnia and Herzegovina, the infusion of the aerial parts has been utilized for treatment of gastrointestinal ailments and diarrhea [27, 28], whereas in Israel it has been utilized for chronic skin disease, dyspepsia, and hemorrhoids [96]. The plant *Maryamnokhodi* Batlaghi has similar uses in Iran, where it has also been used in the treatment of tuberculosis [138]. In Britain, it has been in use by women “very frequently” in a decoction to suppress menstruation or as a vermicide [137].

*Teucrium marum* is an aromatic herb, diuretic, nervine, stimulant, stomachic, and tonic. The plant is supposed to possess very active powers and has been recommended in the treatment of many diseases, being considered useful in treating cases of nervousness [69]. It is used in the treatment of gallbladder and stomach problems [70]. The root bark is considerably astringent and has been used to controlling hemorrhages. It is said to be effective against small threadworms in children [69]. In Sardinia (Italy), where it is called “Gattaria/Erba de gattus”, it is known for its antibacterial, anti-inflammatory, antipyretic, and cicatrizing properties [64].

Similar febrifuge and anti-malaric activities have been reported in Sardinia for *Teucrium massiliense* (Cramedi eru) [65]. *Teucrium flavum* ssp. *glaucum* (Cramedi u'e istropios) [65] and *T. flavum* (Querciola maggiore/Crammedi) [64] are also largely utilized in Sardinia for their cicatrizing properties. The last species is also

► **Table 2** Ethnopharmacological uses of all *Teucrium* taxa.

Species	Vernacular names	Area	Use	Ref
<i>T. alopecurus</i>	H'chichit ben salem	Tunisia	anti-inflammatory properties, flavoring	[22, 23]
<i>T. africanum</i>	Akkedispoot, ubu-Hlungu ambeibos-sie, bitterbossie, paddaklou	South Africa	tonic, against snakebites and anthrax, hemorrhoids, sore throat, stomach disorders, eye inflammations, colds, and fever	[24]
<i>T. antiatlanticum</i>		Morocco	to treat burns and fevers	[25]
<i>T. apollinis</i>	Jada	Libya	antidiabetic, antihypertensive, and for extruding kidney stones	[26]
<i>T. arduini</i>	Arduinjewa iva	Bosnia and Herzegovina	stomach ailments	[27, 28]
<i>T. betonicum</i>	Abrotona, erva branca, herva branca	Portugal, Madeira	stomachic, tonic	[29]
<i>T. bidentatum</i> Hemsl.		China, Guizhou	treatment of dysentery and leukoderma	[30]
<i>T. buxifolium</i> Schreb.		Spain	rheumatism, inflammation	[31]
<i>T. canadensis</i>		Canada	diaphoretic, diuretic, emmenagogue, antiseptic	[32]
<i>T. chamaedrys</i>			astringent, antirheumatic, digestive, fever, anti-inflammatory, diuretic, treatment of wounds, dyspepsia, anorexia, nasal catarrh, chronic bronchitis, gout, rheumatoid arthritis, fever, uterine infections, to reduce body weight	[33–35]
		Balkans	inflammations of the skin, open wounds, joint pain, liver diseases, digestive, diuretic	[36]
	Dubačac	Bosnia and Herzegovina	diarrhea	[27]
		England	treating rheumatism and gout	[37]
	جعدہ الصبیان	Israel, Golan	stomach, intestine pain and inflammation, lack of appetite, jaundice, eye inflammation, inflammation of teeth and gums	[38]
		Iran	diuretic, antiseptic, antipyretic and antihelminthic	[39]
		Palestine	treatment of digestive disorders	[40]
	Podubnica	Serbia	treatment of digestive and pulmonary disorders, coughs, asthma, abscesses, conjunctivitis	[41–43]
	Camedrio, Encinillo	Spain	tonic, stomachic, febrifuge, vesicant, emmenagogue	[44]
	Kisa mahmut, Sancti otu	Turkey	hemorrhoids	[45]
	Uzun mahmut	Turkey, Balıkesir	abdominal pain, kidney stones	[46]
	Kısacık mahmut	Turkey, Central	stomachache	[47]
	Mayasil otu	Turkey, Ayvacık	hemorrhoids	[48]
	Mayasil otu	Turkey, Bayramiç	hemorrhoids, eczema	[49]
	Bodurca mahmut, Kinin otu	Turkey, Acıpayam	hemorrhoids, heart diseases, malaria	[50]
	Kısamahmut otu	Turkey, Bilecik	ulcer in mouth, kidney infection	[51]
	Kısamahmut otu	Turkey, Kırklareli	diuretic, kidney stones, diarrhea, abdominal pain	[52]
	Kısacık mahmut, Sancti otu, Bodurmahmut	Turkey, Uludağ	hemorrhoids	[45, 53]
<i>T. chamaedrys</i> ssp. <i>lydium</i>				<i>continued</i>
<i>T. chamaedrys</i> ssp. <i>chamaedris</i>				

► **Table 2** Continued

Species	Vernacular names	Area	Use	Ref
<i>T. creticum</i>		Palestine	antidiabetic	[54]
<i>T. cubense</i> Jacq.	Agrimonia, verbena	Mexico, Yucatan	diabetes mellitus, bowel diseases, skin infections, anti-inflammatory	[55–57]
<i>T. cyprium</i> ssp. <i>cyprium</i>		Cyprus	against fever and jaundice, astringent, antipruritic	[58]
<i>T. divaricatum</i> ssp. <i>canescens</i>		Cyprus	stomachic, fever, colds, cicatrissant	[58]
<i>T. divaricatum</i> ssp. <i>divaricatum</i>		Cyprus	cicatrissant	[59]
<i>T. divaricatum</i> ssp. <i>villosum</i>	Mürücüotu, buhurcuoğlu otu, böceotu	Turkey, Marmaris	cough, tonic for eyes, sickness, stomachache, urinary diseases, gallbladder disease, kidney stones	[60]
<i>T. flavum</i>	Chamaidrya, Moskhokhortaro, Dontokhorti	Lebanon	stomachic, fever, colds, cicatrissant	[61]
		Greece	antidiabetic, astringent, to heal skin eruptions and wounds	[62]
<i>T. flavum</i> ssp. <i>glaucum</i>	Querciola maggiore/Crammediu.	Italy, Sardinia	antipyretic, cicatrissant, antiseptic	[63, 64]
	Cramedi u' istropios	Italy, Sardinia	cicatrissant	[65]
<i>T. fruticosum</i>	Erba ricottara	Italy, Tuscany	depurative and diuretic	[66]
		Italy, Sicily	hemorrhoids	[67]
<i>T. katschyannum</i>		Cyprus	antipyretic, antidiabetic	[58]
<i>T. kraussi</i> Codd.	ubuHlungu, isiHlungu, umnunwenkhangala	South Africa	tonic, against snakebites and anthrax	[24]
<i>T. maghrebium</i>	kayatat el gearah	Algeria	burns, fevers, antimicrobial	[68]
		Morocco	to treat burns and fevers	[25]
<i>T. marum</i>			diuretic, nervine, stimulant, stomachic, tonic, nervous complaints, astringent, hemorrhoids, worms in children	[69, 70]
<i>T. mascatense</i>	Gattaria/Erba de gattus	Italy, Sardinia	antibacterial, anti-inflammatory and antipyretic, cicatrissant	[64, 65]
	ja'dah	Oman	fever remedy, blood menstruation, stomachache, colic, diabetes	[71, 72]
<i>T. massiliense</i>	Cramedi u eru	Italy, Sardinia	febrifuge, anti-malaric	[65]
<i>T. micropodioides</i>		Cyprus	sedative, antispasmodic, gastric ulcer, gastrointestinal inflammation, diuretic, carminative, antidiarrheal, antipyretic, stimulant, stomachic, anthelmintic, emmenagogue, antidiabetic, against rheumatism, antipruritic, antiseptic	[58]
<i>T. montanum</i>	Iva trava	Bosnia and Herzegovina	liver and stomach diseases	[27]
	Marmahooz	Iran	headache	[73]
	Dubačac mal	Serbia	diuretic, stomachic, analgesic, antispasmodic, antibacterial, antifungal, anti-inflammatory, antioxidant activity	[41, 74]
	Trava iva	Serbia, south	abdominal disorders, headaches, tonic, improving appetite, antipyretic, antituberculosis, immune system strengthening	[43, 75]

continued



▶ **Table 2** Continued

Species	Vernacular names	Area	Use	Ref
<i>T. oliverianum</i> (Cing. ex Benth.) R.Br.	Qassapa	Saudi Arabia	for diabetes	[76]
<i>T. orientale</i>	Ja'ada	Lebanon	wound skin and injuries, fever	[77]
	Maryam nokhodi, Chaye alafi	Iran	antipyretic, hot flashes in women	[78, 79]
<i>T. parvifolium</i>	Dağ kekeği	Turkey	hemorrhoids	[45]
<i>T. persicum</i>	Marv-e-talkh, Arak	Iran	abdominal pain, headaches	[80]
<i>T. polium</i>	Bar majasili	Albania	digestive	[81]
	Kheyata	Algeria	hypoglycemic, hypolipidemic, anti-inflammatory, antibacterial, antioxidant	[82]
	Jaada	Algeria	anti-inflammatory, anti-diarrhea, antibacterial, facilitates digestion, disinfectants, anti-diabetes, anti-eczema, tonic, for skin diseases	[83]
		Armenia	stomach diseases, gynecological diseases, analgesic, anti-inflammatory, antibacterial	[84]
	Iva mediteranska	Bosnia and Herzegovina	stomach diseases	[27, 28]
	جعدہ الصبيان	Israel, Golan	kidney and liver diseases, diabetes, stomach and intestine pain and inflammation	[38]
	Ab Lileh, Olileh	Iran, Boyer Ahmad	menstruation disorders, toothache, body and joint pain, abortion, gynecological infections, carminative	[85]
	Maryam nokhodi	Iran	antimicrobial	[78]
	Ja' deh	Iran	for learning and memory	[86]
		Iran	antimalarial	[87]
		Iran, Fars	antidiabetic, anti-inflammatory, antinociceptive, antibacterial, antihypertensive, antihyperlipidaemic	[88]
	Kalpooreh, Alpe, Chez Koochi	Iran	diabetes	[89]
	Kalpooreh	Iran	menstruation	[90]
	Kalpooreh	Iran	antimicrobial, antidiabetic, anti-inflammatory, antispasmodic, analgesic, antioxidant	[91]
	Kalpureh	Iran	anti-diarrheal, hypnotic, antiparasitic, antifungal, antitussive, diabetes mellitus, rheumatoid arthritis, paranasal sinusitis, bloating, menorrhoeal discharge, wound disinfection, gingivitis, tonsillitis, acne, itching, dyspepsia, amenorrhoea	[92, 93]
	Kalpurak	Iran Saravan	antipyretic, insect, snake and scorpion bites, wound healing, stomachache, abdominal pain, flatulency, emesis, stomach acidification, hypertension, sedative, toothache, diabetes, hyperlipidemia	[94]
		Iran	diuretic, hypoglycemic, antifungal, antispasmodic, antirheumatic, anti-inflammatory, antibacterial	[95]
		Israel	kidney stones, liver diseases, stomach and intestine inflammation	[96]

continued



► **Table 2** Continued

Species	Vernacular names	Area	Use	Ref
	Polio/Tumbu feminedda	Italy, Sardinia	myalgias, vulnery, stomach pain, colds, menopause disorders, sedative for toothache, against insect bites, skin diseases	[63, 64]
	Jeada, Jadeh	Jordan	anti-inflammatory, antispasmodic, antifatulent, antidiabetic, for kidney stones and cancer	[97–99]
		Jordan	diuretic, diaphoretic, tonic, antispasmodic and cholagogic, antipyretic, antibacterial, anti-inflammatory, antirheumatic, hypoglycemic, antioxidant, antinociceptive	[100]
	Jeada	Jordan, Badia	stomach and colic spasm, inflammation, anorexia, and jaundice	[101]
	Gaada	lybia, Cyrenaica	diabetes, gastritis, thyroiditis, anemia, common cold, hypertension, renal stones	[102]
	Jaada	Morocco	digestive disorders, liver problems, inflammation, hypertension, fever, diabetes, rheumatism, parasitic diseases	[103–105]
	الصبيان	Palestine	veterinary: diarrhea, colic, bleeding, scabies, flatulence	[106]
	Ja'da	Palestine	antispasmodic, antidiarrheal effects	[107]
	Ja'da	Palestine	intestinal and cardiac disorders	[108]
		Palestine	abdominal pain, indigestion, diabetes, liver diseases, hypertension, anti-inflammatory	[109–111]
	Takmezout, Djajda	Sahara	chills, fever	[112]
	Jaada, Jaa'd	Saudi Arabia	febrifuge, vermifuge, stomach, intestinal troubles, colds, fevers	[113, 114]
	Polio de flor blanca, Polium blanc	Spain	tonic, antictic, antihelmintic	[44]
	Gurisa, Jaadeh, جعدة	Syria, Aleppo	diabetes, cancer, antispasmodic, stomach hyperacidity	[115]
	Kisamahmut	Turkey	diabetes, kidney stones	[46]
	Several vernacular names	Turkey	hemorrhoids	[45]
	Kokar yavşan, Peryavşanotu, Sırçanotu, Yavşan	Turkey, Central	colds, antipyretic, rheumatic pain, stomachache	[47]
	Kisa Mahmut Otu	Turkey, Ayvacik	antipyretic, cough, tonic	[48]
	Cay kekigi, Kekikmiş	Turkey, Acipayam	diabetes, abdominal pain	[50]
	Merwend (Kurdish)	Turkey, Batman	abdominal pain, digestive, colds, diabetes, stomachache, antitussive	[116]
	Mayasil otu	Turkey, Bayramiç	hemorrhoids, eczema	[49]
	Acı yavşan	Turkey, Bilecik	stomach diseases, wounds, carminative	[51]
	Peryavşan	Turkey, Kahramanmaraş	lung inflammations, stomach ulcers, diabetes disease, fever lowering	[117]
	Kefen otu	Turkey, Karaisalı	menstruation, common cold	[118]
	Kckik	Turkey, Kırklareli	flu, colds, abdominal pain	[52]
	Urper	Turkey, Maden	diabetes, stomachache, antipyretic, colds, liver disorders, inflammation, stomachic, wounds	[119, 120]
				continued

Species	Vernacular names	Area	Use	Ref
<i>T. polium</i> ssp. <i>capitatum</i>	Cıgde	Turkey, Midyat	stomachache	[121]
	Kisamahmut	Turkey, Silopi	stomach diseases, wounds	[122]
	Meyremxort	Turkey, Solhan	antihypertensive, colds and flu, diabetes, diarrhea, headache, stomachache	[123]
	Jaadah, Al'ja'adeh', Khayata', Gattaba	Tunisia	anti-inflammatory, antioxidant, antimicrobial, antinociceptive, antipyretic, anti-gastric ulcer, hepatoprotective, hypolipidemic, hypoglycemic, cicatrizant	[124]
<i>T. polium</i> ssp. <i>capitatum</i>		Greece	refreshing, spice, diabetes, intestinal troubles	[125]
	Ja'ada	Lebanon	diabetes, insomnia, neurological disorders, abdominal cramps	[77]
	جعدة	Palestine	veterinary: diarrhea, colic, bleeding, scabies, flatulence	[106, 126]
	Cat Thyme, Jedeh Subian	Palestine	diuretic, antipyretic, diaphoretic, antispasmodic, tonic, anti-inflammatory, antihypertensive, anorexic, analgesic, antibacterial, antidiabetic effects	[54, 127]
<i>T. polium</i> ssp. <i>geyrii</i>	Takmazzut	Algeria	wound healing, as tea and a spice, analgesic	[128, 129]
<i>T. pruinosum</i>	Ja'ada	Lebanon	gastrointestinal disorders, wounds, fever, colds	[77]
<i>T. quadrifarium</i>		China	colds, inflammation	[130]
<i>T. ramosissimum</i>	Hachichet belgacem ben salem	Tunisia	intestinal inflammation, gastric ulcer, as a cicatrizing agent	[131]
<i>T. royleanum</i>		Tunisia	digestive disorders	[132]
		India, Lahaul: Udaipur	allelopathic, antibacterial, antifungal, antispasmodic, astringent, antipyretic, anti-allergic	[133]
	Katheri	Pakistan, Kutlia Valley	eye diseases, nervous debility	[134]
<i>T. sandrasicum</i>		Turkey	diuretic, diaphoretic, tonic, antipyretic, antidiabetic, antispasmodic, cholagogic	[135]
<i>T. sauvegi</i>		Tunisia	wound healing, antidiabetic, anti-inflammatory, and to treat ulcers, colic, and food poisoning	[136]
<i>T. scordium</i>			gastrointestinal ailments, wound healing, anthelmintic, antifungal, antiseptic, diaphoretic, tonic, antidote for poisons, anti-inflammatory, antitubercular	[69]
	Iva mediteranska	Bosnia and Herzegovina	diarrhea	[27]
	Vodena iva	Bosnia and Herzegovina	gastrointestinal ailments	[28]
	Water germ ander	Britain, Cambridgeshire	to suppress menstruation, vermicide	[137]
	Maryamnokhodi Batlaghi	Iran	tonic, antitussive, for treatment of lung tuberculosis, jaundice, hemorrhoids for healing of wounds	[138]
		Israel	chronic skin disease, dyspepsia, hemorrhoid	[96]
		Spain	diaphoretic, anti-venomous, anthelmintic	[44]

*continued*

► **Table 2** Continued

Species	Vernacular names	Area	Use	Ref
<i>T. scorodonia</i>		Canada, British Columbia	astringent, carminative, diaphoretic, diuretic, emmenagogue, tonic and vulnerary, skin and blood diseases, fevers, colds	[69]
		Italy	ethnoveterinary: mastitis	[139]
		England, Isle of Man	astringent, anti-scurvy, antiseptic and eupeptic properties	[140]
	Wood sage	Britain, various parts	amoebic dysentery	[137]
	Wood sage	Ireland	tea, rheumatism, headache, jaundice	[137]
	hierba lobera/hoja de lobo	Spain, Cantabria	rheumatism, gripe, indigestion, palpitations, colds and coughs, tuberculosis	[137]
<i>T. stocksianum</i>	ja'dah	Oman, UEA	infected wounds	[141]
		UEA	against fever, stomachache	[71, 142]
		Iran, Hormozgan	gastric ulcers and abdominal discomfort	[143]
	Spariki	Pakistan, Dir lower	against fever, stomachache, and intestinal problems	[144]
	Ger Boota	Pakistan, Chonthra Karak	hypertension	[145]
	Masstura	Pakistan, Darra Adam Khel	typhoid fever, jaundice	[146]
<i>T. trifidum</i>	Speer botay	Pakistan, Malakand	diabetes, cooling agent	[147]
		South Africa	diabetes, gastrointestinal ailments, inflammatory conditions, burning feet syndrome, jaundice, cough, diarrhea, pyrexia, sore throat, expectorant	[148–151]
	Aambeibossie, Akkedispoot, Kaaitjedrieblaar, Koorsbossie, etc.	China	indigestion, hemorrhoids, fever and influenza, against snakebites and anthrax, healing of wounds	[24]
	Shan-Huo-Xiang	Taiwan	hemoptysis, hematemesis, pulmonary abscesses, traumatic injuries, bites of rabies-stricken dogs or venomous snakes	[152]
		Thailand	dysmenorrhea	[153]
	Pawn tshis nyeg	Saudi Arabia, Yemen	promoting fetal stabilization, treating coughs, fever, stomachache, dysmenorrhea	[153]
<i>T. yemense</i>	Rechal Fatima, Istaqtas	Libya	diabetes, kidney problems, rheumatism, anthelmintic, insect repellent	[154–156]
	Jada		antidiabetic, antihypertensive, and for extruding kidney stones	[26]

known in Greece (vernacular names: Chamaidrya, Moskhokhortaro, Dontokhortiis) as an antidiabetic, astringent, and to heal skin eruptions and wounds [62]. Another plant used locally in Italy is *Teucrium fruticans*, which, in Tuscany, is known for the depurative and diuretic effects of its infusion [66], whereas in Sicily, where it is known as “Erba ricottara”, the direct application of the leaves is used in the treatment of hemorrhoids [67].

In the isle of Madeira, Portugal, *Teucrium betonicum*, locally known as “abrotona, erva branca, herva branca” is used as stomachic and tonic [29].

*Teucrium arduini* is an Illyric-Balcanic endemic species distributed in Mediterranean and sub-Mediterranean areas in Croatia, Bosnia and Herzegovina, Montenegro, Serbia, and northern Albania. The aerial parts of this species (“Arduinijeva iva”) are used in Bosnia and Herzegovina in the form of tea to help heal stomach discomforts [27, 28].

*Teucrium montanum*, commonly known as mountain germander (dubačac mali in Serbian), is a perennial plant, distributed in Europe and the Middle East. It is a South European mountain species and grows on limestone rocks, pastures, and pine forests in the mountain regions. This plant species has long been consumed both as an herbal medicine and as a nourishing food. It is widely used in Serbia as a diuretic, stomachic, analgesic, and also as an antispasmodic, antibacterial, antifungal, anti-inflammatory, and antioxidant activity agent [74]. In the eastern part of the same country, where it is known as “Trava-iva”, the infusion of the whole plant has been utilized for immune system strengthening [75], disorders of the abdominal organs, headaches, as tonic, for improving appetite, and antipyretic (“bitter tea”-blend: mixed with other herbs). Externally, it has been used for treatment of tuberculosis [bath soak: add to yellow camomile (*Anthemis tinctoria*) or by inhalation of the smoke] [43]. In Bosnia and Herzegovina, the infusion of the aerial parts has been reported for treating liver and stomach diseases [27]. Its use has also been reported in Iran to treat headaches [73].

## North Africa

Several species of *Teucrium* growing in North Africa have been used in the traditional medicine of this area. *Teucrium ramosissimum* grows widely in the arid Mediterranean climate and in calcareous substrates. Since ancient times, its aerial parts have been used in Tunisian traditional medicine, where it is known as “Hachichet belgacem ben salem” for the treatment of intestinal inflammation, as a remedy for gastric ulcer, and in external use as a cicatrizing agent [131, 132]. *Teucrium alopecurus* (H’chichit ben salem) is an endemic species limited to South Tunisia widely used in its traditional medicine and known to possess anti-inflammatory properties, and its aerial parts have been used for many years as an infusion alone or in combination with other species [22]. In the folk medicine of this region, many people apply the powder of this species on the external inflamed area to reduce swelling and pain [23]. Additionally, *Teucrium sauvagei*, endemic to the same area of Tunisia, has been utilized in the following ways: the leaves have been applied for wound healing, antidiabetic and anti-inflammatory remedies, treating ulcers, colic, and against food poisoning [136]. *Teucrium maghrebicum*, in Algeria called “kayatat el gerah”, is used in traditional medicine of this country and Moroc-

co to treat burns, fevers, and microbial infections [68]. A similar usage has been reported in Morocco for *Teucrium antiatlanticum* [25]. *Teucrium apollinis* and *Teucrium zanonii*, both known in Libya as “Jada”, have been used for its antidiabetic and antihypertensive effects, and for extruding kidney stones [26]. *T. polium* ssp. *geyrii* (Takmazzut) in Algeria is reported for wound healing, as a tea and spice, and as an analgesic [128, 129].

## Middle East

*T. polium* subsp. *capitatum* (syn. *T. capitatum*) is a perennial, pubescent, aromatic plant, 20–50 cm high, with green-greyish leaves and white flowers, which appears from June to August. It grows wild in Southern Europe, Central and Southwest Asia, and North Africa. The plant is mixed with boiled water and sugar to form a refreshing beverage. The leaves are used in cooking as a spice [125]. In Lebanon, the infusion of its aerial parts (Ja’ada) are utilized for diabetes, insomnia, neurological disorders, and abdominal cramps [77]. The plant is also used in Palestine, where it is known as “Cat Thyme, Jedeh Subian and جعدة”, for its diuretic, antipyretic, diaphoretic, antispasmodic, tonic, anti-inflammatory, antihypertensive, anorexic, analgesic, antibacterial, antidiabetic effects [54, 127], and, in veterinary medicine, to treat diarrhea, colic, bleeding, scabies, and flatulence [106, 126].

Several other taxa are utilized in the folk medicine of the eastern part of the Mediterranean Sea. In Lebanon, *Teucrium pruinosum* (Ja’ada) is used for gastrointestinal disorders, wounds, fever, and cold [77], *Teucrium divaricatum* ssp. *villosum* is used for fever and colds, and as a cicatrizing and stomachic [61], and *Teucrium orientale* is used for wounded skin and fever [77]. This last one is also used as an antipyretic and for women’s hot flashes in Iran, where it is known as “Maryam nokhodi” and “Chaye alafi” [78, 79]. In Palestine, *Teucrium creticum* is well known for its antidiabetic properties [54].

The ethnopharmacological activities of *Teucrium* taxa growing in Cyprus has been reviewed by Arnold [162]. *Teucrium micropodioides* has been by far the one most used: the infusion of the flowering parts as a sedative and against tuberculosis; the infusion of the whole plant as an antispasmodic (gastric ulcer, gastrointestinal inflammation), diuretic (kidney stones and cystitis), carminative, and emmenagogue (sterility in the female); the infusion of the leaves as an antipyretic (cold), stimulant, stomachic, anthelmintic, and antidiabetic; the application of compresses from pounded fresh leaves in external use against rheumatism as well as an antipruritic and antiseptic (against skin eruption and boils) [58]. In the traditional medicine of this island, the whole plant of *Teucrium cyprium* ssp. *cyprium* is used in the form of an infusion against fever and jaundice. The topical application of the juice of the fresh plant has a healing, astringent, and antipruritic effect [58]. *Teucrium kotschyianum* is used in traditional medicine as an antipyretic and antidiabetic [58]. With regard to *T. divaricatum* ssp. *canescens*, the infusion of the flowering plant is mainly used as a stomachic. In cases of fever and the common cold, the steam is inhaled. Externally, the infusion of the plant is used as a cicatrizing agent [58]. *T. divaricatum* ssp. *divaricatum* has been reported in Cyprus as a cicatrizing agent [59], whereas the same species (Mürücüotu, buhurcuoğlu otu, böceotu) has been largely employed in Turkey for coughs, sickness, stomachache, urinary diseases, gallbladder

disease, kidney stones, and as a tonic for eyes [60]. Two other Turkish species are noteworthy of mention. The aerial parts of *Teucrium sandrasicum* are widely used in the daily diet. The plant is also valued as a traditional medicine and is used for diuretic, diaphoretic, tonic, antipyretic, antidiabetic, antispasmodic, and cholagogic purposes [135]. The decoction of the aerial parts of *Teucrium parviflorum*, on the other hand, has been utilized in traditional treatment against hemorrhoids in Turkey [45].

### Arabia-Pakistan-Iran-India

*Teucrium yemense* (Defl.), locally known as Reehal Fatima, is a perennial herb commonly grown in Djibouti, Ethiopia, Saudi Arabia, Sudan, and Yemen. In Yemeni folk medicine, the entire crushed plant is put into an with water, and the liquid is consumed orally to treat diabetes, kidney problems, and rheumatism and as an anthelmintic. Its use as an insect repellent has also been reported [154–156].

*Teucrium mascatense* Boiss. is an aromatic perennial plant that grows 25 cm high and is frequently seen on rocky hills and mountain slopes in northern Oman. It shares the common Arabic name ja'dah with the related species *Teucrium stocksianum* Boiss., a plant more common throughout the Middle East, whose properties have been reported above. *T. mascatense* is also used as a fever remedy and to reduce blood flow during menstruation. Omani people have been aware of this herb for several ages, and it has become popular and famous since a long time. The leaves are boiled in water for a long time, then the solution is cooled and consumed as a drink for stomachaches and colic. Dried leaves are burned, and the smoke is placed under bed covers for treating fevers. The leaves of *T. mascatense* are also boiled in water with the leaves of *Rhazya stricta*, *Fagonia indica*, myrrh, sea salt, and black salt (potassium chloride); the warm "tea" is taken for abdominal colic, fever, and diabetes. Drinking the water in which the leaves have been boiled is believed to reduce blood flow during menstruation [71, 72].

*T. stocksianum* Boiss. (Lamiaceae) is a perennial, woody, aromatic herb that is native to the mountainous regions of the United Arab Emirates (UAE), northern Oman, Pakistan, and Iran, and is also present in North Africa and the East Mediterranean zone. It is a popular treatment for stomachache, kidney problems, renal colic, colds, and diabetes, as well as an anti-fever remedy in the herbal medicine of the UAE and Sultanate of Oman and Iran [142, 144]. In Pakistan, where it is locally known as "Speer botay", the leaves and young shoots are commonly used for the preparation of traditional medicines to treat several ailments, including gastrointestinal ailments and inflammatory conditions. In addition to the gastroprotective effect, a decoction of *T. stocksianum* has been used for the treatment of diabetes, burning feet syndrome, as a blood purifier, and for the treatment of hypertension, epilepsy, and sore throats. The people of Malakand Division, Pakistan, have good knowledge about this plant for its medicinal use. Ethnobotanically, the juice of *T. stocksianum* is given for the treatment of jaundice and as a blood purifier, as well as a cooling agent. The decoction of the plant is also prescribed to treat chronic fever. Leaves are soaked in water overnight and the juice is consumed before breakfast to treat diarrhea and abdominal pain. Young leaves are boiled in water and the obtained juice is used for curing coughs

[149]. In the Darra Adam Khel region of Pakistan, where it is known as Masstura, leaves and stems are kept in water for some time or boiled before taken as water and used as a cooling agent and against diabetes [147]. The native Khattak tribes of the Chonthra, district Karak, Pakistan, know this plant as Ger Boota. They use the decoction of the whole plant for curing undiagnosed fever. The plant is soaked overnight in water and the decoction is taken orally before breakfast for typhoid and jaundice [146]. The decoction of the whole plant (Spariki) has also been reported for the treatment of hypertension by the local people of the district Dir lower, Pakistan, although its abuse can cause body weakness [145].

In the same country, in the area of Kutlla Valley, the infusion of *Teucrium royleanum* (Katheri) is utilized for eye diseases and nervous debility [134]. The leaves and stems of *T. royleanum* are also used in India (Lahaul: Udaipur), where it is known for its allelopathic, antibacterial, antifungal, antispasmodic, astringent, antipyretic, and anti-allergic properties [133]. *Teucrium persicum* (Marv-e-talkh, Arak) is traditionally used in Iran for abdominal pain and headaches [80].

### South Africa

The ethnopharmacological uses of three species of *Teucrium* growing in South Africa (*Teucrium africanum*, *Teucrium kraussii*, and *Teucrium trifidum*) have been exhaustively reviewed [24]. The Xhosa, Mfengu, Gcaleka, Mpondo, and Thembu ethnic groups drink an infusion of the leaf of *T. africanum* for snakebites and as a tonic. It is also used to sterilize anthrax-infected meat by boiling it with the plant. In the Willowmore district, a strong decoction is drunk for the treatment of hemorrhoids and is often applied locally for the same condition. The decoction is frequently taken as a diaphoretic in feverishness. Africans in the Butterworth district either chew the leaf or swallow a decoction of the leaf for the relief of a sore throat. Its use as a remedy for stomach disorders and in eye inflammations has also been reported.

*T. trifidum* is a popular remedy among the older Dutch folks. Brandy, in which the plant has been soaked, is taken as a stomachic in indigestion and tonic and a tea-like infusion is drunk for the relief of hemorrhoids. Both Europeans and Africans take a decoction for fever and influenza. The Xhosa use an infusion as a snakebite remedy, for sore throats, and to sterilize anthrax-infected meat by boiling it with the plant. Both the Xhosa and Gcaleka regard the plant as a tonic. Hewat states that it is a carminative. An infusion of the leaf is used by Europeans as a diabetes remedy and is said to be slightly purgative. Externally, a preparation of the plant is applied locally for whitlow and bee stings and to aid the healing of wounds [24].

### Essential Oils

The chemical composition of EOs obtained from 99 *Teucrium* taxa has been investigated. The major compounds (> 3%) occurring in the chemical composition of the EOs are reported in ► **Table 3**.

In the EOs of *Teucrium* species, generally, the main compounds are represented by sesquiterpene hydrocarbons, such as germacrene D and  $\beta$ -caryophyllene, or monoterpene hydrocarbons such as  $\alpha$ - and  $\beta$ -pinene. The taxa can be grouped into two different

► **Table 3** Main compounds (>3%) of the EOs from *Teucrium* taxa.

Taxa	Origin	Parts	Method	Main compounds	Ref.
<b>Section <i>Chamaedrys</i></b>					
<i>T. chamaedrys</i>	Corsica, Corti	ap	HD	$\beta$ -caryophyllene (29.0), germacrene D (19.4), $\alpha$ -humulene (6.8), $\delta$ -cadinene (5.4), ( <i>E</i> )- $\beta$ -farnesene (4.4), caryophyllene oxide (3.2)	[163]
	Corsica	ap	HD	( <i>E</i> )- $\alpha$ -caryophyllene (33.9), germacrene D (18.5), $\alpha$ -humulene (7.5), ( <i>E</i> )- $\beta$ -farnesene (5.1), $\delta$ -cadinene (4.6), caryophyllene oxide (3.1)	[164]
	Croatia	ap	HD	$\beta$ -caryophyllene (47.6), germacrene D (29.0), $\beta$ -copaene (5.7), caryophyllene oxide (4.5)	[165]
	Iran, Mazandaran	ap	HD	germacrene-D (16.5), ( <i>Z</i> )- $\beta$ -farnesene (12.2), $\beta$ -caryophyllene (10.5), $\alpha$ -pinene (9.1), $\delta$ -cadinene (7.4), $\beta$ -pinene (4.8), $\beta$ -bourbonene (3.8), $\alpha$ - <i>trans</i> -bergamotene (3.5)	[166]
	Iran	ap	HD	$\alpha$ -muurolene (15.3), $\beta$ -caryophyllene (15.0), $\alpha$ -pinene (7.9), ( <i>Z</i> )- $\beta$ -farnesene (7.6), $\beta$ -pinene (5.9), limonene (5.1), germacrene A (3.9), $\alpha$ -cadinene (3.8), $\alpha$ -copaene (3.0)	[167]
	Kosovo	ap	HD	germacrene D (24.1), hexadecanoic acid (12.7), eicosane (10.9), $\delta$ -cadinene (7.0), sclareolide (5.5), hexacosane (4.5), linoleic acid (4.0), $\beta$ -caryophyllene (3.9), ( <i>E</i> )-farnesyl acetate (3.3)	[168]
	Sardinia	ap	HD	$\beta$ -caryophyllene (27.4), germacrene D (13.5), caryophyllene oxide (12.3), ( <i>E</i> )- $\beta$ -farnesene (6.5), $\alpha$ -pinene (4.4), $\beta$ -pinene (3.4), $\beta$ -bourbonene (3.0)	[163]
	Serbia-Montenegro	ap	HD	$\beta$ -caryophyllene (26.9), germacrene D (22.8), $\alpha$ -humulene (6.7), caryophyllene oxide (5.5), $\alpha$ -pinene (5.3), 3-octanol (3.7), $\delta$ -cadinene (3.1)	[169]
	Turkey, Denizli	lv	DT	$\beta$ -pinene (13.1), germacrene D (9.5), $\alpha$ -pinene (8.9), $\alpha$ -farnesene (8.0), $\alpha$ -gurjunene (7.8), $\gamma$ -elemene (7.4), $\gamma$ -cadinene (6.4), heptacosane (4.8)	[170]
	Turkey, Baskil	ap	HD	germacrene D (32.1), $\beta$ -caryophyllene (14.2), $\delta$ -cadinene (13.1), bicyclogermacrene (6.7), $\beta$ -farnesene (4.3), neophytadiene (4.1)	[171]
<i>T. chamaedrys</i> ssp. <i>chamaedrys</i>	Turkey, Kelkit	ap	HD	germacrene D (16.7), $\alpha$ -pinene (15.8), $\beta$ -caryophyllene (11.8), $\beta$ -pinene (8.9), $\beta$ -myrcene (4.1), $\beta$ -bourbonene (3.1)	[172]
	Turkey, Çamli	ap	HD	$\beta$ -caryophyllene (19.7), $\alpha$ -pinene (12.5), germacrene D (9.3), $\beta$ -pinene (6.6), caryophyllene oxide (6.1), $\beta$ -bourbonene (3.6)	[172]
<i>T. chamaedrys</i> ssp. <i>sypsiense</i>	Turkey	ap	MD	caryophyllene oxide (27.7), $\alpha$ -pinene (11.4), caryophyllenol II (5.3), caryophyllenol I (4.0), $\beta$ -pinene (3.9), humulene epoxide-II (3.7), oct-1-en-3-ol (3.1)	[173]
	Iran	ap	HD	$\beta$ -caryophyllene (18.2), germacrene D (10.8), carvacrol (9.5), $\alpha$ -humulene (6.4), caryophyllene oxide (4.8), linalool (3.7), $\alpha$ - <i>trans</i> -bergamotene (3.3), $\beta$ -bourbonene (3.2), $\delta$ -cadinene (3.1), ( <i>E</i> )- $\alpha$ -farnesene (3.0)	[174]
<i>T. chamaedrys</i> ssp. <i>trapezunticum</i>	Turkey	ap	MD	$\beta$ -caryophyllene (18.2), nonacosane (11.8), germacrene D (10.8), caryophyllene oxide (7.4), $\alpha$ -pinene (7.0), dodecanoic acid (4.5), oct-1-en-3-ol (3.6), pentacosane (3.0), $\beta$ -bourbonene (3.2), $\beta$ -pinene (3.1)	[173]
	Cyprus, Kambos	st	HD	<i>allo</i> -aromadendrene (17.7), $\alpha$ -copaene (8.2), $\alpha$ -cadinene (8.1), <i>trans</i> - $\beta$ -bergamotene (6.5), $\alpha$ -cedrene (5.7), <i>trans</i> - $\beta$ -farnesene (5.4)	[58]
<i>T. divaricatum</i> ssp. <i>canescens</i>	Cyprus, Katodrys	lv	HD	$\beta$ -cubebene (26.7), $\beta$ -caryophyllene (17.6), $\alpha$ -pinene (12.1), $\beta$ -pinene (6.2), limonene (4.2), $\alpha$ -humulene (4.0), $\gamma$ -elemene (4.0), $\beta$ -bourbonene (3.0)	[58]
	Cyprus, Katodrys	st	HD	isopulegol (17.4), $\alpha$ -terpineol (17.0), myrtenal (7.2), $\beta$ -bourbonene (6.0), $\beta$ -guaiene (5.6), $\alpha$ -pinene (4.2), $\alpha$ -himachelene (3.5)	[58]
<i>T. chamaedrys</i> ssp. <i>chamaedrys</i>	Cyprus, Stavrouni	lv	HD	$\beta$ -cubebene (23.7), $\alpha$ -pinene (18.1), $\beta$ -caryophyllene (14.0), $\beta$ -pinene (10.7), limonene (6.7), $\alpha$ -humulene (5.6), $\gamma$ -elemene (3.9)	[58]
	Cyprus, Stavrouni	st	HD	$\beta$ -cubebene (26.1), $\beta$ -caryophyllene (17.0), $\alpha$ -humulene (7.9), $\alpha$ -pinene (7.7), $\beta$ -pinene (5.7), $\gamma$ -elemene (4.5), limonene (4.0), caryophyllene oxide (4.0)	[58]

continued

▶ Table 3 Continued

Taxa	Origin	Parts	Method	Main compounds	Ref.
<i>T. divaricatum</i> ssp. <i>divaricatum</i>	Greece	ap	HD	$\delta$ -cadinene (20.5–19.0), $\gamma$ -cadinene (13.4–8.5), bisabolene (12.2–5.9), $\beta$ -caryophyllene (12.5–10.4), limonene (8.5–1.2), $\alpha$ -humulene (5.7–2.9), $\alpha$ -pinene (4.9–1.3), <i>allo</i> -aromadendrene (3.7–0.5), spathulenol (3.3–1.1), $\beta$ -pinene (3.1–0.6)	[175]
<i>T. divaricatum</i> ssp. <i>vilosum</i>	Lebanon	ap	HD	$\beta$ -caryophyllene (30.1), caryophyllene oxide (6.1), hexahydrofarnesyl acetone (4.6), linalool (3.4), hexadecanoic acid (3.1)	[61]
<i>T. flavum</i>	Croatia, Dalmatia	ap	HD	$\alpha$ -pinene (17.3), $\beta$ -caryophyllene (15.8), $\beta$ -pinene (11.2), <i>allo</i> -aromadendrene (9.2), limonene + 1,8-cineole (6.2), $\alpha$ -cubebene (4.3), $\gamma$ -terpinene (3.5), $\delta$ -cadinene (3.2)	[176]
	Croatia, Split	ap	HD	$\beta$ -caryophyllene (23.1), germacrene D (15.3), $\alpha$ -pinene (10.5), $\beta$ -pinene (8.4), limonene (7.9), <i>n</i> -amyl-isovalerate (3.7)	[165]
	Greece, Mt Pileum	ap	HD	caryophyllene (12.2), 4-vinyl guanaco (9.7), caryophyllene oxide (7.9), $\alpha$ -humulene (6.0), linalool (3.4), $\beta$ -bourbonene (3.1)	[177]
	Iran	lv	HD	$\beta$ -caryophyllene (30.6), germacrene D (21.3), $\alpha$ -humulene (8.4), $\tau$ -cadinol (6.9), $\delta$ -cadinene (4.9), <i>trans</i> - $\alpha$ -bergamotene (4.8), spathulenol (4.5), caryophyllene oxide (3.8), $\beta$ -bisabolene (3.1)	[178]
	Montenegro	ap	HD	$\beta$ -bisabolene (35.0), $\alpha$ -pinene (17.5), $\beta$ -pinene (11.5), limonene (6.4), $\beta$ -caryophyllene (5.4), $\alpha$ -humulene (3.6)	[168]
	Sicily	lv	MHD	$\beta$ -bisabolene (47.0–31.5), germacrene D (14.0–9.6), $\beta$ -caryophyllene (4.6–3.1), $\delta$ -cadinene (4.1–2.3), viridiflorol (5.0–2.5), phytol (4.0–3.3)	[179]
	Sicily	fl	MHD	$\beta$ -bisabolene (48.2), germacrene D (7.7), $\beta$ -caryophyllene (4.7), $\delta$ -cadinene (4.3)	[179]
	Sicily	fr	MHD	$\beta$ -bisabolene (48.7), germacrene D (4.3), $\beta$ -caryophyllene (3.2)	[179]
<i>T. flavum</i> ssp. <i>flavum</i>	Italy, Marche	ap	SPEM	( <i>Z,E</i> )- $\alpha$ -farnesene (33.9–27.3), ( <i>E</i> )- $\beta$ -farnesene (13.3–12.3), germacrene D (13.2–3.1)	[180]
	Italy, Marche	ap, dry	HD	( <i>Z,E</i> )- $\alpha$ -farnesene (11.5), linalool (7.6), $\beta$ -bisabolene (7.5), ( <i>E</i> )- $\beta$ -farnesene (7.3), 11- $\alpha$ H-Himachal-4-en-1- $\beta$ -ol (6.2), $\beta$ -caryophyllene (5.7), germacrene D (5.5), $\alpha$ -pinene (5.3), $\beta$ -pinene (4.5), limonene (3.5)	[181]
	Italy, Marche	ap, fresh	HD	( <i>Z,E</i> )- $\alpha$ -farnesene (14.9), 11- $\alpha$ H-himachal-4-en-1- $\beta$ -ol (10.1), germacrene D (6.6), ( <i>E</i> )- $\beta$ -farnesene (5.7), $\beta$ -caryophyllene (5.1), $\beta$ -bisabolene (5.0)	[181]
	Italy, Marche	ap, dry	SPEM	( <i>Z,E</i> )- $\alpha$ -farnesene (33.9), ( <i>E</i> )- $\beta$ -farnesene (12.3), $\alpha$ -zingiberene (6.0), $\beta$ -caryophyllene (5.1), germacrene D (3.1)	[181]
	Italy, Marche	ap, fresh	SPEM	( <i>Z,E</i> )- $\alpha$ -farnesene (27.3), ( <i>E</i> )- $\beta$ -farnesene (13.3), germacrene D (13.2), $\beta$ -caryophyllene (8.4), zingiberene (6.5)	[181]
	Italy, Liguria	ap	HD	$\alpha$ -pinene (19.0), germacrene D (11.9), $\beta$ -pinene (10.6), limonene (9.0), $\alpha$ -bulnesene (8.9), ( <i>Z,E</i> )-farnesol (4.7), ( <i>E</i> )- $\beta$ -farnesene (3.3)	[182]
	Italy, Tuscany	ap	HD	$\alpha$ -pinene (22.6), $\beta$ -pinene (15.8), limonene (13.2), germacrene D (6.9), ( <i>E,E</i> )- $\alpha$ -farnesene (4.8)	[182]
	Greece, Zakynthos	ap	HD	caryophyllene (13.5), caryophyllene oxide (8.5), 4-vinyl guaiaicol (6.0), $\alpha$ -humulene (5.0), hexahydrofarnesyl acetone (3.4), $\alpha$ -copaene (3.3)	[183]
	Corsica	ap	HD	$\alpha$ -pinene (21.9), limonene (20.0), $\beta$ -pinene (18.1), ( <i>Z</i> )- $\alpha$ -ocimene (15.5)	[164]
	Corsica	ap	HD	limonene (22.3–21.9), $\alpha$ -pinene (21.5–19.8), $\beta$ -pinene (18.1–16.4), ( <i>Z</i> )- $\beta$ -ocimene (17.0–14.5)	[184]
	Tunisia	ap	HD	$\beta$ -caryophyllene (32.5), $\alpha$ -humulene (17.8), germacrene D (6.0), caryophyllene oxide (4.9), ( <i>Z</i> )- $\gamma$ -bisabolene (4.0)	[185]
					continued



Taxa	Origin	Parts	Method	Main compounds	Ref.
<i>T. flavum</i> ssp. <i>glaucaum</i>	Corsica	ap	HD	limonene (27.4), $\alpha$ -pinene (12.2), $\beta$ -pinene (10.3), ( <i>Z</i> )- $\alpha$ -ocimene (6.0), ( <i>E</i> )-phytol (4.5)	[164]
	Corsica	ap	HD	limonene (31.8–21.1), $\alpha$ -pinene (17.6–8.5), $\beta$ -pinene (12.4–9.7), ( <i>Z</i> )- $\beta$ -ocimene (8.1–2.4), ( <i>E</i> )-phytol (5.5–2.4), ( <i>E</i> )- $\beta$ -farnesene (4.4–1.3)	[184]
<i>T. flavum</i> ssp. <i>hellenicum</i>	Greece	lv	HD	germacrene D (21.9), $\beta$ -caryophyllene (18.1), spathulenol (17.9), ( <i>E</i> )- $\beta$ -farnesene (7.3), $\beta$ -bisabolene (7.1), $\beta$ -cubebene (5.2), $\alpha$ -pinene (3.4), myrcene (3.7), $\beta$ -pinene (3.1)	[65]
	Greece	fl	HD	germacrene D (22.3), $\beta$ -caryophyllene (22.2), $\alpha$ -humulene (11.8), $\beta$ -bisabolene (7.6), $\alpha$ -pinene (6.8), $\beta$ -pinene (5.2)	[65]
<i>T. marum</i>	Corsica	ap	HD	caryophyllene oxide (9.8), ( <i>E</i> )- $\alpha$ -bergamotene (8.2), $\beta$ -bisabolene (7.5), ( <i>E</i> )- $\beta$ -caryophyllene (5.3), $\beta$ -sesquiphellandrene (3.7), estragole (3.5), octadecyl acetate (3.3), humulene epoxide II (3.2), (3 <i>Z</i> ,6 <i>E</i> ,10 <i>E</i> )- $\alpha$ -springene (3.2), geranyl acetate (3.0)	[164, 186]
<i>T. marum</i> ssp. <i>drosocalyx</i>	Balearic Is, Minorca Favariix	ap	SDE	dolichodial (34.8), $\alpha$ -bergamotene (11.5), <i>p</i> -allyl-anisole (7.0), caryophyllene epoxide (5.6), $\beta$ -bisabolene (5.1), $\beta$ -caryophyllene (4.5), epidolichodial (3.0)	[187]
	Balearic Is, Minorca Canutells	ap	SDE	dolichodial (89.5), $\beta$ -caryophyllene (3.2)	[187]
<i>T. marum</i> ssp. <i>marum</i>	Balearic Is, Minorca Biniancolla	ap	SDE	dolichodial (81.2), epidolichodial (7.8)	[187]
	Balearic Is, Minorca Favariix	ap	SDE	dolichodial (48.3), $\beta$ -caryophyllene (5.3), epidolichodial (3.5)	[187]
<i>T. marum</i> ssp. <i>occidentale</i>	Balearic Is, Minorca Barrac d'Algendar	ap	SDE	dolichodial (72.5–42.1), $\beta$ -caryophyllene (7.7–5.2), caryophyllene oxide (7.0–2.6), epidolichodial (4.2–2.1)	[187]
	Balearic Is, Minorca Cala En Caldès	ap	SDE	dolichodial (35.8), caryophyllene epoxide (8.7), $\beta$ -caryophyllene (7.8), $\alpha$ -bergamotene (8.4), $\beta$ -bisabolene (7.1)	[187]
<i>T. marum</i> ssp. <i>occidentale</i>	Balearic Is, Minorca El Toro	ap	SDE	dolichodial (74.0), $\beta$ -bisabolene (4.4), epidolichodial (3.7)	[187]
	Balearic Is, Mallorca Sierra de Alfabia	ap	SDE	$\beta$ -caryophyllene (34.7–23.9), caryophyllene epoxide (30.6–20.7), $\delta$ -cadinene (10.2–1.6), $\alpha$ -humulene (8.3–5.8), $\beta$ -bisabolene (10.0), $\alpha$ -bergamotene (5.9–0), humuladienone (5.5–4.3), $\alpha$ -bisabolol (4.1–1.5)	[187]
<i>T. marum</i> ssp. <i>marum</i>	Balearic Is, Mallorca Castel d'alarò	ap	SDE	$\beta$ -caryophyllene (23.1–21.2), caryophyllene epoxide (23.9–19.3), $\delta$ -cadinene (12.9–10.5), $\beta$ -bisabolene (9.5–9.4), $\alpha$ -humulene (6.0–5.0), $\alpha$ -bisabolol (6.2–5.1), $\gamma$ -cadinene (5.0–3.9), humuladienone (3.8–3.2),	[187]
	Balearic Is, Mallorca Penyal Fumat	ap	SDE	caryophyllene epoxide (20.8), $\beta$ -caryophyllene (14.3), $\alpha$ -bisabolol (10.5), $\delta$ -cadinene (8.1), $\gamma$ -cadinene (7.6), humuladienone (3.8), dolichodial (3.5), $\alpha$ -humulene (3.5)	[187]
<i>T. marum</i> ssp. <i>marum</i>	Balearic Is, Mallorca Esporles	ap	SDE	dolichodial (28.9), $\beta$ -caryophyllene (19.9), $\beta$ -bisabolene (11.9), caryophyllene epoxide (11.6), $\delta$ -cadinene (8.5), $\alpha$ -humulene (4.4)	[187]
	Sardinia	ap	HD	<i>iso</i> -caryophyllene (20.2), $\beta$ -bisabolene (14.7), $\beta$ -sesquiphellandrene (11.3), $\alpha$ -santalene (11.0), dolichodial (9.4), $\alpha$ -caryophyllene (7.2), 4-allyl anisole (3.8), caryophyllene oxide (3.2)	[188]
<b>Section <i>Isotrifodon</i></b>					
<i>T. antiatlanticum</i>	Morocco	ap	HD	germacrene D (13.7), $\delta$ -cadinene (12.7), $\alpha$ -gurjunene (11.5), $\gamma$ -muurolene (8.0), <i>allo</i> -aromadendrene (3.1)	[25]
<i>T. cavernarum</i>	Turkey	ap	HD	$\beta$ -caryophyllene (32.9), germacrene D (20.7), caryophyllene oxide (14.1), bicyclogermacrene (6.3), $\alpha$ -humulene (3.9)	[189]
					continued

► Table 3 Continued

Taxa	Origin	Parts	Method	Main compounds	Ref.
<i>T. montbretii</i> ssp. <i>heliotropifolium</i>	Greece, Karpathos	ap	HD	carvacrol (13.9), caryophyllene oxide (12.7), hexadecanoic acid (9.8), caryophyllene (7.8), caryophylladienol I (3.7), linalool (3.5), $\beta$ -bourbonene (3.5)	[177]
	Greece, Karpathos	ap	HD	carvacrol (13.5), hexadecanoic acid (10.7), caryophyllene oxide (8.8), caryophyllene (8.2), germacrene D (3.7), caryophyllenol II (3.2)	[190]
	Turkey	ap	SD	germacrene D (20.8), pulegone (9.5), bicyclogermacrene (9.2), hexadecanoic acid (7.9), spathulenol (6.5), $\beta$ -pinene (3.9), $\beta$ -bourbonene (3.6)	[189]
<i>T. persicum</i>	Iran, Fars	ap	HD	caryophyllene oxide (10.6), $\alpha$ -pinene (9.4), geranyl linalool (7.8), $\gamma$ -cadinene (7.4), elemol (6.9), $\alpha$ -cadinol (5.5), elemol acetate (3.6), $\beta$ -caryophyllene (3.0), $\beta$ -eudesmol (3.0)	[191]
	Iran, Busheh	ap	HD	<i>epi</i> - $\alpha$ -cadinol (23.2), $\alpha$ -pinene (17.3), $\alpha$ -cadinol (9.7), $\beta$ -pinene (5.8), $\delta$ -cadinene (5.4), limonene (4.6), myrcene (4.1), $\beta$ -caryophyllene (4.1), $\gamma$ -cadinene (3.8)	[192]
	Iran, Lar Mountain	ap	HD	$\alpha$ -cadinene (9.7), 1,4-cadinadiene (9.2), $\alpha$ -terpinyl acetate (7.9), linalyl acetate (7.7), linalool (7.6), cadinol (6.2), 1,8-cineole (5.7), $\gamma$ -terpineol (4.4)	[80]
<b>Section <i>Poliium</i></b>					
<i>T. algarbiensis</i>	Portugal	ap	HD	limonene (11.8), $\beta$ -pinene (10.2), germacrene D (7.6), sabinene (7.2), myrcene (5.7), $\tau$ -cadinol (5.0), $\alpha$ -cadinol (3.9), bicyclogermacrene (3.0), $\delta$ -cadinene (3.0)	[193]
<i>T. alopercus</i>	Tunisia, Matmata	ap	HD	$\delta$ -cadinene (13.4), nerolidyl acetate (12.3), $\alpha$ -humulene (12.3), $\alpha$ -guaiene (10.2), $\beta$ -caryophyllene (8.2), $\gamma$ -muurolene (4.5), ( <i>E</i> )-nerolidol (4.5), bicyclogermacrene (4.1)	[194]
	Tunisia, Gafsa	ap	HD	$\alpha$ -bisabol (16.2), (+)- <i>epi</i> -bicyclicosequiphellandrene (15.4), $\alpha$ -cadinol (8.5), pentane, 3-methyl (6.1), bicyclo[3.1.0]hex-2-ene, 4-methyl-1-(1-methylethyl)- (5.1), $\beta$ -phellandrene (3.8)	[22, 23]
<i>T. antitauricum</i>	Turkey	ap	HD	germacrene D (28.2), $\beta$ -caryophyllene (27.6), caryophyllene oxide (7.5), bicyclogermacrene (5.5), $\alpha$ -humulene (4.2), aromadendrene (3.6)	[195]
<i>T. apollonis</i>	Libya	ap	HD	$\beta$ -caryophyllene (22.4), limonene (11.8), germacrene D (11.8), $\alpha$ -pinene (5.8), sesquilavandulol (4.0), $\beta$ -citronellene (3.8), $\delta$ -cadinene (3.7)	[196]
<i>T. carolipaui</i>	Spain, Alicante	ap	HD	$\tau$ -cadinol (17.0–5.0), $\tau$ -muurolol (12.3–11.3), $\alpha$ -cadinol (12.3–8.1), $\beta$ -eudesmol (10.1–6.2), $\delta$ -cadinene (7.6–3.9), $\gamma$ -cadinene (4.5–0.3), $\alpha$ -copaene (4.3–1.2)	[197]
	Spain, Almeira	ap	HD	$\delta$ -cadinene (14.3), 3- $\beta$ -hydroxy- $\alpha$ -muurolene (9.4), $\alpha$ -cadinol (7.2), cadina-1,4-diene (4.3), caryophyllene oxide (4.5), 1- <i>epi</i> -cubanol (4.1), cubenol (3.5)	[198]
<i>T. cyprium</i> ssp. <i>cyprium</i>	Cyprus, Sun valley	lv	HD	sabinene (21.2), $\delta$ -cadinene (9.6), $\alpha$ -cadinene (8.4), $\beta$ -guaiene (4.7), $\beta$ -caryophyllene (4.6), $\alpha$ -pinene (3.3)	[58]
	Cyprus, Chionistra	lv + fl	HD	sabinene (11.9), $\delta$ -cadinene (8.1), $\beta$ -caryophyllene (7.1), $\alpha$ -pinene (5.5), $\gamma$ -terpinene (4.6), <i>p</i> -cymene (3.7)	[58]
	Cyprus, Chionistra	st	HD	$\delta$ -cadinene (11.4), $\alpha$ -cadinene (5.9), carvacrol (4.3), $\beta$ -guaiene (4.0)	[58]
<i>T. gnaphalodes</i>	Spain	ap	HD	$\beta$ -caryophyllene (12.1), sabinene (8.8), <i>trans</i> -pinocarveol (7.8), $\beta$ -pinene (7.1), myrtenal (5.7), <i>p</i> -cymen-8-ol (4.5), ledol (4.1), dehydrosabinaketone (3.9), <i>allo</i> -aromadendrene (3.4), caryophyllene oxide (3.4), limonene (3.1)	[199]
					continued

► **Table 3** Continued

Taxa	Origin	Parts	Method	Main compounds	Ref.
<i>T. haenseleri</i>	Spain	fl	HD	$\beta$ -pinene (30.3), $\alpha$ -pinene (20.0), ( <i>E</i> )-pinocervol (3.8), limonene (3.3), $\alpha$ -campholenal (3.1), $\beta$ -mycene (3.0)	[200]
	Spain	lv-fl stage	HD	$\beta$ -pinene (24.0), $\alpha$ -pinene (17.5), ( <i>E</i> )-pinocervol (5.4), $\alpha$ -campholenal (4.7), $\delta$ -cadinene (4.7), ( <i>E</i> )-verbenol (3.4), myrtenal (3.2)	[200]
<i>T. levicephalum</i>	Spain	lv-vg stage	HD	$\beta$ -pinene (30.9), $\alpha$ -pinene (22.7), ( <i>E</i> )-pinocervol (5.4), limonene (3.3), $\beta$ -mycene (3.1), sabinene (3.0), $\delta$ -cadinene (3.0)	[200]
	Spain	ap	HD	sabinene (57.4–47.5), $\alpha$ -pinene (19.3–19.1), germacrene D (9.9–5.0), limonene (8.3–7.1), $\beta$ -caryophyllene (4.6–1.7), germacrene B (3.7–0.9)	[197]
<i>T. leucocladum</i>	Egypt	ap	HD	patvholi alcohol (31.2), $\beta$ -pinene (12.7), $\alpha$ -pinene (11.0), $\alpha$ -cadinol (9.3), $\tau$ -cadinol (5.5), mycene (5.3), viridiflorol (5.4), epizonarene (4.5)	[201]
<i>T. libanitis</i>	Spain	ap	HD	$\alpha$ -pinene (21.2–9.9), $\tau$ -cadinol (11.8–1.1), $\delta$ -cadinene (9.7–5.3), sabinene (6.6–5.8), $\alpha$ -cadinol (6.0–0.9), germacrene D (4.3–1.4), $\alpha$ -cedrene (4.2–1.1), caryophyllene oxide (4.0–1.6)	[202]
	Portugal	ap	HD	elemol (12.0–2.6), $\beta$ -pinene (11.9–2.5), limonene (11.5–1.2), sabinene (9.6–2.1), $\alpha$ -cadinol (9.1–4.2), $\alpha$ -pinene (8.5–0.8), myrcene (7.3–2.5), $\delta$ -cadinene (7.3–2.0), $\tau$ -cadinol (6.2–5.2), germacrene D (6.0–1.0), terpien-4-ol (5.5–1.9), $\beta$ -selimene (4.0–1.0), $\beta$ -caryophyllene (3.9–0.7)	[193]
<i>T. lusitanicum</i> ssp. <i>aereiformis</i>	Spain, Malaga	ap	HD	limonene (15.1), $\beta$ -pinene (5.2%), $\alpha$ -copaene (4.5), terpinen-4-ol (3.5), $\alpha$ -cadinol (3.3)	[203]
<i>T. mascartense</i>	Oman, Jabal Al-Akhdhar	lv	HD	linalool (27.8), linalyl acetate (12.6), $\beta$ -eudesmol (10.1), limonene (5.7), $\alpha$ -bergamotene (5.0) <i>cis</i> -linalool oxide (furanoid) (4.6), <i>trans</i> -linalool oxide (furanoid) (4.1), $\alpha$ -terpineol (3.0)	[71]
	Oman, Nizwa	lv	HD	limonene (17.0), linalool (12.3), $\alpha$ -pinene (10.1), $\beta$ -eudesmol (10.1), linalyl acetate (4.3), <i>trans</i> - $\alpha$ -bergamotene (4.2), $\beta$ -pinene (3.5)	[204]
<i>T. micropodiodes</i>	Cyprus, Akamas	lv	HD	$\beta$ -pinene (17.6), $\alpha$ -pinene (6.6), $\beta$ -bisabolene (6.4), limonene (4.3), $\beta$ -caryophyllene (4.3), sabinene (4.1), $\alpha$ -cedrene (3.7), <i>trans</i> -pinocarveol (3.5), $\gamma$ -elemene (3.5)	[58]
	Cyprus, Akamas	st	HD	$\beta$ -bisabolene (10.8), $\beta$ -pinene (5.7), $\beta$ -caryophyllene (5.0), <i>trans</i> -nerolidol (4.0), <i>trans</i> -pinocarveol (3.5)	[58]
	Cyprus, Kambos	fl	HD	$\alpha$ -cedrene (21.0), $\beta$ -caryophyllene (16.3), $\alpha$ -humulene (7.8), $\gamma$ -elemene (3.6), caryophyllene oxide (3.6)	[58]
	Cyprus, Kambos	st	HD	$\gamma$ -elemene (6.0), $\beta$ -bisabolene (5.5), <i>trans</i> -nerolidol (3.5), $\alpha$ -cedrene (3.3), $\alpha$ -himachalene (3.2), $\delta$ -cadinene (3.2), nerol (3.2), $\beta$ -caryophyllene (3.0), <i>trans</i> -pinocarveol (3.0), caryophyllene oxide (3.0)	[58]
	Cyprus, Kambos	fr + fl	HD	$\alpha$ -cedrene (8.8), $\beta$ -pinene (6.3), $\gamma$ -elemene (5.9), <i>trans</i> -pinocarveol (3.9), $\alpha$ -pinene (3.0)	[58]
	Cyprus, Mosphiloti	lv + fl	HD	$\beta$ -pinene (43.5), $\alpha$ -pinene (14.7), $\alpha$ -cedrene (5.9), limonene (5.8), <i>trans</i> - $\beta$ -farnesene (4.8), myrtenal (3.7), pinocarvone (3.3), nerol (3.2), $\gamma$ -elemene (3.0)	[58]
	Cyprus, Mosphiloti	st	HD	sabinene (18.8), $\beta$ -pinene (11.2), $\alpha$ -cedrene (9.6), $\alpha$ -pinene (6.6), $\alpha$ -terpinene (6.0), $\gamma$ -elemene (5.2)	[58]
	Croatia	ap	HD	germacrene D (17.2), $\beta$ -pinene (12.9), $\beta$ -caryophyllene (7.1), limonene (4.6), myrcene (4.2), linalool (3.6), $\beta$ -bourbonene (3.4), hexacosane (3.4), pentacosane (3.3), tetracosane (3.1)	[165]
	Turkey	ap	HD	sabinene (11.3), $\delta$ -cadinene (6.3), germacrene D (5.8), $\alpha$ -copaene (5.7), ( <i>E</i> )- $\beta$ -farnesene (5.5), $\tau$ -cadinol (5.4), $\alpha$ -pinene (5.2), linalool (3.2), $\beta$ -pinene (3.1)	[205]
	Serbia-Mont Mt. Orjen	ap	HD	germacrene D (15.0), $\alpha$ -pinene (12.4), $\beta$ -eudesmol (10.1), $\beta$ -caryophyllene (6.9), $\beta$ -pinene (4.8), $\delta$ -cadinene (4.5), $\gamma$ -cadinene (4.1), cadinol (3.6), bicyclogermacrene (3.5)	[169]
Serbia, Jadovnik	ap	HD	$\delta$ -cadinene (17.2), $\beta$ -selimene (8.2), $\alpha$ -calacorene (5.0), 1,6-dimethyl-4-(1-methylethyl)-naphthalene (4.9), caryophyllene (4.3), copaene (4.2), torreyol (3.9), 4-terpineol (3.9), cadiena-1,4-diene (3.4), $\beta$ -sesquiphellandrene (3.3), $\gamma$ -curcumene (3.2), $\tau$ -cadinol (3.1)	[206, 207]	
Serbia, Jabura	ap	HD	$\delta$ -cadinene (8.1), $\beta$ -caryophyllene (5.1), $\tau$ -muurolol (4.2), $\alpha$ -pinene (4.0), dehydrosesquiceneole (3.9), $\gamma$ -cadinene (3.6), $\alpha$ -cadinol (3.5)	[208]	

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continued

► Table 3 Continued

Taxa	Origin	Parts	Method	Main compounds	Ref.
<i>T. montanum</i> ssp. <i>jailae</i>	Slovakia	ap	HD	germacrene D (12.8), $\beta$ -caryophyllene (8.0), <i>epi</i> - $\alpha$ -cadinol (4.5), $\alpha$ -pinene (3.1), bicyclogermacrene (3.1), <i>epi</i> -cubenol (3.0), cubenol (3.0)	[209]
<i>T. polium</i>	Algeria, Bordj Bou Arreridj	ap	HD	germacrene D (13.8), $\beta$ -eudesmol (8.7), bicyclogermacrene (4.9), $\beta$ -caryophyllene (4.2), shyobunol (3.9), $\beta$ -pinene (3.3), <i>trans</i> -calamenene (3.2), $\delta$ -cadinene (3.2)	[210]
	Algeria, Bordj Bou Arreridj	fl	HD	germacrene D (12.5), shyobunol (5.6), $\delta$ -cadinene (4.7), bicyclogermacrene (4.6), $\beta$ -eudesmol (4.5), $\alpha$ -cadinol (3.6)	[210]
	Algeria, Bouira	ap	HD	germacrene D (25.0), $\beta$ -pinene (11.3), bicyclogermacrene (10.4), spathulenol (5.8), limonene (4.0), <i>trans</i> -cadinol (3.5)	[211]
	Algeria	ap	HD	$\beta$ -pinene (16.6), germacrene D (14.8), $\alpha$ -pinene (7.2), spathulenol (6.4), limonene (5.6), bicyclogermacrene (5.5)	[212]
	Algeria, Mt. Tessala	ap	HD	D-germacrene (18.9), ( <i>E</i> )- $\beta$ -ocimène (12.7), bicyclogermacrene (11.0), $\beta$ -pinene (9.0), carvacrol (7.0), spathulenol (4.2), linalol (4.0), $\alpha$ -pinene (3.2)	[213]
	Algeria, Tlemcen	ap	HD	germacrene D (25.8), bicyclogermacrene (13.0), $\beta$ -pinene (11.7), carvacrol (8.9), spathulenol (6.5), $\delta$ -cadinene (4.3), $\alpha$ -pinene (4.0), citronelle (3.6)	[214]
	Algeria, North East	ap	HD	$\alpha$ -pinene (18.0–14.1), $\beta$ -pinene (18.1–15.0), germacrene D (19.0–3.8), myrcene (10.4–8.2), limonene (8.7–5.3), sabinene (4.3–2.7)	[215]
	Croatia	ap	HD	$\beta$ -caryophyllene (52.0), germacrene D (8.7), limonene (5.9), $\beta$ -thujone (5.7), $\alpha$ -humulene (4.6), ( <i>Z</i> )- $\beta$ -farnesene (4.3), <i>trans</i> - $\alpha$ -bergamotene (4.1)	[165]
	Algeria, Birsa	ap	HS	$\alpha$ -guaiane (11.3), $\beta$ -caryophyllene (9.5), $\gamma$ -elemene (9.2), $\beta$ -farnesene (7.6), farnesol (6.1), 6-methyl-5-hepten-2-one (4.4), <i>allo</i> -aromadendrene (4.3), $\delta$ -guaiane (4.2), geranyl acetone (3.6), $\alpha$ -gurjunene (3.4)	[216]
	Algeria, El Mamounia	ap	HD	limonene (29.9–26.4), spathulenol (17.2–13.3), 1-adamantanemethylamine (9.8–0), camphor (8.2–0), pinocarvone (7.8–5.6), <i>trans</i> -cadinol (5.4–3.7), pinene oxide (4.8–0), $\alpha$ -terpineol (4.6–0), $\beta$ -myrcene (4.0–0), $\alpha$ -phellandrene (3.4–0)	[217]
	France, Montserrat	lv	DCM	germacrene D (26.4), $\beta$ -pinene (19.3), myrcene (11.4), $\alpha$ -pinene (6.3), bicyclogermacrene (4.8), limonene (4.4), $\beta$ -selinene (3.9), <i>trans</i> - $\alpha$ -bergamotene (3.0), $\delta$ -cadinene (3.0)	[218]
	France, Rougon	fl	DCM	germacrene D (34.4), $\beta$ -pinene (14.1), $\alpha$ -pinene (10.3), myrcene (7.2), bicyclogermacrene (5.8), $\beta$ -caryophyllene (5.4), $\alpha$ -humulene (4.7)	[218]
	France, Rougon	lv	DCM	germacrene D (31.9), $\beta$ -pinene (14.0), myrcene (9.0), $\alpha$ -pinene (8.9), $\beta$ -caryophyllene (7.4), $\beta$ -bourbonene (7.1), bicyclogermacrene (6.2), $\alpha$ -humulene (5.8)	[218]
	France, Lure Mt.	fl	DCM	germacrene D (21.4), $\alpha$ -pinene (14.8), $\beta$ -pinene (12.2), myrcene (9.9), $\beta$ -caryophyllene (9.7), $\alpha$ -humulene (7.9), bicyclogermacrene (4.5)	[218]
	France, Lure Mt.	lv	DCM	germacrene D (18.1), $\beta$ -pinene (15.4), $\alpha$ -pinene (14.6), $\beta$ -caryophyllene (8.8), myrcene (8.6), $\alpha$ -humulene (5.6), $\delta$ -cadinene (4.7), sabinene (4.3), bicyclogermacrene (3.0)	[218]
	France, Rustrel	lv	DCM	germacrene D (35.0), $\alpha$ -pinene (20.0), $\beta$ -pinene (10.9), myrcene (9.6), $\delta$ -cadinene (4.0), bicyclogermacrene (3.7), $\beta$ -guajumene (3.1)	[218]
	France, Gras	fl	DCM	$\beta$ -pinene (22.7), $\beta$ -caryophyllene (14.7), $\alpha$ -pinene (14.3), germacrene D (12.7), sabinene (6.5), myrcene (6.2), $\alpha$ -humulene (4.8), limonene (3.0)	[218]

continued

► **Table 3** Continued

Taxa	Origin	Parts	Method	Main compounds	Ref.
	France, Gras	lv	DCM	sabinene (25.5), $\beta$ -pinene (17.9), $\beta$ -caryophyllene (16.7), $\alpha$ -pinene (11.5), germacrene D (11.1), myrcene (5.0), $\alpha$ -humulene (3.7), $\alpha$ -thujene (3.2)	[218]
	France, Notre Dame la Brune	fl	DCM	sabinene (21.8), $\beta$ -pinene (16.2), germacrene D (14.9), $\beta$ -caryophyllene (12.1), $\alpha$ -pinene (9.7), myrcene (6.4), bicyclogermacrene (4.4), limonene (3.9)	[218]
	France, Notre Dame la Brune	lv	DCM	sabinene (20.1), $\beta$ -pinene (14.9), germacrene D (12.1), $\beta$ -caryophyllene (12.7), $\alpha$ -pinene (9.1), thymol (7.9), myrcene (6.5), bicyclogermacrene (3.3), limonene (3.7)	[218]
	Greece, Mt. Hymettus	lv + fl	HD	$\tau$ -cadinol (9.3), $\beta$ -caryophyllene (7.7), caryophyllene oxide (5.9), $\alpha$ -cadinol (5.4), $\alpha$ -humulene (3.7), <i>trans</i> -verbenol (3.0), $\gamma$ -cadinene (3.0)	[219]
	Greece, Mt. Hymettus	lv + fl	Et <sub>2</sub> O/pent	$\tau$ -cadinol (10.8), caryophyllene oxide (9.0), $\alpha$ -cadinol (7.8), undecane (7.5), $\epsilon$ -cadinene (3.0), dodecane (3.0)	[219]
	Iran, Kashan	lv + fl	HD	$\beta$ -caryophyllene (18.0), germacrene D (13.2), spathulenol (10.4), $\beta$ -pinene (9.7), $\alpha$ -pinene (9.0), bicyclogermacrene (9.0), caryophyllene oxide (7.1), limonene (4.6), ( <i>Z</i> )- $\beta$ -farnesene (3.1)	[220]
	Iran, Kashan	lv + fl	CO <sub>2</sub>	germacrene D (23.6), $\beta$ -caryophyllene (16.5), bicyclogermacrene (11.9), $\alpha$ -pinene (9.8), $\beta$ -pinene (7.2), ( <i>Z</i> )- $\beta$ -farnesene (6.0), spathulenol (4.0), limonene (3.7)	[220]
	Iran, Khuzestan	ap	HD	$\gamma$ -muurolene (23.1), $\gamma$ -elemene (16.8), spathulenol (11.6), $\beta$ -caryophyllene (9.2), limonene (9.2), 3-carene/ $\alpha$ -pinene (8.0), $\beta$ -eudesmol (7.5), $\beta$ -pinene (5.8), germacrene B (3.4)	[221]
	Iran, Fars	ap	HD	limonene (37.7), 2,4-di- <i>tetr</i> -butylphenol (10.8), <i>p</i> -cymene (8.2), $\alpha$ -pinene (4.3), valerianol (3.9), $\beta$ -pinene (3.7), hedyacryol (3.6)	[222]
	Iran	ap		bicyclodec-1-ene (11.7), 1,3-cyclooctadiene (9.7), <i>iso</i> -aromadendrene epoxide (4.9), 2,3,3-trimethyl-3-cyclopentene acetaldehyde (3.2), bicyclohexene,4-methylene (3.0)	[223]
	Iran, Kermanshah	ap	HD	( <i>Z</i> )- $\alpha$ -caryophyllene (19.5), cedrol (14.5), germacrene D (7.5), $\alpha$ - <i>epi</i> -cadinol (5.3), $\alpha$ -pinene (4.6), salicylic acid butyl ester (4.4), ( <i>E</i> )- $\gamma$ -bisabolene (3.9), ( <i>E</i> )- $\beta$ -farnesene (3.7)	[224]
	Iran, Kermanshah	ap	SPME	( <i>Z</i> )- $\alpha$ -caryophyllene (18.9), cedrol (15.2), germacrene D (7.9), $\alpha$ - <i>epi</i> -cadinol (5.3), $\alpha$ -pinene (4.3), salicylic acid butyl ester (4.8), ( <i>E</i> )- $\gamma$ -bisabolene (4.0), ( <i>E</i> )- $\beta$ -farnesene (3.9), $\alpha$ -humulene (3.0)	[224]
	Iran, Behbahan	ap	HD	$\beta$ -bisabolol (23.0), 11-acetoxyeudesman-4 $\alpha$ -ol (16.0), $\beta$ -caryophyllene (11.1), $\alpha$ -bisabolol (5.6), $\alpha$ -bisaboloxide B (3.7), $\beta$ -pinene (3.3), dehydro-sesquiceneol (3.2), bicyclogermacrene (3.1)	[225]
	Iran, Haft Kel	ap	HD	$\beta$ -bisabolol (18.6), 11-acetoxyeudesman-4 $\alpha$ -ol (16.9), $\alpha$ -bisabolol (14.2), $\beta$ -caryophyllene (10.5), caryophyllene oxide (4.4), $\beta$ -pinene (3.6)	[225]
	Iran, Masjed-e-Solaiman	ap	HD	$\alpha$ -bisabolol (26.5), 11-acetoxyeudesman-4 $\alpha$ -ol (18.1), $\beta$ -caryophyllene (11.2), caryophyllene oxide (6.6), $\alpha$ -bisaboloxide B (4.8), $\beta$ -pinene (3.2), dehydro-sesquiceneol (3.2), limonene (3.1)	[225]
	Iran, Lali	ap	HD	11-acetoxyeudesman-4 $\alpha$ -ol (28.8), $\alpha$ -bisabolol (25.1), $\beta$ -caryophyllene (8.2), $\alpha$ -bisaboloxide B (5.0), caryophyllene oxide (4.5), dehydro-sesquiceneol (3.2)	[225]
	Iran, Kerman	ap	HD	spathulenol (15.1), $\beta$ -pinene (11.0), $\beta$ -myrcene (10.0), germacrene B (10.1), germacrene D (8.1), bicyclogermacrene (8.2), linalool (4.0)	[226-228]
	Iran, Tehran	ap	HD	$\beta$ -caryophyllene (29.0), farnesene (13.0), $\beta$ -pinene (11.0), germacrene D (6.5), $\alpha$ -pinene (5.5), limonene (4.2), $\beta$ -bisabolene (3.7)	[229]
	Iran	ap	HD	$\alpha$ -pinene (16.2), spathulenol (10.6), carvacrol (8.0), $\beta$ -pinene (7.1), <i>trans</i> -verbenol (6.3), caryophyllene oxide (5.7), $\beta$ -eudesmol (5.7), limonene (5.2), $\beta$ -caryophyllene (3.7), germacrene D (3.5)	[230]
					continued

► Table 3 Continued

Taxa	Origin	Parts	Method	Main compounds	Ref.
	Iran, Hormozgan	fr	HD	$\alpha$ -pinene (18.2), elemol (14.5), $\beta$ -pinene (10.1), cubenol (10.0), limonene (5.0), $\beta$ -caryophyllene (4.2), myrcene (3.4)	[231]
	Iran, Fars	ap	HD	11-acetoxyeudesman-4- $\alpha$ -ol (26.3), $\alpha$ -bisabolol (24.6), $\beta$ -caryophyllene (9.8), caryophyllene oxide (5.3), $\beta$ -pinene (4.2), dehydro-sesquicinelol (3.7)	[232]
	Iran, Rayen	ap	HD	1,2,3,6,7,7a-hexahydro-5H-inden 5-one (25.8), terpinyl acetate (19.6), 3-methyl-4-propyl-2,5-furandione (13.2), ( <i>E</i> )-1,3,5-undecatriene (9.0), $\beta$ -phellandrene (6.2), 4-nitrophenyl laurate (5.9), pulegone (4.3)	[233]
	Iran, Kerman	ap	HD	spathulenol (18.4), epizonaren (9.6), bicyclo heptenol (6.8), germacrene D (6.3), $\beta$ -caryophyllene (6.2), <i>p</i> -mentha-1,5-dien-8-ol (3.8), 7- <i>epi</i> - $\alpha$ -selinene (3.3)	[91]
	Iran, Kerman	ap	HD	$\alpha$ -pinene (11.2), <i>cis</i> -verbenol (6.2), $\alpha$ -terpineol (5.2), verbenol (4.3), (1 <i>S</i> )-verbenone (4.2), myrtenol (3.2)	[234]
	Iran, Ilam,	st	HD	$\alpha$ -muurolol (25.0), $\alpha$ -cadinol (15.7), $\beta$ -caryophyllene (10.9), caryophyllene oxide (6.5), elemol (5.5), hexadecanoic acid (5.2), $\gamma$ -cadinene (3.8)	[235]
	Iran, Ilam,	lv	HD	$\alpha$ -muurolol (20.0), $\beta$ -caryophyllene (10.1), $\alpha$ -cadinol (8.1), ( <i>Z</i> )-nerolidol (7.1), $\beta$ -pinene (6.6), $\gamma$ -cadinene (4.6), caryophyllene oxide (3.8), elemol (3.2), limonene (3.1), $\alpha$ -humulene (3.1), $\delta$ -cadinene (3.0)	[235]
	Iran, Ilam,	rt	HD	$\alpha$ -muurolol (19.5), $\alpha$ -cadinol (13.0), $\beta$ -caryophyllene (10.6), hexadecanoic acid (16.4), eicosane (4.9), ( <i>E</i> )-9-octadecanoic acid (4.2), elemol (3.5), caryophyllene oxide (3.2)	[235]
	Iran, Ardebil	ap	HD	lycopersene (26.0), dodecane (14.8), 1,5-dimethyl-decahydronaphthalene (9.3), tridecane (7.4), undecane (7.2), decane (3.8), heptadecane (3.4)	[236]
	Iran, Kerman	lv	HD	$\alpha$ -pinene (12.5), linalool (10.6), caryophyllene oxide (9.7), $\beta$ -pinene (7.1), $\beta$ -caryophyllene (7.0), bornyl acetate (5.3), $\alpha$ -camphene (5.7), camphor (5.2), carvacrol (5.2), germacrene D (5.0), $\gamma$ -cadinene (3.7), 1,8-cineole (3.6), 3-octanol (3.3), 1-octen-3-ol (3.0)	[237]
	Iran, Fars	ap	HD	$\alpha$ -pinene (30.8), $\beta$ -pinene (12.0), myrcene (8.9), limonene (7.9), $\beta$ -caryophyllene (5.6), germacrene D (6.9), bicyclogermacrene (4.5), valerianol (3.4), 7- <i>epi</i> - $\alpha$ -eudesmol (3.2)	[238]
	Iran, Fars	ap	HS	$\alpha$ -pinene (38.8), $\beta$ -pinene (15.5), myrcene (21.0), limonene (13.1), <i>trans</i> - $\beta$ -ocimene (3.4)	[238]
	Iran, Fars	ap	HD	$\alpha$ -pinene (25.8%), myrcene (12.5), germacrene-D (11.8), $\beta$ -pinene (11.8), limonene (8.5), bicyclogermacrene (7.2), spathulenol (4.6)	[239]
	Iran, Mashhad	ap	HD	( <i>E</i> )-piperitenone oxide (21.7), $\alpha$ -pinene (11.3), carvone (11.3), spathulenol (6.2), $\beta$ -pinene (5.8), limonene (5.0), myrcene (4.3), $\beta$ -eudesmol (4.3), caryophyllene oxide (3.4)	[240]
	Jordan, Al-Salt	ap	HD	8-cedren-13-ol (24.8), $\beta$ -caryophyllene (8.7), germacrene D (6.8), sabinene (5.2), $\alpha$ -humulene (4.3), <i>allo</i> -aromadendrene (4.5), $\delta$ -cadinene (3.5)	[241]
	Jordan, Tiail	ap	Hex	bisoflex DNP (36.5), diethylphthalate (24.1), hexanedioic acid (10.3), nonacosane (5.6), <i>n</i> -hexatriocontane (3.6), cyclohexane (3.3), isooctane (3.2), spathulenol (3.0)	[242]
	Jordan, Bathayeh	ap	Hex	<i>n</i> -hexatriocontane (19.1), hexanedioic acid (12.3), nonacosane (10.7), diethylphthalate (7.3), bisoflex 91 (6.8), spathulenol (6.0), germacrene D (4.1), pentadecane (3.3), caryophyllene oxide (3.2)	[242]
	Jordan, Jdaideh	ap	Hex	phenol-2-methoxy-3-(2propenyl) (13.6–12.0), bisoflex DNP (12.8–6.4), hexanedioic acid (9.7–0), phthalic acid dinonyl ester (9.3–0), <i>n</i> -hexatriocontane (9.0–7.7), 2-hexanal (8.4–6.6), thyme-camphor (8.4–4.7), bisoflex 91 (7.7–6.4), heptane 3,4,5-trimethyl (4.8–0), pentadecane (4.6–2.6), 2-methylpent-2-en-4-one (4.2–1.9), carvacrol (3.5–2.8), 3,8-dimethylundecane (3.4–3.1), 6,6-dimethyl-5,6-dihydropyran (3.4–2.9), $\alpha$ -bisabolol (3.1–3.0)	[242]

continued

▶ **Table 3** Continued

Taxa	Origin	Parts	Method	Main compounds	Ref.
	Jordan, Gawa'a	ap	Hex	spathulenol (21.9), isooctane (19.2), pentane 2,2,4-trimethyl (8.5), $\alpha$ -bisaboloxide (5.5), 2-hexanal (4.9), heptane (4.4), $\delta$ -cadinene (3.6), nonacosane (3.3), phthalic acid dinonylester (3.2)	[242]
	Jordan, Ain Janna	fl	HD	gaulyl acetate (9.5), $\alpha$ -cadinol (9.4), $\tau$ -cadinol (9.2), guaial (8.7), spathulenol (8.6), elemol (8.2), camphene (6.4), endobornyl acetate (5.9), $\alpha$ -terpineol (5.1), terpineol (5.0), verbenol (4.7), linalool (4.2)	[243]
	Montenegro	ap	HD	carvacrol (67.8), sabinen (10.7), $\alpha$ -pinene (3.6)	[244]
	Morocco, Midelt	ap	HD	3-carene (16.5), $\gamma$ -muurolene (14.0), $\alpha$ -pinene (9.9), caryophyllene (7.5), $\alpha$ -phellandrene (6.9), muurolol (6.5), $\alpha$ -gurjunene (6.5), $\alpha$ -himachalene (5.6), $\tau$ -cadinol (5.1), germacrene D-4-ol (3.9), <i>allo</i> -aromadendrene (3.2)	[245]
	Oman	ap	SFME	ledeneoxide (II) (20.5), linalyl acetate (11.2), $\beta$ -eudesmol (11.6), $\alpha$ - <i>trans</i> -bergamatenone (6.8)	[246]
	Russia, Orgievsky	ap	HD	<i>trans</i> -cadin-1,4-diene (13.3), <i>trans</i> - $\beta$ -farnesene (8.2), $\tau$ -cadinol (6.6), $\gamma$ -chymachalene (6.6), germacrene D (6.2), $\beta$ -curcumene (6.0), <i>cis</i> - $\beta$ -farnesene (6.0), (1E,4Z)-germacrene B (5.1), cadalene (3.7), $\gamma$ -elemene (3.6)	[247]
	Saudi Arabia, Sudair	ap	HD	cedrol > guaial > $\delta$ -cadinene > limonene > cedrenol > $\gamma$ -cadinene > linalool > $\alpha$ -phellandrene > terpinen-4-ol, > $\beta$ -pinene*	[248]
	Saudi Arabia, Gabal Al-aquiq	ap	HD	(E)-3-carene-2-ol (12.1), $\delta$ -cadinene (8.4), spathulenol (7.0), $\tau$ -muurolene (5.9), terpinen-4-ol (5.8), (E)-pinocarveol (5.4), $\beta$ -linalool (5.3), <i>p</i> -cymen-3-ol (4.3), $\tau$ -gurjunene (3.5), verbenone (3.0)	[249]
	Saudi Arabia, Tabuk	ap	HD	caryophyllene oxide (17.8), farnesol (14.3), spathulenol (11.9), $\alpha$ -curcumene (7.2), ledene oxide (7.1), caryophyllene (5.2)	[250]
	Saudi Arabia, North	ap	HD	$\gamma$ -muurolene (8.7), $\alpha$ -cadinol (5.9), $\delta$ -cadinene (5.1), $\beta$ -pinene (4.6), $\beta$ -gurjurenene (4.43), $\alpha$ -limonene (4.3), $\alpha$ -pinene (3.8), $\alpha$ -thujene (3.7), spathulenol (3.4)	[251]
	Saudi Arabia, Riyadh	ap	HD	$\alpha$ -cadinol (49.5), $\delta$ -cadinene (10.2), limonene (3.6)	[252]
	Serbia, Nis	ap	HD	germacrene D (31.0), bicyclogermacrene (6.7), spathulenol (5.0), oct-1-en-3-ol (4.3), $\gamma$ -cadinene (4.3)	[208]
	Serbia-Mont, Cijevna	ap	HD	$\beta$ -pinene (19.8), germacrene D (11.9), $\alpha$ -pinene (6.4), limonene (4.5), <i>trans</i> - $\alpha$ -bergamotene (3.0)	[169]
	Syria, Aleppo	ap	HD	$\alpha$ -pinene (27.5), $\beta$ -pinene (12.4), myrtenal (8.5), terpinol (8.5), $\alpha$ -humulene (3.6)	[253]
	Tunisia	ap	Hex	myrcene (15.5), germacrene D (9.0), $\alpha$ -pinene (6.6), $\beta$ -pinene (5.8), $\alpha$ -cadinol (5.1), $\beta$ -caryophyllene (4.0)	[254]
	Tunisia, South West	ap	HD	$\alpha$ -pinene (17.0), $\beta$ -pinene (12.7), limonene (6.6), $\beta$ -myrcene (6.1), germacrene D (5.9)	[255]
	Tunisia, North	ap	HD	carvacrol (56.1), $\beta$ -caryophyllene (7.7), $\alpha$ -pinene (5.0)	[256]
	Turkey, Gaziantep	ap	HD	$\beta$ -pinene (18.0), $\beta$ -caryophyllene (17.8), $\alpha$ -pinene (12.0), caryophyllene oxide (10.0), myrcene (6.8), germacrene D (5.3), limonene (3.5), spathulenol (3.3)	[257]
	Turkey, Ardahan	ap	HD	(Z)- $\beta$ -farnesene (15.5), $\beta$ -phellandrene (10.8), $\alpha$ -farnesene (10.7), germacrene D (9.7), $\beta$ -gurjunene (7.5), ledene (6.3), limonene (5.9)	[258]
	Turkey, Elazığ	ap	HD	$\beta$ -pinene (10.2), germacrene D (17.8), $\alpha$ -pinene (8.9), $\beta$ -caryophyllene (8.2), myrcene (6.2), bicyclogermacrene (5.5), limonene (4.1)	[259]
<i>T. polium</i> ssp. <i>album</i>	Egypt, Sinai	ap	HD	patchouly alcohol (33.3), 10-cadinol (9.0), $\alpha$ -cadinol (5.9), $\delta$ -cadinene (4.0), $\beta$ -eudesmol (3.3)	[260]
<i>T. polium</i> ssp. <i>aurasiacum</i>	Algeria, Aures	ap	HD	$\alpha$ -cadinol (46.8), 3- $\beta$ -hydroxy- $\alpha$ -muurolene (22.5), $\alpha$ -pinene (9.5), $\beta$ -pinene (8.3)	[261, 262]
	Algeria, Aures	ap	HD	limonene (34.7), $\alpha$ -pinene (25.4), $\beta$ -pinene (8.6), $\beta$ -myrcene (5.2), $\alpha$ -elemol (4.2)	[263]
<i>T. polium</i> ssp. <i>aureum</i>	Morocco, Midelt	ap	HD	caryophyllene (19.1), $\gamma$ -muurolene (13.0), $\tau$ -cadinol (11.0), $\alpha$ -gurjunene (9.2), rosifolol (8.8), 3-carene (7.0), <i>allo</i> -aromadendrene (5.1), $\alpha$ -pinene (3.5), myrtenol (3.0)	[245]
					continued



► Table 3 Continued

Taxa	Origin	Parts	Method	Main compounds	Ref.
<i>T. polium</i> ssp. <i>capitatum</i>	Algeria, Boussaada	ap	HD	$\gamma$ -cadinol (18.3), germacrene D (15.3), $\beta$ -pinene (10.5), carvacrol (5.5), bicyclogermacrene (5.5), $\alpha$ -pinene (4.1), limonene (3.1)	[264]
	Bulgaria	ap	HD	$\beta$ -pinene (26.8), germacrene D (17.7), $\alpha$ -pinene (9.3), limonene (6.4), <i>trans</i> -nerolidol (4.6), bicyclogermacrene (4.0), myrtenal (3.3), spathulenol (3.2)	[265]
	Corsica	ap	HD	$\alpha$ -pinene (24.1), $\beta$ -pinene (9.2), $\alpha$ -thujene (8.1), terpinen-4-ol (6.2), limonene (5.2), sabinene (4.1), <i>p</i> -cymene (4.0)	[212]
	Corsica, Corti	ap	HD	$\alpha$ -pinene (28.8), $\beta$ -pinene (7.2), <i>p</i> -cymene (7.0), $\alpha$ -thujene (5.0), terpinen-4-ol (4.6), <i>p</i> -cymene-4-ol (3.0), limonene (3.0)	[266]
	Corsica	ap	HD	$\alpha$ -pinene (24.1), $\beta$ -pinene (9.2), $\alpha$ -thujene (8.1), terpinen-4-ol (6.6), limonene (5.2), sabinene (4.1), <i>p</i> -cymene (4.0)	[164]
	Crete, Greece	ap	HD	caryophyllene (9.8), carvacrol (10.1), torreyol (7.6), $\alpha$ -cadinol (4.5), <i>cis</i> -verbenone (3.7) germacrene D (3.1), $\alpha$ -humulene (3.8), $\delta$ -cadinene (3.1), $\alpha$ -amorphene (3.0)	[177]
	Greece	ap	HD	$\alpha$ -pinene (14.8), $\beta$ -pinene (12.8), $\beta$ -caryophyllene (11.3), <i>epi</i> - $\alpha$ -cadinol (7.7), myrcene (5.5), germacrene D (4.8), sabinene (4.7), $\alpha$ -humulene (3.3), $\alpha$ -cadinol (3.2), limonene (3.1)	[267]
	Kos, Greece	lv+fl	HD	germacrene D (53.7), ( <i>E</i> )- $\beta$ -farnesene (10.0), bicyclogermacrene (9.1), spathulenol (3.2), limonene (3.1)	[268]
	Crete, Greece	ap	HD	caryophyllene (10.1), carvacrol (9.6), torreyol (6.5), caryophyllene oxide (5.0), $\alpha$ -cadinol (4.0), <i>cis</i> -verbenone (4.0) germacrene D (3.9), $\alpha$ -humulene (3.4), $\delta$ -cadinene (3.1), germacrene D 4-ol (3.0)	[190]
	Iran	ap	HD	$\alpha$ -cadinol (46.2), caryophyllene oxide (25.9), <i>epi</i> - $\alpha$ -muurolol (8.1), cadalene (3.7)	[269]
	Morocco	ap	HD	<i>endo</i> -borneol (33.0), naphthalene, 1,2,3,5,6,8a-hexahydro-4,7-dimethyl-1-(1-methyl ethyl)-, (1 <i>s</i> - <i>cis</i> )- (19.6), bronyle acetate (15.6), $\alpha$ -terpineol (12.0), bicyclo[3.1.0]hexan-3-ol, 4-methyl-1-(1-methylethyl)- (10.9)	[270]
	Portugal	ap	HD	$\gamma$ -cadinol (24.1–1.6), sabinene (11.2–1.1), $\beta$ -pinene (10.3–1.3), $\delta$ -cadinene (9.8–3.0), $\alpha$ -cadinol (9.8–1.6), $\alpha$ -pinene (7.7–0.6), $\gamma$ -cadinene (5.5–0), $\beta$ -caryophyllene (5.4–3.3), germacrene D (3.6–0), myrcene (3.5–0.8), ( <i>Z</i> )-verbenol (3.5–0), terpine-4-ol (3.5–1.4), limonene (3.1–0.6), carvacrol (3.0–0), $\beta$ -cubebene (3.0–1.1)	[271]
	Serbia	ap	HD	germacrene D (31.8), linalool (14.0), $\beta$ -pinene (10.7), $\beta$ -caryophyllene (8.8), bicyclogermacrene (6.2), $\alpha$ -pinene (3.5)	[265]
<i>T. polium</i> ssp. <i>gabestanum</i>	Tunisia	ap	HD	$\beta$ -pinene (36.0), $\alpha$ -pinene (13.3), $\alpha$ -thujene (8.5), <i>p</i> -cymene (5.2), verbenone (5.0), myrcene (4.7)	[272]
<i>T. polium</i> ssp. <i>geyrii</i>	Algeria	ap	HD	limonene (11.2), $\delta$ -cadinene (10.0), $\beta$ -caryophyllene (9.1), caryophyllene oxide (4.7), $\gamma$ -cadinol (4.3), <i>cis</i> - $\alpha$ -bisabolene (3.4), $\alpha$ -humulene (3.2), germacrene B (3.1)	[273]
<i>T. polium</i> ssp. <i>pilosum</i>	Qatar	ap	HD	$\beta$ -eudesmol (19.1), $\gamma$ -cadinene (18.4), spathulenol (11.6), $\delta$ -cadinene (8.3), $\alpha$ -cadinol (5.1), germacrene D (4.4)	[260]
<i>T. polium</i> ssp. <i>valentinum</i>	Spain	ap	HD	$\alpha$ -pinene (15.8), $\beta$ -pinene (11.7), sabinene (7.2), <i>trans</i> -pinocarveol (4.3), terpinen-4-ol (4.5), <i>p</i> -cymene (3.8), limonene (3.2)	[199]
<i>T. puechiae</i>	France	ap	HD	$\beta$ -caryophyllene (16.7–16.0), germacrene-D (11.8–11.2), $\alpha$ -pinene (8.7–8.5), $\gamma$ -elemene (6.0–5.5), $\beta$ -pinene (5.0–4.9), $\alpha$ -humulene (4.6–4.0), $\beta$ -myrcene (3.2–3.1), sabinene (3.2–3.1)	[274]
					continued

► **Table 3** Continued

Taxa	Origin	Parts	Method	Main compounds	Ref.
<i>T. ramosissimum</i>	Tunisia, Gafsa	ap	HD	$\beta$ -eudesmol (44.5), caryophyllene oxide (9.3), $\alpha$ -thujene (5.5), sabinene (4.7), $\tau$ -cadinol (3.9)	[131]
	Tunisia, Gafsa	ap	HD	$\beta$ -eudesmol (22.1), <i>p</i> -cymene (13.0), $\alpha$ -cadinol (10.7), 1,6-germacradien-5-ol (10.0), $\alpha$ -thujene (7.3), sabinene (7.3), <i>allo</i> -aromadendrene (4.8), $\gamma$ -cadinene (3.6), $\beta$ -caryophyllene (3.2)	[275]
	Tunisia, Gafsa	ap	HD	$\delta$ -cadinene (23.8–15.3), $\delta$ -cadinol (18.7–8.4), $\beta$ -eudesmol (17.5–7.8), $\alpha$ -thujene (6.3–0.7), tujol (5.7–0), $\gamma$ -gurjunene (4.9–2.8), cubenol (4.7–0.4), 8-cedrene (4.9–2.1), <i>cis</i> - $\alpha$ -santalol (4.5–1.1), <i>o</i> -cymene (4.5–0), $\alpha$ -pinene (3.7–0.3), sabinene (3.5–0.4)	[276]
<i>T. sauvegi</i>	Tunisia, Gafsa	ap	HD	$\delta$ -cadinol (18.7), $\delta$ -cadinene (18.6), $\beta$ -eudesmol (12.13), $\gamma$ -gurjunene (4.3), 8-cedrene (4.0)	[277]
	Tunisia, Gafsa	lv	HD	$\beta$ -eudesmol (22.1), <i>p</i> -cymene (13.0), $\alpha$ -cadinol (10.7), 1,6-germacradien-5-ol (10.0), $\alpha$ -thujene (7.3), sabinene (7.3), <i>allo</i> -aromadendrene (4.8), $\gamma$ -cadinene (3.6), $\beta$ -caryophyllene (3.2)	[278]
<i>T. stocksianum</i>	Tunisia	lv	HD	$\beta$ -eudesmol (28.8), $\tau$ -cadinol (17.5), $\alpha$ -thujene (8.7), $\gamma$ -cadinene (5.6), sabinene (4.8), $\beta$ -selinene (4.2)	[279]
	UEA	ap	HD	$\alpha$ -cadinol (14.6), $\delta$ -cadinene (13.8), $\tau$ -cadinol (8.1), seychellene (6.4), $\beta$ -caryophyllene (6.1), germacrene D-4-ol (3.0)	[280]
	South Iran	fr	HD	$\alpha$ -cadinol (37.6), $\alpha$ -pinene (9.7), caryophyllene oxide (4.9), $\beta$ -selinene (3.9), $\delta$ -cadinene (3.8), $\beta$ -pinene (3.5)	[281]
	Iran, Swat	ap BB	HD	caryophyllene oxide (37.1), <i>o</i> -cymene (18.6), germacrene B (5.6), caryophyllene (4.2), $\alpha$ -caryophyllene (3.2)	[282]
	Iran, Swat	ap FB	HD	<i>cis</i> - $\alpha$ -santalol (16.3), D-limonene (12.8), <i>o</i> -cymene (12.4), ( <i>Z</i> )- $\beta$ -farnesene (8.5), $\alpha$ -phellandrene (7.3), bicyclo [3.1.0] hexane,4-methylene-1-(1-methyl) (5.3), caryophyllene (3.5), <i>p</i> -cymen-8-ol (3.1), $\alpha$ -caryophyllene (3.1)	[282]
<i>T. turredanum</i>	Iran, Swat	ap AFB	HD	1H-cycloprop[ <i>e</i> ]azulen-7-ol,decahydro-1,1,7-trimethyl-4-methylene (38.2), <i>cis</i> - $\alpha$ -santalol (26.4), <i>o</i> -cymene (11.0), germacrene B (4.5)	[282]
	Pakistan, Swat	ap	HD	$\alpha$ -cadinene (12.9), $\alpha$ -pinene (10.3), myrcene (8.6), $\beta$ -caryophyllene (8.2), seychellene (6.7), germacrene D (6.2)	[283, 284]
	South Iran	ap	HD	$\alpha$ -pinene (23.0), $\beta$ -pinene (13.0), <i>epi</i> - $\alpha$ -cadinol (9.1), sabinene (6.6), myrcene (6.3), $\alpha$ -cadinol (3.3), limonene (3.2)	[144]
	South Iran	fl	HD	camphene (20.6), $\alpha$ -cadinol (19.7), myrcene (10.2), carvacrol (9.9), ( <i>Z</i> )- $\gamma$ -bisabolene (5.0), linalool (3.3), camphor (3.0)	[285]
<i>T. yemenense</i>	South Iran	ap	HD	$\alpha$ -pinene (22.0), <i>cis</i> -sesquisabinene hydrate (12.0%), <i>epi</i> - $\beta$ -bisabolol (6.6%), $\beta$ -pinene (6.5), guaioi (5.4%), $\delta$ -cadinene (4.9), $\beta$ -eudesmol (4.4%), $\alpha$ -copaene (3.3)	[144]
	South Iran	ap	HD	$\alpha$ -pinene (36.6), $\beta$ -pinene, (14.1), $\beta$ -cubebene (5.0)	[286]
	Oman	lv	HD	$\alpha$ -cadinol (7.6), $\beta$ -selinene (6.4), <i>trans</i> -verbenol (5.9), caryophyllene oxide (5.7%), $\delta$ -cadinene (5.1%), $\alpha$ -phellandren-8-ol (5.0), verbenone (5.0), $\tau$ -murolol (3.4), $\beta$ -caryophyllene (3.3)	[142]
<i>T. zanonii</i>	Spain	ap	HD	$\beta$ -caryophyllene (32.6–15–6), $\alpha$ -humulene (10.1–4.7), $\beta$ -bisabolol (8.3–6.4), <i>cis</i> - $\gamma$ -bisabolene (6.9–4.6), caryophyllene oxide (4.5–3.1), $\beta$ -bisabolene (3.3–2.0)	[202]
	Yemen, Dhamar	lv	HD	7- <i>epi</i> - $\alpha$ -selinene (20.1), caryophyllene oxide (20.1), $\beta$ -caryophyllene (11.2), $\gamma$ -selinene (5.5), $\alpha$ -humulene (4.0), valencene (3.7), ledol (3.6), <i>cis</i> -sesquisabinene hydrate (3.4)	[287]
<i>T. zanonii</i>	Yemen, Taiz	lv	HD	$\beta$ -caryophyllene (19.1), $\alpha$ -cadinol (9.5), $\delta$ -cadinene (6.5), $\alpha$ -humulene (6.4), $\tau$ -cadinol (5.7), $\tau$ -murolol (4.9), shyobunol (4.6), caryophyllene oxide (4.3), germacrene D-4-ol (3.1)	[287]
	Yemen, Taiz	lv	HD	$\delta$ -cadinene (34.9), $\beta$ -caryophyllene (22.7), $\alpha$ -humulene (6.1), $\alpha$ -selinene (5.4)	[156]
	Libya	fl	HD	$\beta$ -pinene (14.1), linalool (11.0), linalyl acetate (11.1), germacrene D (8.8), $\gamma$ -elemene (7.8), $\alpha$ -terpinol (5.6), D-limonene (3.5)	[288]

continued

► Table 3 Continued

Taxa	Origin	Parts	Method	Main compounds	Ref.
<b>Section <i>Pycnobotrys</i></b>					
<i>T. quadrifarium</i>	India, Garampani	ap	HD	$\beta$ -caryophyllene (38.3), germacrene D (9.4), $\alpha$ -humulene (5.9), $\alpha$ -pinene (5.7), $\alpha$ -salinene (5.4), sesquisabinene (4.8)	[289]
	India, Kumaun	ap	HD	$\beta$ -caryophyllene (25.0), $\alpha$ -cubebene (20.1), copane-4- $\alpha$ -ol (10.0), aromadendrane (6.3), pinocamphe (3.3), $\alpha$ -pinene (2.3), <i>trans</i> -bergamotene (2.3), $\alpha$ -humulene (4.2), germacrene-D (3.7)	[290]
	China	ap	HD	germacrene D (8.8), linalool (8.2), camphene (7.8), $\beta$ -caryophyllene (7.3), $\beta$ -cadinene (6.8), 1,8-cineole (6.5), 4-terpineol (5.8), $\alpha$ -terpineol (5.1), <i>trans</i> -geraniol (3.2)	[130]
<b>Section <i>Scordium</i></b>					
<i>T. melissoides</i>	Iran	ap	HD	$\alpha$ -pinene (27.7), $\beta$ -pinene (16.4), limonene (12.4), germacrene D (10.2), $\beta$ -caryophyllene (8.9), ( <i>Z</i> )- $\gamma$ -bisabolene (7.5), $\alpha$ -humulene (4.5)	[291]
	Serbia-Monten	ap	HD	$\alpha$ -pinene (17.7), $\beta$ -pinene (10.0), cadinol (6.7), $\delta$ -cadinene (6.3), $\beta$ -caryophyllene (5.5), $\alpha$ -copaene (5.2), $\alpha$ -cadinol (4.3), $\gamma$ -cadinene (3.7)	[169]
<i>T. scordium</i>	Iran, Mazandaran	ap	HD	$\beta$ -caryophyllene (22.8), ( <i>E</i> )- $\beta$ -farnesene (10.4), caryophyllene oxide (8.6), 1,8-cineole (6.1), $\beta$ -eudesmol (5.1), $\alpha$ -pinene (3.3), $\beta$ -pinene (3.2)	[292]
	Iran, Kerman	ap	HD	pulegone (39.1), $\beta$ -caryophyllene (20.1), $\beta$ -farnesene (5.7), menthofuran (4.2), 1,8-cineole (4.1), $\alpha$ -humulene (3.1)	[293]
<i>T. scordium</i> ssp. <i>scordiododes</i>	Serbia	ap	HD	menthofuran (11.9), ( <i>Z</i> )-octadec-9-enoic acid (11.5), ( <i>Z,Z</i> )-octadeca-9,12-dienoic acid (7.9), hexadecanoic acid (6.3), $\beta$ -caryophyllene (3.5), ( <i>E</i> )-phytol (3.5)	[208]
	Italy, Sicily	ap	HD	caryophyllene oxide (25.8), $\alpha$ -pinene (19.4), $\beta$ -pinene (8.5), 4-(1,5-dimethylhex-4-enyl)cyclohex-2-enone (6.4), $\beta$ -sesquiphellandrene (5.9), ( <i>E</i> )- $\beta$ -caryophyllene (4.4), $\beta$ -bisabolene (3.8), sesquisabinene (3.4)	[294]
<b>Section <i>Scorodonia</i></b>					
<i>T. asiaticum</i>	Balearic Is.	ap	HD	calamene (23.1), linalool (15.4), $\alpha$ -murolene (9.9), $\alpha$ -calocorene (8.6), linalyl acetate (6.2), germacrene D (5.2), $\alpha$ -humulene + <i>allo</i> -aromadendrene (3.8), $\alpha$ -terpineol (3.2)	[295]
	Canada	lv	HD	germacrene D (32.7), caryophyllene (13.6), $\delta$ -cadinene (13.0), $\alpha$ -humulene (10.2), linalool (6.0)	[296]
<i>T. canadensis</i>	Cyprus, Spilia	lv	HD	$\beta$ -cubebene (26.8), $\beta$ -burbonene (23.0), $\beta$ -caryophyllene (22.4), $\alpha$ -humulene (7.6), caryophyllene oxide (4.5), $\gamma$ -terpinene (3.1)	[58]
	Cyprus, Spilia	fl	HD	$\beta$ -caryophyllene (35.1), $\beta$ -cubebene (25.1), $\alpha$ -humulene (12.2)	[58]
<i>T. kotschyannum</i>	Cyprus, Spilia	st	HD	$\beta$ -burbonene (20.9), $\beta$ -caryophyllene (20.6), $\beta$ -cubebene (10.6), $\alpha$ -humulene (6.7), <i>allo</i> -aromadendrene (5.8), caryophyllene oxide (4.7), anethole (3.7), $\alpha$ -caryophyllene (3.2)	[58]
	Cyprus, Stavros	lv	HD	$\beta$ -caryophyllene (19.3–18.9), $\beta$ -cubebene (11.8–11.4), $\beta$ -burbonene (11.4–7.1), caryophyllene oxide (7.7–0.3), $\alpha$ -humulene (7.2–6.1), <i>trans</i> -pinocarveol (3.9–2.7), $\delta$ -cadinene (3.4–3.2)	[58]
<i>T. kotschyannum</i>	Cyprus, Stavros	st	HD	$\beta$ -caryophyllene (18.8–13.6), caryophyllene oxide (11.7–7.9), $\beta$ -cubebene (10.2–4.2), $\beta$ -burbonene (9.4–5.8), $\alpha$ -humulene (7.3–4.4), <i>trans</i> -pinocarveol (3.8–2.6), $\delta$ -cadinene (3.1–1.2)	[58]
	Cyprus, Cedar Valley	fr	HD	$\beta$ -caryophyllene (31.6), $\beta$ -cubebene (15.1), $\alpha$ -humulene (11.0), $\beta$ -burbonene (4.5), caryophyllene oxide (4.2), $\delta$ -cadinene (3.4)	[58]
<i>T. kotschyannum</i>	Cyprus, Cedar Valley	st	HD	$\beta$ -caryophyllene (22.8), $\beta$ -cubebene (12.7), $\alpha$ -humulene (8.5), $\beta$ -burbonene (6.7), caryophyllene oxide (5.9), $\delta$ -cadinene (3.3), <i>trans</i> -pinocarveol (3.1)	[58]

continued

► Table 3 Continued

Taxa	Origin	Parts	Method	Main compounds	Ref.
<i>T. massiliense</i>	Corsica	ap	HD	6-methyl-3-heptyl acetate (20.3), germacrene D (7.6), 3-octanyl-acetate (7.1), pulegone (6.7), isobutyl isovalerate (5.9), linalool (4.8), citronello (3.6), 3-methyl butyl isovalerate (3.3), (Z)- $\beta$ -ocimene (3.1)	[297]
	Corsica	ap	HD	6-methyl-3-heptyl acetate (19.1), 3-octanyl-acetate (7.0), pulegone (6.9), germacrene D (6.1), isobutyl isovalerate (5.8), linalool (5.2), citronello (4.1), 3-methyl butyl isovalerate (3.4)	[164]
	Sardinia, Mt. Albo	ap	HD	3,7-dimethyloctan-2-one (15.2), butyl 2-methylbutyrate (12.1), linalool (10.6), linalyl acetate (7.1), zingiberene (4.7), <i>v</i> -cadinene (4.1), ( <i>E</i> )- $\alpha$ -farnesene (3.8), $\delta$ -3-carene (3.3), $\beta$ -bisabolene (3.1)	[298]
	Sardinia, Cagliari	ap	HD	6-methyl-3-heptyl acetate (19.5), 3-octanyl-acetate (7.1), linalool (5.8), $\beta$ -bisabolene (5.4), isobutyl isovalerate (3.0)	[297]
<i>T. pseudoscorodonia</i> ssp. <i>baeticum</i>	Morocco	lv	HD	<i>N</i> -formylmorpholine (25.1), 4-acetyl-morpholine, (17.6), 2-oxabicyclo[2.2.2]octan-6-one, 1,3,3-trimethyl-(6.5), heptylcyclohexane (6.0), 3-methyl-2-butenic acid, 2-ethylcyclohexyl ester (3.7)	[299]
<i>T. royleanum</i>	Pakistan	ap	HD	$\beta$ -santalene (20.7), <i>cis</i> - $\alpha$ -bisabolene (11.8), <i>o</i> -cymene (8.7), $\alpha$ -bisabolol (6.0), terpineol-4 (3.9), germacrene D (4.3), $\beta$ -caryophyllene (3.2), $\beta$ -eudesmol (3.0)	[300]
	India	ap	HD	$\beta$ -caryophyllene (23.6), germacrene D (28.9), $\alpha$ -humulene (5.7), 9- <i>epi</i> - $\beta$ -caryophyllene (5.6), 1-octen-3-ol (8.5), linalool (4.8)	[289]
<i>T. salviastrum</i>	Portugal	ap	HP	aristolene + $\beta$ -caryophyllene (21.6), $\alpha$ -humulene + <i>allo</i> -aromadendrene (19.0), germacrene D (7.7), caryophyllene oxide + spathulenol (18.6), humulene epoxide (3.0)	[295]
	Portugal	ap, lv, fl	HD	( <i>E</i> )- $\beta$ -farnesene (29.3–26.1), $\beta$ -caryophyllene (26.6–19.1), germacrene D (21.6–13.7), (Z)- $\beta$ -ocimene (4.6–2.1), $\alpha$ -humulene (4.1–3.1), caryophyllene oxide (3.6–1.4)	[301]
<i>T. scorodonia</i>	Italy, Elba	lv	HD	$\alpha$ -cubebene (18.3), $\beta$ -elemene (10.7), <i>cis</i> -caryophyllene (10.6), $\alpha$ -bergamotene (6.8), $\beta$ -selinene (6.7), $\beta$ -cubebene (5.2), eremophilene (3.2)	[302]
	Italy, Elba	br, ca, co	HD	$\beta$ -elemene (21.4–0), sabinene (18.1–6.1), $\alpha$ -terpinolene (17.9–0), hex-3-enyl acetate (14.4–0), (Z)-hex-3-en-1-ol (14.1–0), oct-1-en-3-ol (12.9–0), $\alpha$ -cubebene (12.4–0), hexenal (10.7–4.8), <i>cis</i> -caryophyllene (10.5–0.9), $\alpha$ -pinene (10.1–0), oct-7-en-1-ol (8.9–0), $\alpha$ -copaene (6.8–0), eremophilene (6.5–0), limonene (6.4–0), $\alpha$ -bergamotene (5.5–0), $\beta$ -selinene (3.9–0), $\beta$ -cubebene (3.5–0)	[302]
	Italy, Prealps	lv	HD	$\beta$ -cubebene (7.8), $\alpha$ -terpinolene (7.7), <i>v</i> -elemene (6.8), <i>cis</i> -caryophyllene (5.2), phenylacetaldehyde (4.9), $\alpha$ -bergamotene (4.8), $\alpha$ -cubebene (4.6), $\beta$ -selinene (4.1), $\beta$ -pinene (4.1), $\alpha$ -humulene (3.9), eremophilene (3.2)	[302]
	Italy, Prealps	br, ca, co	HD	phenylacetaldehyde (41.5–0), $\alpha$ -pinene (18.8–0), eremophilene (15.3–0), $\beta$ -cubebene (15.2–1.5), sabinene (11.8–0), <i>v</i> -elemene (10.4–0), $\alpha$ -bergamotene (10.0–0), $\beta$ -pinene (9.6–0), oct-1-en-3-ol (8.9–0), linalool (8.5–0), <i>cis</i> -caryophyllene (6.9–0), 3-methylenecycloheptene (4.5–0), $\beta$ -selinene (3.9–0), $\alpha$ -gurjunene (3.3–0)	[302]
<i>T. scorodonia</i> ssp. <i>baeticum</i>	Algeria	ap	HD	$\beta$ -caryophyllene (35.4), germacrene D (22.1), $\alpha$ -humulene (9.3), caryophyllene oxide (4.3), bicyclogermacrene (3.8), linalool (3.5), spathulenol (3.2)	[303]
	Spain	ap	HD	aristolene + $\beta$ -caryophyllene (39.7–35.1), aromadendrene (14.0–10.6), germacrene D (11.3–4.9), caryophyllene oxide + spathulenol (9.1–4.9), $\alpha$ -cubebene (6.0–4.5), humulene epoxide (3.9–2.2)	[295]

continued

► Table 3 Continued

Taxa	Origin	Parts	Method	Main compounds	Ref.	
<i>T. scorodonia</i> ssp. <i>scorodonia</i>	Corsica	ap	HD	( <i>E</i> )- $\alpha$ -caryophyllene (21.1), germacrene B (8.3), $\alpha$ -humulene (6.9), germacrene D (6.7), $\alpha$ -cubebene (6.2), $\delta$ -elemene (3.9), zingiberene (3.6), $\alpha$ -gurjunene (3.5), $\beta$ -bisabolene (3.3)	[164]	
	Corsica	ap	HD	$\beta$ -caryophyllene (21.1), germacrene B (8.3), $\alpha$ -humulene (6.9), germacrene D (6.7), $\alpha$ -cubebene (6.2), $\gamma$ -elemene (3.9), $\alpha$ -gurjunene (3.5), $\beta$ -bisabolene (3.3)	[303]	
	Italy	ap	HD	germacrene B (26.2), $\beta$ -caryophyllene (25.2), $\alpha$ -cubebene (8.0), $\alpha$ -humulene (8.0), $\beta$ -cubebene (6.5), germacrene D (6.3), $\alpha$ -gurjuene (6.0), $\alpha$ -copaene (4.3), $\alpha$ -cuprenene (3.2), $\delta$ -cadinene (3.0)	[304]	
	Poland; cultivated	ap	HD	$\beta$ -caryophyllene (22.3), caryophyllene oxide (15.4), $\alpha$ -humulene (8.4), $\alpha$ -cubebene (5.3), oct-1-en-3-ol (4.4), humulene epoxide 2 (4.4), germacrene D (3.0)	[305]	
	Spain	ap	HD	aristolene + $\beta$ -caryophyllene (21.0–12.3), germacrene D (13.4–6.4), caryophyllene oxide + spathulenol (13.0–4.2), $\alpha$ -copaene (9.3–4.8), $\alpha$ -cubebene (8.5–4.7), aromadendrene (6.5–0.9), $\beta$ -pinene (6.0–0.4), $\beta$ -bourbonene (5.7–4.5), humulene epoxyde (5.4–2.6), $\delta$ -cadinene (3.6–2.2), longipinene (3.3–t), calamenene (3.2–2.6)	[295]	
<i>T. siculum</i>	Italy, Euganei	lv	HD	$\alpha$ -pinene (28.6), $\alpha$ -bergamotene (13.7), phenylacetaldehyde (9.8), limonene (7.3), benzaldehyde (5.7), ethyl <i>trans</i> -cinnamate (3.9)	[302]	
	Italy, Euganei	br, ca, co	HD	ethyl <i>trans</i> -cinnamate (51.7–0), $\alpha$ -pinene (28.7–0), phenylacetaldehyde (17.9–0), ethyl <i>cis</i> -cinnamate (14.5–0), benzaldehyde (13.7–0), 1-phenylethanol (8.1), hex-3-enyl acetate (7.6–0), $\alpha$ -bergamotene (6.9–0), limonene (6.3–0), eptanal (3.9–0), $\alpha$ -gurjunene (3.5–0)	[302]	
	Italy, Tuscany	lv	HD	$\beta$ -caryophyllene (32.9), $\beta$ -selinene (7.3), $\beta$ -farnesene (5.6), eugenol (3.5), sesquiphellandrene (3.1)	[302]	
	Italy, Tuscany	br, ca, co	HD	linalool (75.7–0), isopropyl-3-methylbutyrate (24.2–0), carvone (9.5–0)	[302]	
	Italy, Sicily	lv	HD	$\beta$ -caryophyllene (25.6), isoeugenol (23.8), $\delta$ -cadinene (18.6), oct-1-en-3-ol (5.5), linalool (3.6)	[302]	
	Italy, Sicily	br, ca, co	HD	isoeugenol (43.6–28.1), ethyl <i>trans</i> -cinnamate (39.1–15.5), $\beta$ -farnesene (24.2–0), ethyl <i>cis</i> -cinnamate (21.4–11.2), linalool (11.3–0)	[302]	
	Italy, Sicily	ap	HD	( <i>E</i> )- $\beta$ -caryophyllene (30.9), 1-octen-3-ol (9.0), $\alpha$ -humulene (8.6), germacrene D (8.0), linalool (7.6), ( <i>2E</i> )-hexanal (3.6), caryophyllene oxide (3.6)	[294]	
	<b>Section <i>Spinularia</i></b>					
	<i>T. botrys</i>	Serbia-Montenegro	ap	HD	$\beta$ -caryophyllene (20.4), ( <i>E</i> )- $\beta$ -farnesene (17.7), $\alpha$ -humulene (13.9), $\alpha$ -pinene (8.1), $\beta$ -pinene (7.9), limonene (5.5), caryophyllene oxide (4.4)	[169]
	<i>T. maghrebinum</i>	Algeria	ap	HD	$\delta$ -cadinene (12.7), germacrene D (11.4), $\gamma$ -cadinene (9.5), 4-vinyguaiaicol, (4.0), $\beta$ -caryophyllene (3.7), limonene (3.7), $\alpha$ -cadinol (3.3)	[68]
cultived, Milan, Italy		ap	HD	germacrene D (14.3), $\delta$ -cadinene (13.5), $\gamma$ -cadinene (7.5), caryophyllene (4.9), limonene (4.4), caryophyllene oxide (4.0)	[190]	

continued

► **Table 3** *Continued*

Taxa	Origin	Parts	Method	Main compounds	Ref.
<b>Section <i>Stachybotrys</i></b>					
<i>T. arduini</i>					
	Croatia, Poljicka	old apic p	HD	germacrene D (23.6), $\beta$ -caryophyllene (17.3), $\delta$ -cadinene (9.7), cyperene (8.2)	[306]
	Croatia, Poljicka	young lv	HD	germacrene D (57.8), $\beta$ -caryophyllene (13.5), germacrene B (10.0)	[306]
	Croatia, Mt. Biokovo	ap	HD	$\beta$ -caryophyllene (19.9), caryophyllene oxide (14.6), (E)- $\beta$ -farnesene (5.6), $\delta$ -cadinene (5.3), spathulenol (5.0), aromadendrene (4.9), $\alpha$ -humulene (4.8), viridifloene (4.3)	[307]
	Croatia, Mt. Biokovo	ap	HD	$\beta$ -caryophyllene (32.9), germacrene D (16.4), borneol (5.4), $\delta$ -elemene (3.6), $\beta$ -thujone (3.5), camphor (3.2), $\beta$ -bourbonene (3.1)	[308]
	Croatia, Mt. Biokovo	ap	HD	$\beta$ -caryophyllene (35.2), germacrene D (18.7), borneol (4.9), camphor (4.4), $\delta$ -cadinene (4.2)	[309]
	Serbia-Mont, Njegusi	ap	HD	$\beta$ -caryophyllene (24.5), germacrene D (21.9), $\alpha$ -humulene (5.3), caryophyllene oxide (5.1), bicyclogermacrene (4.3), 3-octanol (3.6)	[169]
	Montenegro, Kotor	ap	HD	germacrene D (17.0), $\beta$ -caryophyllene (15.0), linalool (7.0), $\beta$ -burbonene (5.6), $\alpha$ -terpinolene (5.2), 1-octen-3-ol (4.7), $\alpha$ -amorphene (4.7), $\alpha$ -cadinol (4.6)	[310]
	Croatia, Ucka	ap	HD	pulegone (26.3), $\beta$ -caryophyllene (22.1), germacrene D (11.9), piperitone oxide (10.3), caryophyllene oxide (5.5)	[311]
	Croatia, Mt. Velebit, Susanj	ap	HD	$\beta$ -caryophyllene (29.1), germacrene D (18.7), piperitone oxide (10.3), caryophyllene oxide (10.2), linalool (5.6), pulegone (3.5)	[311]
	Croatia, Mt. Velebit, Velaki	ap	HD	$\beta$ -caryophyllene (35.4), caryophyllene oxide (17.1), germacrene D (9.6), linalool (5.6), pulegone (3.1)	[311]
	Croatia, Mt. Biokovo, Vosak	ap	HD	$\beta$ -caryophyllene (33.7), caryophyllene oxide (14.6), germacrene D (12.2), pulegone (4.1)	[311]
	Croatia, Mt. Biokovo, Svjure	ap	HD	$\beta$ -caryophyllene (28.8), caryophyllene oxide (14.2), germacrene D (12.5), linalool (3.4)	[311]
	Croatia, Mt. Siježnca	ap	HD	$\beta$ -caryophyllene (31.3), caryophyllene oxide (16.8), germacrene D (8.9), linalool (5.3), germacrene (4.6), spathulenol (4.5), $\alpha$ -humulene (3.2)	[311]
	Bosnia and Herzegovina, Diva Grabov.	ap	HD	$\beta$ -caryophyllene (30.1), germacrene D (28.9), caryophyllene oxide (6.1), $\alpha$ -humulene (3.5), spathulenol (3.3)	[311]
	Bosnia and Herzegovina, Mt. Prenj	ap	HD	piperitone oxide (39.1), germacrene D (15.2), $\beta$ -caryophyllene (8.2), linalool (6.6), caryophyllene oxide (4.4), spathulenol (4.1), limonene (3.9)	[311]
	Montenegro, Mt. Orjen	ap	HD	$\beta$ -caryophyllene (29.2), germacrene D (17.3), caryophyllene oxide (8.9), pulegone (4.9), piperitone oxide (4.6), spathulenol (4.5), $\alpha$ -humulene (4.2), germacrene (3.9)	[311]
	Montenegro, Mt. Lovcen	ap	HD	$\beta$ -caryophyllene (24.7), germacrene D (16.6), caryophyllene oxide (10.8), piperitone oxide (8.8), linalool (4.6)	[311]
	Montenegro, Trebjesa	ap	HD	$\beta$ -caryophyllene (30.7), germacrene D (18.1), caryophyllene oxide (7.2), linalool (4.5), piperitone oxide (3.3), germacrene (3.2)	[311]
	cultived, Milan, Italy	ap	HD	caryophyllene (10.0), hexadecanoic acid (9.3), caryophyllene oxide (7.7), germacrene D (5.8), spathulenol (5.8), cedrenol (4.8), heptacosane (4.0), hexahydrofarnesylacetone (3.8), $\alpha$ -humulene (3.1)	[190]
					<i>continued</i>

► Table 3 Continued

Taxa	Origin	Parts	Method	Main compounds	Ref.			
<i>T. hyrcanicum</i>	Iran, Caspian	ap	HD	hexahydrofarnesyl acetone (12.7), linalool (11.7), (E)- $\beta$ -farnesene (10.7), dihydroedulane (8.6), <i>ar</i> -curcumene (8.5), $\beta$ -himachalene (4.2), <i>trans</i> - $\beta$ -ionone (3.4)	[167, 312]			
				Iran, Sari	ap	HD	(E)- $\alpha$ -bergamotene (65.5), linalool (20.9)	[313]
				Iran, Babol	ap	HD	(E)- $\alpha$ -bergamotene (57.5), $\alpha$ -terpineol (12.3), 6–10–14-trimethyl pentadecanone (4.1), linalool (3.4), phytol (3.1)	[313]
	Iran, Tonekabon	ap	HD	(E)- $\alpha$ -bergamotene (33.3), (E)- $\beta$ -farnesene (16.4), camphene (6.0), 6–10–14-trimethyl pentadecanone (3.5), $\alpha$ -himachalene (3.3), $\beta$ -bisabolene (3.2), linalool (3.1), <i>ar</i> -curcumene (3.1)	[313]			
	Iran, Qaemshahr	ap	HD	(E)- $\alpha$ -bergamotene (86.9), 6–10–14-trimethyl pentadecanone (3.4)	[313]			
	Iran, Amol	ap	HD	(E)- $\alpha$ -bergamotene (49.7), (E)- $\beta$ -farnesene (7.6), phytol (4.9), linalool (4.5), 6–10–14-trimethyl pentadecanone (3.6)	[313]			
	Iran, Shirgah	ap	HD	(E)- $\alpha$ -bergamotene (43.9), (E)- $\beta$ -farnesene (6.4), phytol (5.6), 6–10–14-trimethyl pentadecanone (5.0), $\alpha$ -cadinol (4.1), 1,8-cineole (4.0), $\alpha$ -himachalene (3.7)	[313]			
	Iran, Gorgan	ap	HD	(E)- $\alpha$ -bergamotene (54.5), (E)- $\beta$ -farnesene (8.0), 6–10–14-trimethyl pentadecanone (6.9), phytol (5.8), $\alpha$ -cadinol (3.3), caryophyllene oxide (3.1)	[313]			
	Iran, Ramsar	ap	HD	(E)- $\alpha$ -bergamotene (32.6), (E)- $\beta$ -farnesene (11.0), <i>trans</i> -piperitone epoxide (6.4), 6–10–14-trimethyl pentadecanone (5.7), $\beta$ -bisabolene (5.0), <i>cis</i> -piperitone epoxide (4.7), $\alpha$ -cadinol (4.1), caryophyllene oxide (3.8), linalool (3.1).	[313]			
	Iran, Fooman	ap	HD	(E)- $\alpha$ -bergamotene (17.5), (E)- $\beta$ -farnesene (21.4), $\alpha$ -cadinol (8.0), <i>ar</i> -curcumene (4.1), carvacrol (6.4), 6–10–14-trimethyl pentadecanone (6.6), caryophyllene oxide (6.4)	[313]			
	Iran, Behshahr	ap	HD	(E)- $\alpha$ -bergamotene (21.4), 6–10–14-trimethyl pentadecanone (14.2), (E)- $\beta$ -farnesene (7.8), $\alpha$ -cadinol (3.8), linalool (3.2)	[313]			
	Iran, Savadkook	ap	HD	(Z)- $\beta$ -farnesene (21.4), aromadendrene (4.3), $\beta$ -caryophyllene (4.1), $\beta$ -pinene (3.4), methyl hexadecanoate (3.4), (E)- $\beta$ -ionone (3.2), <i>n</i> -hexadecanol (3.1)	[314]			
<i>T. lamifolium</i> ssp. <i>lamifolium</i>	Turkey	ap	HD	$\beta$ -caryophyllene (44.8–23.5), <i>trans</i> - $\beta$ -bergamotene (26.4–0), germacrene D (22.2–5.6), (Z)- $\beta$ -farnesene (14.0–3.0), caryophyllene oxide (8.1–2.7), hexadecanoic acid (5.8–0.7)	[315]			
<i>T. lamifolium</i> ssp. <i>stachyophyllum</i>	Turkey	ap	HD	<i>trans</i> - $\beta$ -bergamotene (41.1–38.1), $\beta$ -caryophyllene (8.9–8.7), $\alpha$ -humulene (6.4–6.1), germacrene D (7.4–6.6), hexadecanoic acid (4.6–2.8)	[315]			
<i>T. oxylepis</i> ssp. <i>oxylepis</i>	Spain	ap	HD	$\alpha$ -cadinol (12.8), aristolene + $\beta$ -caryophyllene (10.4), $\alpha$ -cubebene (8.5), <i>epi</i> -cubanol (7.7), $\delta$ -cadinene (7.2), $\alpha$ -copaene (4.8), calamarene (3.7), aromadendrene (3.6), sabinene (3.5), germacrene D (3.3)	[295]			
<i>T. oxylepis</i> ssp. <i>maritanum</i>	Spain	ap	HD	calamarene (13.1–7.9), linalool (12.9–7.1), $\tau$ -cadinol (9.2–5.7), $\alpha$ -cadinol (8.8–6.1), $\gamma$ -cadinene (7.9–7.4), $\alpha$ -cubebene (6.1–0.2), germacrene D (5.9–5.2), $\alpha$ -copaene (4.8–3.3), aristolene + $\beta$ -caryophyllene (4.3–3.5), <i>ar</i> -curcumene (3.1–0.8)	[295]			
<b>Section <i>Teucriopsis</i></b>								
<i>T. abutiloides</i>	Madeira	ap	HD	1-octen-3-ol (20.1), germacrene D (13.4), $\delta$ -cadinene (11.4), <i>allo</i> -aromadendrene (9.1), $\beta$ -bisabolene (4.2), $\alpha$ -cadinol (3.8), $\gamma$ -muurolene (3.0)	[316]			
<i>T. betonicum</i>	Madeira	ap	HD	1-octen-3-ol (24.2), $\beta$ -caryophyllene (12.1), bicycloelemene (6.8), linalool (6.2), zingiberene (5.2), caryophyllene oxide (5.0), phenylacetaldehyde (3.3), $\alpha$ -humulene (3.3), <i>n</i> -nonanal (3.0)	[316]			

continued



▶ **Table 3** Continued

Taxa	Origin	Parts	Method	Main compounds	Ref.
<i>T. hetrophyllum</i>	Madeira	ap-fl stage	HD	$\gamma$ -cadinol (20.7), $\alpha$ -pinene (16.2), $\alpha$ -cadinol (11.0), $\beta$ -pinene (8.7), 1-octen-3-ol (3.5)	[317]
	Madeira	ap-vg stage	HD	$\gamma$ -cadinol (17.0), $\alpha$ -pinene (16.4), $\alpha$ -cadinol (9.0), 1-octen-3-ol (8.0), $\beta$ -pinene (4.2)	[317]
	Canary Is	ap	HD	( <i>E</i> )- $\alpha$ -bisabolene (20.8), $\beta$ -caryophyllene (15.1), $\alpha$ -pinene (8.5), caphene (5.2), $\beta$ -pinene (4.3), linalool (3.0), $\alpha$ -humulene (3.4), $\beta$ -bisabolene (3.3), caryophyllene oxide (3.4)	[318]
<b>Section <i>Teucrium</i></b>					
<i>T. africanum</i>	S. Africa	ap	HD	$\alpha$ -cubebene (23.9), $\beta$ -cubebene (20.5), calamarene (4.0), pathoulene (3.7), $\alpha$ -copaene (3.2), bicyclosesquiphellendrene (3.2), $\delta$ -cadinene (3.0)	[24]
<i>T. glyssipholium</i>	Turkey	ap	HD	<i>trans</i> - $\beta$ -caryophyllene (16.9), <i>ar</i> -curcumene (11.4), bisabolene (11.1), caryophyllene oxide (5.1), limonene (3.5)	[319]
<i>T. brevifolium</i>	Greece, Karpathos	ap	HD	spathulenol (9.0), $\delta$ -cadinene (4.2), caryophyllene oxide (3.8), <i>trans</i> -pinocarveol (3.8), $\beta$ -pinene (3.6), viridiflorol (3.4), $\beta$ -eudesmol (3.4), cadalene (3.4)	[177]
<i>T. creticum</i>	Cyprus, Kato Lefkara	fl + lv + fr	HD	$\beta$ -caryophyllene (22.0), caryophyllene oxide (15.7), spathulenol (14.2), linalool (10.6), germacrene D (5.4), $\alpha$ -humulene (4.3), bicyclogermacrene (3.8), $\alpha$ -bisabolol oxide (3.4)	[320]
	Cyprus, Kato Lefkara	fl + lv	HD	linalool (23.1), $\beta$ -caryophyllene (13.3), caryophyllene oxide (11.3), spatulenol (7.1), germacrene D (6.5), $\alpha$ -bisabolol oxide (6.2), bicyclogermacrene (5.9), $\beta$ -bourbonene (3.8), geraniol (3.3), germacrene B (3.1), $\alpha$ -humulene (3.0)	[320]
	Cyprus, Kato Lefkara	st	HD	$\alpha$ -bisabolol oxide (16.7), $\beta$ -bourbonene (9.9), linalol (8.1), calamenene (3.6), caryophyllene oxide (3.5)	[320]
	Cyprus, Katopyrgos	fl	HD	$\beta$ -caryophyllene (21.5), caryophyllene oxide (13.8), germacrene D (10.8), spathulenol (8.6), $\alpha$ -humulene (5.7), geraniol (5.5), bicyclogermacrene (5.0)	[320]
<i>T. fruticans</i>	Italy, Tuscany	ap fl	HD	$\beta$ -pinene (21.2), germacrene D (17.7), myrcene (12.8), $\beta$ -caryophyllene (12.2), $\beta$ -phellandrene (4.3), $\beta$ -selinene (4.1), $\alpha$ -pinene (3.6), limonene (3.5), $\alpha$ -humulene (3.0)	[321]
	Italy, Tuscany	ap fr	HD	germacrene D (24.4), $\beta$ -caryophyllene (21.8), $\beta$ -pinene (7.1), $\beta$ -selinene (6.9), myrcene (5.7), $\alpha$ -humulene (5.5)	[321]
	Italy, Sicily	ap	HD	germacrene D (29.4), 1-octen-3-ol (19.7), ( <i>E</i> )- $\beta$ -caryophyllene (19.6), <i>trans</i> -calamenene (7.3), linalool (6.0), $\alpha$ -humulene (5.6), <i>trans</i> -cadinol-1,4-diene (4.0)	[294]
	Malta	ap	HD	germacrene D (50.0), ( <i>E</i> )- $\beta$ -caryophyllene (21.9), 1-octen-3-ol (7.4), $\alpha$ -humulene (3.3), linalool (3.2), <i>trans</i> -cadinol-1,4-diene (3.0), $\beta$ -pinene (3.0)	[294]
<i>T. multicaule</i>	Turkey, Erzincan	ap	HD	germacrene D (13.2), caryophyllene oxide (10.9), spathulenol (6.6), $\beta$ -caryophyllene (5.6), (6 <i>Z</i> ,10 <i>Z</i> )-pseudo phytol (4.1), myrtenol (3.8), $\alpha$ -cadinol (3.6), $\delta$ -cadinene (3.2), hexadecanoic acid (3.2)	[322]
	Turkey, Elazığ	ap	HD	caryophyllene oxide (31.1), thymol (13.2), terpineol (10.6), spathulenol (7.6), azulene (3.3)	[259]
<i>T. orientale</i> ssp. <i>glabrescens</i>	Iran	fl-ap	HD	$\beta$ -cubebene (34.5), $\alpha$ -cubebene (16.6), $\alpha$ -copaene (10.1), $\beta$ -caryophyllene (10.0), caryophyllene oxide (4.7), <i>n</i> -eicosane (4.7), $\alpha$ -amorphene (3.8)	[323]
	Turkey, Maras	ap	HD	$\alpha$ -pinene (18.2), elemol (14.5), $\beta$ -pinene (10.1), cubenol (10.0), limonene (5.0), $\beta$ -caryophyllene (4.2), myrcene (3.4)	[324]
	Turkey, Kusakkaya	ap	SPME	nonanal (25.0), thujal-2,4(10)-diene (22.9), tetracosane (15.2), pentacosane (7.2), eicosane (6.8), decanal (4.5), 2-amyl furan (3.9)	[325]
					continued

► Table 3 Continued

Taxa	Origin	Parts	Method	Main compounds	Ref.
<i>T. orientale</i> ssp. <i>orientale</i>	Iran	ap	HD	caryophyllene oxide (33.5), linalool (17.0), $\beta$ -caryophyllene (9.3), $\delta$ -cadinene (3.7), carvacrol (3.2), $\alpha$ -copaene (3.0)	[326]
	Turkey Erzurum	ap, bud st	HD	linalool (29.1), $\beta$ -caryophyllene (23.6), 3-octanol (10.4), germacrene D (8.8), $\beta$ -bourbonene (5.7), $\gamma$ -gurjunene (3.6)	[327]
	Turkey Erzurum	ap fl st	HD	linalool (30.9), $\beta$ -caryophyllene (13.8), 3-octanol (10.4), germacrene D (6.7), $\beta$ -bourbonene (4.5)	[327]
	Turkey Erzurum	ap veg st	HD	$\beta$ -bourbonene (19.2), 3-octanol (13.2), linalool (10.6), $\beta$ -caryophyllene (9.5), $\alpha$ -cubebene (6.9), germacrene D (6.2), $\alpha$ -copaene (5.6), ( <i>E</i> )- $\gamma$ -bisabolene (5.2)	[327]
	Turkey, Erzurum	ap	HD	$\beta$ -caryophyllene (15.3), germacrene D (14.2), caryophyllene oxide (14.0), spathulenol (6.4), bicyclogermacrene (3.6), hexadecanoic acid (3.1)	[328]
	Turkey, Karaman	ap	HD	germacrene D (246), $\beta$ -caryophyllene (22.6), hexadecanoic acid (7.9), bicyclogermacrene (6.7), caryophyllene oxide (5.6)	[324]
<i>T. orientale</i> ssp. <i>puberulens</i>	Turkey, Tersun Mt.	ap	HD	$\beta$ -caryophyllene (21.7), 2-methyl cumarone (20.0), germacrene D (10.6), $\alpha$ -humulene (4.8), $\delta$ -cadinene (4.1), bicyclogermacrene (3.4)	[172]
	Turkey, Erzurum	ap	HD	$\beta$ -caryophyllene (15.3), germacrene D (14.2), caryophyllene oxide (14.0), spathulenol (6.4), bicyclogermacrene (3.6), hexadecanoic acid (3.1)	[328]
	Turkey, Aksaray	ap	HD	germacrene D (33.4), hexadecanoic acid (12.8), $\beta$ -caryophyllene (8.5), bicyclogermacrene (8.5), $\beta$ -cubebene (3.5)	[324]
<i>T. orientale</i> ssp. <i>taylora</i>	Iran	ap-fr	HD	linalool (28.6), caryophyllene oxide (15.6), 3-octanol (9.5), $\beta$ -pinene (8.7), $\beta$ -caryophyllene (7.3), 1,8-cineol (4.5), germacrene D (4.1), $\beta$ -bisabolene (3.4)	[329, 330]
<i>T. parviflorum</i>	Turkey	ap	HD	$\beta$ -caryophyllene (18.6), germacrene D (9.2), caryophyllene oxide (8.8), bicyclogermacrene (6.0), $\delta$ -cadinene (4.5), $\alpha$ -pinene (4.4), $\beta$ -bisabolene (4.4), $\beta$ -farnesene (3.7)	[331]
<i>T. pestalozzae</i>	Turkey	ap	HD	$\beta$ -caryophyllene (27.6), germacrene D (13.8), $\alpha$ -humulene (5.6), ( <i>E</i> )- $\beta$ -farnesene (4.4), linalool (3.8), caryophyllene oxide (3.3), germacrene B (3.2), ledene (3.0)	[205]
<i>T. pruinsum</i>	Palestine	lv	MU	agarospirol (43.5), caryophyllene (19.3), D-limonene (3.7), $\alpha$ -caryophyllene (3.4), caryophyllene oxide (3.1)	[332]
<i>T. pseudochamaepitys</i>	Tunisia	ap	HD	hexadecanoic acid (26.1), apiole (7.1), caryophyllene oxide (6.3), myristicin (4.9), ( <i>F</i> )- $\beta$ -damascenone (4.6), $\alpha$ -cubebene (3.9), $\beta$ -caryophyllene (3.5), elemicin (3.3), pentadecanol (3.1), cadidene-1,4-diene (3.1)	[333]
<i>T. sandrasicum</i>	Turkey	ap	HD	germacrene D (27.9), $\beta$ -caryophyllene (9.1), sabinene (8.9), $\alpha$ -pinene (6.5), bicyclogermacrene (5.8), linalool (5.6), terpinen-4-ol (4.5), $\beta$ -pinene (3.8), $\alpha$ -humulene (3.2), hexadecanoic acid (3.0)	[205]
<i>T. trifidum</i>	S. Africa	ap	HD	$\beta$ -cubebene (31.1), $\alpha$ -cubebene (11.4), $\beta$ -caryophyllene (7.7), $\delta$ -cadinene (5.2), bicyclosesquiphellendrene (4.2), <i>epi</i> -cubebol (4.2), cubebol (3.5)	[24]
<b>Section not determined</b>					
<i>T. atratum</i>	Algeria, cultivated	ap	HD	<i>r</i> -cadinol (40.1), thymol (22.1), cravacrol (14.0), spathulenol (5.6), $\alpha$ -cubanol (5.0), $\alpha$ -cadinol (5.0)	[262, 334]

ap = aerial parts; fl = flowers; lv = leaves; fr = fruits; st = stems; br = bact; ca = calyx; co = corolla; rt = roots; BB = before bloom; FB = full bloom; AFB = after full bloom; CO<sub>2</sub> = Supercritical extraction; DCM = dichloromethane maceration; DT = direct thermal desorption method; Et<sub>2</sub>O/pent = diethyl ether/pentane maceration; HD = hydrodistillation; Hex = Mmaceration in hexane; HS = headspace; MD = microdistillation; MHD = Mmicrowave-assisted hydrodistillation; MU = microwave ultrasonic; SDE = Ssimultaneous distillation-extraction; SFME = rapid solvent-free microwave extraction; SPME = headspace solid-phase micro-extraction; \* percentage not reported in the original paper

► **Table 4** The antioxidant activity of the essential oils from *Teucrium* taxa.

Species	Origin	Test type	Ref.
<i>T. alyssifolium</i>	Turkey	IC <sub>50</sub> (µg/mL) DPPH 132	[319]
<i>T. flavum</i> ssp. <i>flavum</i>	Tunisia	IC <sub>50</sub> (µg/mL) DPPH 1230	[185]
<i>T. marum</i> ssp. <i>marum</i>	Italy	IC <sub>50</sub> (µg/mL) DPPH 13.13, X/XO 0.161	[188]
<i>T. massiliense</i>	Italy	IC <sub>50</sub> (µg/mL) DPPH 13.30, LO 37.0	[298]
<i>T. orientale</i> ssp. <i>orientale</i>	Turkey	IC <sub>50</sub> DPPH not determined	[327]
<i>T. orientale</i> ssp. <i>taylori</i>	Iran	IC <sub>50</sub> (µg/mL) DPPH 121.6; β-carotene/LO 79.85 (comparable to BHT)	[329]
<i>T. polium</i>	Algeria	TEAC (mg TE/gr DWP): DPPH 19.14 (F) and 18.01 (B), FRAP 20.21 (F) and 18.21 (B)	[210]
<i>T. polium</i>	Algeria	IC <sub>50</sub> (µg/mL) DPPH 547.68, ABTS 3.84, CUPRAC 9.82, β-carotene 33.47	[211]
<i>T. polium</i>	Iran	IC <sub>50</sub> (µg/mL) DPPH 9200, LO > 2000	[226]
<i>T. polium</i>	Iran	IC <sub>50</sub> (µg/mL) DPPH ca. 600, β-carotene/LO ca. 600	[232]
<i>T. polium</i>	Iran	IC <sub>50</sub> (µg/mL) DPPH ca. 250	[233]
<i>T. polium</i> ssp. <i>aurum</i>	Marocco	IC <sub>50</sub> (µg/mL) DPPH ca. 7200, FRAP 3500	[245]
<i>T. polium</i> ssp. <i>polium</i>	Marocco	IC <sub>50</sub> (µg/mL) DPPH 3700, FRAP 2310	[245]
<i>T. polium</i>	Tunisia	IC <sub>50</sub> (µg/mL) DPPH 20.0, FRAP ND, β-carotene 150	[255]
<i>T. polium</i> ssp. <i>aurasianum</i>	Algeria	IC <sub>50</sub> (µg/mL) DPPH 58.63, EC <sub>50</sub> (µg/mL): FRAP 48.19	[263]
<i>T. polium</i> ssp. <i>capitatum</i>	Algeria	IC <sub>50</sub> (µg/mL) DPPH ca. 300	[264]
<i>T. pruinatum</i>	Palestine	IC <sub>50</sub> (µg/mL) DPPH 16.98	[332]
<i>T. sauegi</i>	Tunisia	IC <sub>50</sub> (µg/mL) DPPH 1000, ABTS 590	[279]
<i>T. pseudochamaepitys</i>	Tunisia	IC <sub>50</sub> (µg/mL) DPPH 770	[333]

classes: the sesquiterpene and monoterpene chemotypes. As can be seen, examining the composition of some very commonly studied taxa (e.g., *T. polium* or *T. polium* ssp. *capitatum*), this variation is intraspecific and probably due to different climatic or soil growing conditions.

### Biological activities

Several biological activities have been disclosed for the EOs of the *Teucrium* genus, and they are discussed in the following paragraphs. Some of the effects, proven both *in vitro* and *in vivo*, can be associated to the traditional uses of the individual species. In other cases, a correlation between the ethnobotanical panorama and rigorous scientific evidence lacks.

The complexity of the chemical composition of EOs makes it rather arduous to interpret the results in terms of interactions with cellular molecular targets, even though the reductionist paradigm is more widely accepted; this is to attribute a particular bioactivity to the principal chemical component of the mixture or to one of the major components, for which a certain activity had been demonstrated for its pure form. The so-called “synergistic” model, based upon what the overall effect of the EO is higher than that of any single component, is advocated by some authors even though, in our opinion, it lacks strong experimental evidence.

### Antioxidant activity

The antioxidant activity was evaluated for the EOs of several members of the genus *Teucrium*; ► **Table 4** reports the more relevant results. A great number of tests have been developed to

measure the antioxidant power, which entail the interaction of a suitable probe with different molecules involved in the complex oxidative pathway, such as primary oxidation products hydroperoxides and/or secondary aldehydes, etc. Therefore, careful attention should be devoted to the selection of coherent data for a matter of comparison. However, most of the data reported in the literature concern the use of the DPPH radical scavaging test, based on radical hydrogen donation power of the sample. The activities disclosed vary from quite weak (order of magnitude of the IC<sub>50</sub> in the DPPH assay 1000 µg/mL) to moderate (10–100 µg/mL) and, in some cases, stronger (1–10 µg/mL). In the case of EOs, the activity of the sample is related to the activity of the single components and attempts were made to make such a correlation explicit, even though these attempts are not always convincing. For example, Yildirim et al. [327] showed a direct correlation between the antioxidant activity of *T. orientale* EO harvested at different vegetative stages and its β-caryophyllene content. On other hand, other authors [319] did not recognize this compound as the main component responsible for the antioxidant activity of the *Teucrium alyssifolium* EO, even though it was found to be the major component (16.97%) in the oil. Surprisingly, the antioxidant activity of the oil was ascribed to the phenolic compounds present as minor components. Another group [188] justified the observed antioxidant activity of the EO of *T. marum* ssp. *marum* to the presence of dolichodial.

Quite an interesting attempt to comprehensively rationalize the correlation between the antioxidant activity and the chemical composition of the EOs was made by Ruberto and Baratta [335],

who investigated the radical scavenging activity of more than 100 individual compounds normally included in the EO composition of many species. They made use of two distinct assays (TBAR and ABAP) that gave comparable results: phenols, allylic alcohols, and unsaturated hydrocarbons, which can better stabilize unpaired electrons, were the more active compounds.

It would be useful and desirable that future investigations concerning the antioxidant activity of EOs will employ these two methods in order to better understand the molecular basis of the efficacy of different blends.

### Antimicrobial activity

The antimicrobial activity of the EOs obtained from plants of *Teucrium* taxa has been largely explored. ▶ **Table 5** includes a survey of the most relevant available literature data, reported as MIC values – where available – as a matter for easier comparison. As can be seen, the range of these values is rather wide, being comprised within three orders of magnitude, from about  $10^{-1}$  to  $10^2$  mg/mL. Just for a matter of clarity, an arbitrary and qualitative classification of the efficacies reported could be stated as good (up to 1 mg/mL), medium (from 1 to 10 mg/mL), and weak ( $> 10$  mg/mL). Only in one study, that is the evaluation of the antimicrobial activity of *T. polium* ssp. *aurasiacum* from Algeria, the results obtained showed MIC values notably high toward all of the tested microbial strains, ranging from 0.08 to 40  $\mu$ g/mL [262]. The authors explained this remarkable antimicrobial potency with the presence of thymol as the major component in the oil, based upon the recognized antimicrobial effect of this compound.

Regarding EOs obtained from the species that showed an activity comprised in the range defined as “good”, it is worth noting that most of them include a significant amount (ca. 9–25%) of  $\alpha$ -pinene, a well-recognized antimicrobial compound [337], in their composition, irrespective of their geographical origin. They are: *T. polium* from Greece [213]; *T. polim* ssp. *aurasiacum* [263,264] from Algeria, ssp. *gabesianum* from Tunisia [272]; *T. flavum* ssp. *glaucom* from Corsica [164]; *T. stocksianum* from Pakistan [283] and *T. yemense* from Yemen [287].

An increasingly deep concern in the field of clinical infections control is the development of multidrug-resistant microbial strains in hospitalized patients. The efficacy of traditional antibiotics to combat this phenomenon is limited and the research on possible new remedies is welcomed and demanding. In this context, the use of new natural products, as well as EOs from plants, seems to be promising. An interesting work on this topic was published in 2016 by Lahmar et al. [275], who isolated multi drug resistant *Acinetobacter baumannii* and lactamase-producing *Escherichia coli* strains from patients and tested the antimicrobial effect of the EO of three species belonging to Tunisian flora, among which was *T. ramosissimum*. The results showed that the MICs values for *T. ramosissimum* EO against MRSA (methicillin resistant *Staphylococcus aureus*) colonies varied from 0.25 to 1 mg/mL. In an attempt to reinstate antibiotic sensitivity, the EO was tested in combination with amoxicillin, tetracyclin, piperacillin, and ofloxacin, for which *A. baumannii* was shown to be resistant. No interaction was found between the EOs and piperacillin, but the active oil, at 15.6 mg/mL, restored the efficacy of ofloxacin by lowering the MIC values from 4- to 8-fold. The tendency of EOs to reduce

antibiotic resistance is more pronounced against MRSA strains (138, 760, and 753). In the case of the MRSA 760 strain, the EO improved the effect of all antibiotics (amoxicillin, piperacillin, tetracycline, and oxacillin), with a reduction of their MIC value. However, the association was not efficient enough to modulate the antibacterial activity of ofloxacin (MIC of 4 mg/mL). The authors correlated the observed activity to the presence of  $\beta$ -eudesmol, *p*-cymene, 1,6-germacradien-5-ol, cedreanol,  $\beta$ -caryophyllene, and the above-cited  $\alpha$ -pinene in the oil. However, it should be underlined that not all of these compounds had been previously shown to be individually active.

*Klebsiella pneumoniae* is an opportunistic pathogen that is known to develop multiple antibiotic-resistant strains responsible for dangerous nosocomial infections, including urinary tract, pneumonia, septicemia, and soft tissue infections. That is because the improvement in the chemical instruments available for its clinical control is of primary importance. In this regard, the good efficacy of *T. polium* EO from Iran [229] against *K. pneumoniae* ATCC 10031, as well as several strains isolated from urine of hospitalized patients, is relevant. However, the association that the authors made between the observed activity and the presence of the main components in the oil, caryophyllene oxide,  $\beta$ -caryophyllene, and  $\beta$ -pinene, seems to be poorly supported as none of the cited compounds was ever demonstrated to be active against *K. pneumoniae*, and  $\alpha$ -pinene, also present in significant amounts in the oil of this sample of *T. polium*, possesses a wider antibiotic activity spectrum [337].

The above reported studies concerning possible clinical application of some EOs as effective antibiotics are surely interesting and promising for external use, but internal use requires much more additional safety and efficacy data.

An interesting potential application of the antimicrobial power of EOs concerns the implementation as preservative additives in food in order to fight microbial contaminations and development. In this context, the EO obtained from *T. polium* [228] was assessed for its efficacy; samples of yogurt and of probiotic yogurt were inoculated with different concentrations of the EO alone and together with variable amounts of *Lactobacillus casei* in order to investigate the inhibitory effect toward the growth of *Salmonella typhimurium* at intervals of 7 days. *T. polium* EO had the best *Salmonella* growth inhibition at 120 and 160 ppm and in synergistic combination with *L. casei*. No *Salmonella* was isolated during the 28 days of preservation of yoghurt or probiotic yoghurt (*L. casei* added) containing different concentrations of *T. polium* EO. The same combination of *T. polium* EO and *L. casei* was successfully applied as a conservative antibacterial agent against *E. coli* O157:H7 in samples of Kishk, a traditional Middle Eastern dish [91]. Further, *T. polium* EO was also evaluated as an additive in a commercial barley soup employing *Bacillus cereus* as a contaminant model [230].

The potential application as preservatives in the food industry is, in our opinion, much less problematic than the previously highlighted clinical one and, consequently, possesses a higher commercial appeal.

► **Table 5** Antimicrobial activity of the EOs of *Teucrium* taxa.

Species	Origin	Test	Target	Ref
<i>T. africanum</i>	South Africa	MIC (mg/ml)	<i>B. cereus</i> ATCC 11778, <i>E. coli</i> ATCC 8739, <i>K. pneumoniae</i> ATCC 13883, <i>M. catarrhalis</i> ATCC 23246, <i>P. aeruginosa</i> ATCC 27858, <i>S. aureus</i> ATCC 2592: 4.0 to > 8.0; <i>S. pyogenes</i> ATCC 8668: 0.16	[24]
<i>T. arduini</i>	Croatia	MIC (mg/ml)	<i>S. aureus</i> ATCC 6538: 6.25, <i>E. faecalis</i> ATCC 21212: 37.50, <i>E. coli</i> ATCC 10536: 12.50, <i>P. aeruginosa</i> ATCC 27853: 6.25, <i>C. albicans</i> ATCC 10231: 7.81, <i>M. gypseum</i> MFBF 53: 12.50, <i>A. brasiliensis</i> ATCC 16404: 25	[308]
<i>T. arduini</i>	Montenegro	MIC (mg/ml)	<i>E. faecalis</i> , <i>E. coli</i> , <i>P. mirabilis</i> , <i>K. pneumoniae</i> , <i>P. aeruginosa</i> , <i>B. subtilis</i> FSB 2: 50, <i>E. faecalis</i> ATCC 29212: 50, <i>M. lysodeikticus</i> ATCC 4698: 50, <i>S. aureus</i> ATCC 25923: 25, <i>S. aureus</i> FSB 30: 25, <i>E. cloacae</i> FSB 22: 25, <i>E. coli</i> ATCC 25922: 50, <i>K. pneumoniae</i> FSB 26: 6.25, <i>P. mirabilis</i> FSB 34: 25, <i>C. albicans</i> ATCC 10259: 50	[310]
<i>T. atratum</i>	Algeria	MIC (µg/ml)	<i>E. aerogenes</i> : 5, <i>E. coli</i> ATCC 25922: 64, <i>K. pneumoniae</i> : 128, <i>P. mirabilis</i> : 128, <i>P. aeruginosa</i> ATCC 27853: 5, <i>S. typhimurium</i> : 64	[262]
<i>T. capitatum</i>	Morocco	MIC (µl/ml)	<i>T. rubrum</i> : 32.3, <i>T. mentagrophytes</i> : 32.3, <i>E. floccosum</i> : 32.3, <i>M. gypseum</i> : 20.4, <i>C. glabrata</i> : 20.4, <i>C. albicans</i> : 15.9, <i>M. canis</i> : 15.9, <i>A. niger</i> : 15.9	[270]
<i>T. chamaedrys</i>	France	MIC (mg/ml)	<i>S. aureus</i> , <i>S. epidermidis</i> , <i>L. innocua</i> , EAEP289, <i>E. aerogenes</i> , <i>C. jejuni</i> : 3.0, > 50.0, 3.0, > 50.0, > 50.0, 1.0	[164]
<i>T. chamaedrys</i>	Turkey	IZD (mm) at 1.0 mg/mL	<i>E. coli</i> ATCC 35218: 5–10, <i>Y. pseudotuberculosis</i> ATCC 911: 10–15, <i>K. pneumoniae</i> ATCC 13883: < 5, <i>S. marcescens</i> ATCC 13880: 5–10, <i>E. faecalis</i> ATCC 29212: 5–10, <i>S. aureus</i> ATCC 25923: 5–10, <i>B. subtilis</i> ATCC 6633: < 5, <i>C. albicans</i> ATCC 60193: < 5, <i>C. tropicalis</i> ATCC 13803: < 5	[172]
<i>T. chamaedrys</i> spp. <i>lydium</i>	Turkey	IZD (mm) at 0.5 mg/mL	<i>E. coli</i> ATCC 35218: < 5, <i>Y. pseudotuberculosis</i> ATCC 911: < 5, <i>K. pneumoniae</i> ATCC 13883: < 5, <i>S. marcescens</i> ATCC 13880: < 5, <i>E. faecalis</i> ATCC 29212: 5–10, <i>S. aureus</i> ATCC 25923: 10–15, <i>B. subtilis</i> ATCC 6633: 10–15, <i>C. albicans</i> ATCC 60193: < 5, <i>C. tropicalis</i> ATCC 13803: < 5	[172]
<i>T. divaricatum</i>	Lebanon	MIC (µg/ml)	<i>B. cereus</i> ATCC 11778: > 100, <i>B. subtilis</i> ATCC 6633: 50, <i>S. aureus</i> ATCC 25923: 100, <i>S. epidermidis</i> ATCC 12228: 25, <i>S. faecalis</i> ATCC 29212: > 100, <i>E. coli</i> ATCC 25922: > 100, <i>P. mirabilis</i> ATCC 25933: > 100, <i>P. vulgaris</i> ATCC 13315: > 100, <i>P. aeruginosa</i> ATCC 27853: > 100, <i>S. typhi</i> Ty2 ATCC 19430: > 100	[61]
<i>T. flavum</i> spp. <i>glaucom</i>	France	MIC (mg/ml)	<i>S. aureus</i> , <i>S. epidermidis</i> , <i>L. innocua</i> , EAEP289, <i>E. aerogenes</i> , <i>C. jejuni</i> : 0.8, 1.5, 1.5, 1.5, 1.5, 0.2	[164]
<i>T. hyrcanicum</i>	Iran	MIC (mg/ml)	<i>B. subtilis</i> : 2.5, <i>S. aureus</i> : 0.625, <i>E. coli</i> : NA, <i>S. typhi</i> : 5, <i>P. aeruginosa</i> : 10, <i>C. albicans</i> : NA, <i>A. niger</i> : 0.625	[314]
<i>T. leucocladium</i>	Egypt	IZD (mm) at 20 mg/ml	<i>E. coli</i> : 12, <i>P. aeruginosa</i> : 15, <i>S. aureus</i> : 12, <i>B. subtilis</i> : 30, <i>C. albicans</i> : 26	[210]
<i>T. marum</i>	France	MIC (mg/ml)	<i>S. aureus</i> , <i>S. epidermidis</i> , <i>L. innocua</i> , EAEP289, <i>E. aerogenes</i> , <i>C. jejuni</i> : 0.4, 25.0, 0.4, 0.4, 0.4, 1.0	[164]
<i>T. marum</i> spp. <i>marum</i>	Italy	MIC (mg/ml)	<i>R. solani</i> : 250, <i>F. oxysporum</i> : 450, <i>B. cinerea</i> : 1000, <i>A. solani</i> : 3800	[188]
<i>T. mascatense</i>	Oman	MIC (mg/ml);	<i>S. aureus</i> [NCTC6571]: 2.0, <i>S. aureus</i> : 2.5, <i>S. albus</i> : 2.0, <i>S. epidermidis</i> : 2.0, <i>Strept. mitis</i> : 1.5, <i>Strept. sanguis</i> : 1.5, <i>M. luteus</i> : 2.5, <i>B. subtilis</i> : 2.0, <i>B. cereus</i> : 1.5, <i>E. coli</i> : 6.0, <i>E. coli</i> [NCTC10418]: 7.0, <i>E. aerogenes</i> : 8.0, <i>K. pneumoniae</i> : 8.5, <i>S. typhi</i> : 6.5, <i>P. vulgaris</i> : 8.5, <i>P. aeruginosa</i> [NCTC10662]: 8.0, <i>P. aeruginosa</i> : 8.5	[71]
		IZD (mm) at 20 mg/ml	<i>C. albicans</i> : 5.5, <i>S. cerevisiae</i> : 5, <i>R. stolonifera</i> : 4.5, <i>P. notatum</i> : 8.0, <i>F. oxysporum</i> : 4.0	
<i>T. massiliense</i>	France	MIC (mg/ml)	<i>S. aureus</i> , <i>S. epidermidis</i> , <i>L. innocua</i> , EAEP289, <i>E. aerogenes</i> , <i>C. jejuni</i> : 0.8, 0.8, 0.8, 0.8, 0.8, 0.8, 1.0	[164]
<i>T. montanum</i>	Serbia	IZD (mm) at 0.3 mg/mL	<i>B. mycoides</i> : 25, <i>B. subtilis</i> : 26, <i>S. aureus</i> : 10, <i>A. tumefaciens</i> : 16, <i>A. chlorococcum</i> : 24, <i>E. cloacae</i> : 24, <i>E. carotovora</i> : 18, <i>K. pneumoniae</i> : 29, <i>Proteus</i> sp.: NA, <i>P. aeruginosa</i> : NA, <i>P. glycinica</i> : 20, <i>P. fluorescens</i> : 22, <i>P. phaseolicola</i> : 23, <i>A. niger</i> : 9, <i>F. oxysporum</i> : 17, <i>P. canescens</i> : 10	[206, 207]
<i>T. orientale</i> var. <i>puberulens</i>	Turkey	IZD (mm) at 0.5 mg/mL	<i>E. coli</i> ATCC 35218: < 5, <i>Y. pseudotuberculosis</i> ATCC 911: < 5, <i>K. pneumoniae</i> ATCC 13883: < 5, <i>S. marcescens</i> ATCC 13880: < 5, <i>E. faecalis</i> ATCC 29212: 10–15, <i>S. aureus</i> ATCC 25923: 5–10, <i>B. subtilis</i> ATCC 6633: 5–10, <i>C. albicans</i> ATCC 60193: < 5, <i>C. tropicalis</i> ATCC 13803: < 5	[172]
				continued

▶ Table 5 Continued

Species	Origin	Test	Target	Ref
<i>T. polium</i>	Algeria	MIC (μL/mL)	<i>B. cereus</i> ATCC 11778: 5, <i>E. faecalis</i> ATCC 29212: 5, <i>E. coli</i> ATCC 25922: 4, <i>P. aeruginosa</i> ATCC 27853: NA, <i>S. aureus</i> ATCC 25923: 3	[214]
<i>T. polium</i>	Greece	IZD (mm) at 0.25 mg/mL	<i>E. coli</i> : 0.9, <i>S. aureus</i> : 17.5, <i>P. aeruginosa</i> : 12.5, <i>P. mirabilis</i> : 11	[213]
<i>T. polium</i>	Iran	MIC (μg/mL)	<i>K. pneumoniae</i> ATCC 10031 and patient urinary isolates: 0.62	[229]
<i>T. polium</i>	Morocco	MIC (μL/mL)	<i>S. aureus</i> ATCC 29213: 1.3, <i>E. coli</i> ATCC 25922: NA, <i>P. aeruginosa</i> ATCC 27853: NA, <i>C. albicans</i> ATCC 10231: NA, <i>A. brasiliensis</i> ATCC 1640: NA	[336]
<i>T. polium</i>	Morocco	MIC (mg/mL)	From individual patients: <i>K. pneumoniae</i> : 0.7, <i>P. aeruginosa</i> : 5.62, <i>S. aureus</i> : 0.17, <i>A. baumannii</i> : 2.81, <i>C. koseri</i> : 2.81, <i>E. coli</i> : 5.62	[245]
<i>T. polium</i> spp. <i>aurasiacum</i>	Algeria	MIC (μg/mL)	<i>E. aerogenes</i> : 40, <i>E. coli</i> ATCC 25922: 0.08, <i>K. pneumoniae</i> : 32, <i>P. mirabilis</i> : 32, <i>P. aeruginosa</i> ATCC 27853: 0.08, <i>S. typhimurium</i> : 40, <i>S. aureus</i> ATCC 25923: 0.16	[262]
<i>T. polium</i> ssp. <i>aureum</i>	Morocco	MIC (mg/mL)	From individual patients: <i>K. pneumoniae</i> : 1.4, <i>P. aeruginosa</i> : 5.62, <i>S. aureus</i> : 0.17, <i>A. baumannii</i> : 1.4, <i>C. koseri</i> : 2.81, <i>E. coli</i> : 2.81	[245]
<i>T. polium</i> spp. <i>capitatum</i>	France	MIC (mg/mL)	<i>S. aureus</i> , <i>S. epidermidis</i> , <i>L. innocua</i> , EAEP289, <i>E. aerogenes</i> , <i>C. jejuni</i> : 0.4, 12.5, 6.0, 0.8, 0.8, 0.2	[164]
<i>T. polium</i> ssp. <i>gabesianum</i>	Tunisia	MIC (mg/mL)	<i>E. coli</i> ATCC 25922, <i>E. faecalis</i> ATCC 29212, <i>S. aureus</i> ATCC 25923, <i>P. aeruginosa</i> ATCC 27853, <i>C. freundii</i> , <i>P. mirabilis</i> : >1; <i>M. canis</i> : 0.062	[272]
<i>T. polium</i> ssp. <i>geyrii</i>	Algeria	MIC (μL/mL)	<i>S. aureus</i> ATCC 27923: 4.9, <i>E. coli</i> ATCC 25922: 12.25, <i>P. aeruginosa</i> ATCC 25853: 12.25, <i>C. albicans</i> : 2.45	[273]
<i>T. polium</i> spp. <i>paurasianum</i>	Algeria	MIC (mg/mL)	<i>E. coli</i> VL, <i>Leisteria</i> VL, <i>Salmonella</i> : 0.66, <i>S. aureus</i> : 0.33, <i>Staphylococcus</i> SP: 0.33, <i>Proteus</i> VL, <i>K. pneumoniae</i> : 0.5	[263]
<i>T. ramosissimum</i>	Tunisia	MIC (mg/mL)	<i>S. aureus</i> ATCC 25923: 0.32, <i>E. faecalis</i> ATCC 29212: 0.36, <i>E. coli</i> ATCC 25922: 0.28, <i>S. enteritidis</i> ATCC 13076: 0.27, <i>S. typhimurium</i> NRRLB 4420: 0.24	[131]
<i>T. sauvagei</i>	Tunisia	MIC (mg/mL)	<i>C. albicans</i> , <i>C. neoformans</i> , <i>T. mentagrophytes</i> var. <i>mentagrophytes</i> , <i>T. mentagrophytes</i> var. <i>interdigitale</i> , <i>T. rubrum</i> , <i>T. soudanense</i> , <i>M. canis</i> , <i>M. gypseum</i> , <i>E. floccosum</i> , <i>A. fumigatus</i> , <i>S. brevicaulis</i> , <i>S. dimidiatum</i> : 0.8–1.0	[279]
<i>T. scorodonia</i> spp. <i>scorodonia</i>	France	MIC (mg/mL)	<i>S. aureus</i> , <i>S. epidermidis</i> , <i>L. innocua</i> , EAEP289, <i>E. aerogenes</i> , <i>C. jejuni</i> : 12.5, > 50.0, 50.0, 0.2, 1.5, 2.0	[164]
<i>T. stocksianum</i>	Oman	MIC (mg/mL)	<i>S. aureus</i> ATCC 9144: 4.5, <i>B. cereus</i> ATCC 11778: 4.5, <i>K. pneumoniae</i> ATCC 4352: 7.5, <i>P. aeruginosa</i> ATCC 25668: 11.0, <i>E. coli</i> ATCC 10536: 8.5, <i>S. aureus</i> : 5.5; wild strains from normal human flora: <i>S. albus</i> : 5.5, <i>S. epidermidis</i> : 5.0, <i>S. mitis</i> : 5.0, <i>S. sanguis</i> : 4.5, <i>E. coli</i> : 9.5, <i>E. aerogenes</i> : 8.0; wild strains from environment: <i>M. luteus</i> : 5.5, <i>B. subtilis</i> : 5.0, <i>S. typhi</i> : 6.5, <i>P. vulgaris</i> : NA, <i>P. aeruginosa</i> : 10.5	[142]
<i>T. stocksianum</i>	Pakistan	MIC (mg/mL)	<i>S. aureus</i> : 0.95, <i>B. subtilis</i> : 0.85, <i>B. cereus</i> : 0.45, <i>E. faecalis</i> : 1.8, <i>E. coli</i> : 0.45, <i>K. pneumoniae</i> : 3.6, <i>P. aeruginosa</i> : 0.25, <i>S. typhi</i> : 0.5	[283]
<i>T. trifidum</i>	South Africa	MIC (mg/mL)	<i>B. cereus</i> ATCC 11778, <i>E. coli</i> ATCC 8739, <i>K. pneumoniae</i> ATCC 13883, <i>M. catarrhalis</i> ATCC 23246, <i>P. aeruginosa</i> ATCC 27858, <i>S. aureus</i> ATCC 25923: > 8.0; <i>S. pyogenes</i> ATCC 866: 4.0	[24]
<i>T. yemense</i>	Yemen	MIC (mg/mL)	<i>S. aureus</i> : 0.16, <i>B. cereus</i> : 0.16, <i>E. coli</i> : 0.31, <i>P. aeruginosa</i> : 1.25, <i>C. albicans</i> : 1.25, <i>A. niger</i> : 0.31, <i>B. cinerea</i> : 0.31	[287]



► **Table 6** Antitumor activity of essential oils of *Teucrium* taxa.

Species	Origin	Cell type/cytotoxicity	Mechanism of action	Recognized targets	Ref
<i>T. alopecurus</i>	Tunisia	KBM5 human myeloid leukemia	Apoptosis activation by PARP cleavage;	PARP, Capsase-9	[23]
			Inhibition of antiapoptotic signalling;	cFLIP, XIAP, BCL-2, Survivin, c-IAP1/2, Bcl-xL, Mcl-1.	
			reduction of NF- $\kappa$ B p65 subunit translocation;	P65	
			reduction of NF- $\kappa$ B activity by blocking I $\kappa$ B $\alpha$ phosphorylation;	I $\kappa$ B $\alpha$	
			inhibition of reporter gene expression;		
			inhibition of NF- $\kappa$ B-induced cell proliferation;	C-myc, cyclin D1	
			inhibition of NF- $\kappa$ B-induced angiogenesis and metastasis;	ICAM1, VEGF, MMP-9	
			inhibition of NF- $\kappa$ B binding to nucleus		
<i>T. alopecurus</i>	Tunisia	HCT-116, U266, SCC4, Panc28, KBM5, MCF-7	Apoptosis activation by PARP cleavage;	PARP, Capsase-3, -8, -9 (HCT-116)	[22]
			production of ROS;		
			inhibition of STAT3 activity	C-myc, cyclin D1	
<i>T. brevifolium</i>	Greece	CACO-2, COR-L23 and C32. IC <sub>50</sub> ( $\mu$ g/mL): 104, 80.7, >200	NA	NA	[177]
<i>T. flavum</i>	Greece	CACO-2, COR-L23 and C32. IC <sub>50</sub> ( $\mu$ g/mL): >200, 104, >200	NA	NA	[177]
<i>T. montbretii</i> ssp. <i>heliotropiifolium</i>	Greece	CACO-2, COR-L23 and C32. IC <sub>50</sub> ( $\mu$ g/mL): 92.2, 143, 135	NA	NA	[177]
<i>T. polium</i> ssp. <i>capitatum</i>	Greece	CACO-2, COR-L23 and C32. IC <sub>50</sub> ( $\mu$ g/mL): 52.7, 104, 91.2	NA	NA	[177]
<i>T. yemense</i>	Yemen	MCF-7, MDA-MB-231, HT29. IC <sub>50</sub> ( $\mu$ g/mL): 24.4, 59.9, 43.7	NA	NA	[287]

## Antitumor activity

Similar to other kinds of bioactivity, the cytotoxicity of *Teucrium* EOs toward cancer cells (► **Table 6**) was correlated with the presence in a mixture of a significant amount of molecules with a well-established anticancer effect, as in the case of  $\alpha$ -bisabolol and (+)-*epi*-bicyclosesquiphellandrene in the oil extracted from *T. alopecurus* [22, 23], and (*E*)-caryophyllene,  $\alpha$ -humulene,  $\delta$ -cadinene, caryophyllene oxide, and  $\alpha$ -cadinol that are present in relevant concentrations within the leaf EOs of *T. yemense* [287]. In other studies, the *in vitro* cytotoxicity was related, in a rather vague way, with the “presence of terpenes” in the oil [177].

NF- $\kappa$ B is a transcription factor with multiple genetic targets that, in tumor cells, control the expression of several proteins involved in cell proliferation and apoptosis as well as metastasis and angiogenesis [338]; this is because the modulation of its activation has been the focus of much research. Furthermore, it is known that EOs and many of their components can affect the response to TNF-induced inflammation by blocking NF- $\kappa$ B activation and p50/p65 units translocation, as well as by reducing the phosphorylation of I $\kappa$ B $\alpha$ . Such evidence offers a promising perspective in the possible application of EOs as anticancer agents in NF- $\kappa$ B-

overexpressing tumors. Interestingly, the inhibition exerted by *T. alopecurus* EO on the TNF-induced activation of NF- $\kappa$ B was shown not to be cell specific [23]. The EO from this species was shown to be cytotoxic against KBM5 cells with a multiple mechanism including apoptosis protein activation, metastasis, and adhesion protein inhibition, as well as NF- $\kappa$ B/nucleus binding inhibition (► **Table 6**). The EO was also able to potentiate the apoptotic effect of anticancer drugs thalidomide, 5-fluorouracyle, and capecitabine.

## Anti-inflammatory activity

The EOs of a number of *Teucrium* species were evaluated for their anti-inflammatory activity by different methods. The oils of *T. flavum*, *Teucrium montbretii* ssp. *heliotropiifolium*, *T. polium* ssp. *Capitatum*, and *Teucrium brevifolium* were evaluated as anti-inflammatory agents by measuring the inhibition of the lipopolysaccharide-induced nitric oxide release in macrophages RAW 264.7 [177]. All of the spp. were found to be very active, showing IC<sub>50</sub> values ranging from 7.1 to 41.4  $\mu$ g/mL, higher than that of the positive control indomethacin (52.8  $\mu$ g/mL). This relevant result was attributed to the presence in the oil of sesquiterpenes spathu-



lenol,  $\delta$ -cadinene, caryophyllene, caryophyllene oxide,  $\alpha$ -humulene, and torreyol. Further, the EO of Palestinian *Teucrium pruinosum*, obtained by an MU apparatus, was proven to be significantly efficient in inhibiting the activity of COX-1 and COX-2 enzymes with IC<sub>50</sub> values of 0.103 and 0.208  $\mu$ g/mL, respectively, with a COX-2/COX-1 ratio comparable to that of the NSAID drug etodolac [332].

## Toxicity

In order to implement the possible therapeutic applications of EOs in human pathology, it is necessary to collect as much data as possible regarding both acute and chronic toxicity, and also the hypothesis that toxicity effects of the mixtures can be different from those already known for their single components.

A few papers deal with this kind of issue; in particular, the toxicity of *Teucrium pseudochamaepitys* was assessed by a viability test on Hep-2 cells, and the CC<sub>50</sub> value was reported between 100 and 1000  $\mu$ g/mL [333]. Unexpectedly, the authors do not furnish any explanation about the choice of this rather heterodox toxicity model. On the other hand, the toxicity of the *T. stocksianum* EO was evaluated by the more standard procedure of the brine shrimp test that gave a rather interesting LD<sub>50</sub> value of 1200  $\mu$ g/mL [283]. An *in vivo* study on rats concerning some pharmacological effects of *T. polium* gave evidence of hepatotoxicity after intraperitoneal administration of doses from 50 to 200 mg/kg bw of the EO [253].

Careful attention should be paid to the issue of the toxicity of *Teucrium* EOs in view of their possible biomedical applications in humans, both with systemic and topical administration routes. The lack of direct experimental evidence may be overcome by collecting data available for oils from other taxa with a similar composition or by combining available toxicity data for, at least, the major chemical constituents.

## Other Bioactivities Related to Human Pharmacology

The antinociceptive activity was investigated for the EO of *T. polium* from Iran [339] by the writhing test in mice, a visceral pain model that measures the reduction of animal writhings caused by intraperitoneal administration of 0.6% acetic acid. The EO was effective in a dose-dependent manner and showed an ED<sub>50</sub> value of 29.41 mg/kg bw, slightly higher than the positive controls hyoscine (14.17 mg/kg bw) and indomethacin (13.17 mg/kg bw). Furthermore, the antinociceptive effect observed in the ethanolic extract of the whole plant was proven to arise from the residual components of the EO in such an extract, as their complete removal by prolonged heating resulted in the full loss of activity. However, the composition of the EO was not given, so it was not possible to determine unambiguous composition-activity correlations. The same species collected in Turkey [253] was evaluated by the tail flick latency test in rats. After intraperitoneal administration of the EO at 50, 100, and 200 mg/kg bw doses, significant results were obtained at 11 and 21 days and the antinociceptive effect observed was attributed to the presence of high levels of 1,8-cineole and  $\beta$ -pinene in the oil. Unfortunately, the range of ef-

fective doses is the same that induces hepatotoxicity, a circumstance that seriously limits the possibility of clinical application.

The antinociceptive effect of *T. stocksianum* EO from Pakistan [284] was assessed by the rat writhing test. Writhes induced by 0.6% acetic acid were effectively inhibited by the EO administered intraperitoneally (ED<sub>50</sub> of 31.5 mg/kg bw). The authors explained this positive effect with the similarity of the compositions of *T. stocksianum* and *T. polium* EOs. However, the perspective for an effective application in therapy is strongly limited, in our opinion, by the fairly high quantity of sample required, its apolar and water-insoluble nature, and the way of administration indicated.

The inhibition activity on the acetylcholinesterase enzyme was evaluated for the EOs of *T. mascatense* [340] and *T. polium* [211] and the results showed a poor effect in both the cases.

The EO obtained from *T. ramosissimum* showed an interesting antimutagenic activity in the bacterial reverse mutation assay conducted on *S. typhimurium* strains TA98, TA100, and TA1535 [341] with the mutagenic agent sodium azide, aflatoxin B1, benzo[a]pyrene, and 4-nitro-o-phenylenediamine. The efficacy was found to be dose dependent and different for the three targets; in particular, the EO introduced at 25 to 250  $\mu$ g/plate doses reduced the aflatoxin B1- and benzo[a]pyrene-induced mutagenicity by 92 to 97% on the TA100 strain and by 45 to 89% on TA98. Further, the reduction of the sodium azide-induced mutagenicity for the two abovementioned strains was within 40–60%, while the inhibition on the TA1535 strain reached a rate of approximately 74% at the oil dose of 250  $\mu$ g/plate. The authors did not explain the observed results with any specific correlation with the EO composition.

## Other Bioactivities Not Related to Human Pharmacology

### Phytotoxic activity

The effect of the EOs obtained from a set of four species belonging to *Teucrium* taxa, i.e., *arduini*, *maghrebinum*, *polium* ssp. *capitatum* and *montbretii* ssp. *heliotropiifolium*, were investigated for their phytotoxic activity by analyzing the germination and the initial radicle elongation of *Raphanus sativus* L. and *Lepidium sativum* L. [190]. *T. polium* was the only one able to affect the germination of *R. sativus* at a dose of 1.25  $\mu$ g/mL, while *T. arduini* affected the germination of *L. sativum* at 2.5  $\mu$ g/mL. On the other hand, the radicle elongation of *R. sativus* was significantly inhibited by all of the EOs tested. The authors interestingly compared the bioactivities of EOs with their main pure components,  $\beta$ -pinene, limonene, linalool, carvacrol, allo-aromadendrene, caryophyllene, and caryophyllene oxide, and confirmed that the bioactivity of the mixtures could be correlated to the presence of active monoterpenes, such as limonene.

### Antiphytoviral activity

The antiphytoviral activity of the four Croatian endemic species *T. polium*, *T. flavum*, *T. montanum*, and *T. chamaedrys* was assessed toward the cucumber mosaic virus, inoculated to *Chenopodium quinoa* Willd. [165]. All of the EOs were active at various degrees in reducing the number of lesions. This activity was well corre-

lated with the composition of the oils, in particular, with the percentage of  $\beta$ -caryophyllene, which explains the observed results for every species except *T. montanum*, which showed better antiviral activity regardless of having the lowest  $\beta$ -caryophyllene content. The presence of a significant percentage of germacrene D,  $\beta$ -pinene, and limonene can explain the relatively high antiviral activity of *T. montanum*.

### Insecticidal activity

EOs are considered valid, ecofriendly, and human biocompatible alternatives to traditional chemical insecticides and pesticides. The literature reports many examples of this kind of research, also dealing with *Teucrium* taxa.

The larvicidal activity of *T. polium* EO was studied on *Musca domestica* [342]. The oil was proven to be active when mixed with feeding material with and had an LC<sub>50</sub> of 80  $\mu$ g/mL. The mechanism of action was attributed to the inhibition activity toward several digestive enzymes that were measured after dissection and removal of the larvae midguts. Inhibition rates were relevant for proteinase trypsin (61.5%), cathepsin B (79%), and cathepsin L (69%); also, carbohydrase activities were inhibited for  $\alpha$ -amylase (93%),  $\alpha$ -glucosidase (69.5%), and  $\beta$ -glucosidase (42%). The authors did not attempt to furnish any explanation about the activity-composition relationship of the oil.

*T. polium* EO was also tested against the larvae of *Ephestia kuehniella* Z. (Lep.: Pyralidae) [343], a pest commonly found in cereal flour. Its LC<sub>50</sub> was found to be 4.91  $\mu$ L/L, while  $\alpha$ -pinene, which was claimed as the mayor component of the oil even though no analytical data were reported, showed an LC<sub>50</sub> of 10.66  $\mu$ L/mL. This larvicidal effect was associated to the reduction of the digestive enzymes activity, in particular,  $\alpha$ -amylase, triacylglycerol lipase, general protease, serine proteases (trypsin and chymotrypsin-like), carboxypeptidases, and aminopeptidases. Another study about this species concerns the use of its EO as both a mosquitoicidal and repellent agent against *Culex pipiens* L. [252]. The oil was moderately toxic with LC<sub>50</sub> of approximately 25  $\mu$ L/L and showed a better repellency of 292 min of protection at 2  $\mu$ L/cm<sup>2</sup>. The relation of the activity with the composition of this oil remains quite uncertain.

The EO obtained from *Teucrium leuocladum* was effective as a larvicidal agent against *C. pipiens*, *M. domestica*, and *Ceratitis capitata* with LC<sub>50</sub> values ranging from 16 to 24  $\mu$ g/mL [201]. Such an activity was related to the alcohols and monoterpenes compounds contained in the oil. The EO obtained from same species was investigated for its potential as a fumigant insecticide and antifeedant agent against *Tribolium castaneum* Herbst, a pest that is considered a dangerous threat for post-harvested cereals [236]. The oil was effective in both of the modes of use in a dose- and time-dependent fashion. The optimal fumigant toxicity versus the adult insects was reached after 72 min of exposure with a 20  $\mu$ L/L solution, with a mortality rate of 98%. Further, a concentration of 14.13  $\mu$ L/L was determined as the optimum value for obtaining a 95% Feeding Deferens Index with 92% desirability. No hypothesis was made about the possible mechanisms of action or the components mainly responsible for the reported insecticidal activity.

A limited fumigant toxicity (LC<sub>50</sub> of 37.9  $\mu$ L/L) against the adults of *Sitophilus oryzae* was observed for the EO of *Teucrium capitatum* from Greece [267]; this was attributed to the circumstance of the presence of sesquiterpenes as the principal constituents of the oil.

*T. polium* subsp. *capitatum* from Iran furnished an EO that was assessed as a fumigant and repellent agent against the stored product pests *Tribolium castaneum* and *Callosobruchus maculatus* [269]. The repellent activity was moderate towards both of the targets with a concentration-dependent repellency index ranging from about 20 to 60% at doses of 0.2 to 3  $\mu$ L/mL of the oil in acetone. The fumigant toxicity was also limited, with LC<sub>50</sub> values of 360 and 149  $\mu$ L/L for *T. castaneum* and *C. maculatus*, respectively. It is the opinion of the authors that the presence of  $\alpha$ -canidol as the main component (46.2%), which is known to be active against several insect species, and a high percentage (25.9%) of caryophyllene oxide, possessing insecticidal activity against *T. castaneum*, could explain the activity found.

The EO of *Teucrium quadrifarium* collected in India was evaluated as a pesticide and insect growth regulator against *Spilarctia obliqua* [290]. Topical application of the oil on 3rd instar larvae determined an increase in larval and pupal periods, augmented both larval mortality and adult deformity, and caused a decrease in larval and pupal weight as well as in adult emergence. The composition of the oil is not given and the authors generically connected the observed findings with the high lipophilic character of the EO. The EO extracted from the same species growing in China showed a strong insecticidal activity against *Liposcelis bostrychophila* [130]. The oil was effective both as a contact toxic agent, with an LC<sub>50</sub> value of 95.1  $\mu$ g/cm<sup>2</sup>, and as a fumigant agent, with an LC<sub>50</sub> of 0.22 mg/L. Even though this paper reports the assessment of the oil composition, no clear connection was found concerning this data and the observed bioactivity.

The EO produced by the species *T. montanum* subsp. *jailae* collected in Slovakia was included in an investigation for the insecticidal activity against the insects *M. domestica* L., *Culex quinquefasciatus*, and *Spodoptera littoralis* [209]. The insecticidal activity toward *M. domestica* was poor, while the activity toward the other targets was relevant, with LD<sub>50</sub> values of 56.7  $\mu$ g per larva for *S. littoralis* and 180.5  $\mu$ g/mL for *C. quinquefasciatus*. The authors admitted the inherent difficulty in relating the biological activity with the EO composition even though the presence of relatively high amounts of (*E*)-caryophyllene and germacrene D, both compounds active toward several pests, may be considered at least an important contribution to the overall action of the mixture.

The acaricidal activity of the EO obtained from an Iranian specimen of *T. polium* was tested in the leaf dipping and fumigant bioassays against the spotted spider mite *Tetranychus urticae* [344]. LC<sub>50</sub> values obtained in the two tests were 1.784% and 5.395  $\mu$ L/L respectively.

### Antiprotozoal activity

The EO obtained from a sample of *T. polium* collected in Tunisia was an effective antileishmanial agent against the species *Leishmania major* (LCO3) and *Leishmania infantum* (LV20) directly isolated from infected patients [256]. The IC<sub>50</sub> values were 0.15 and 0.09  $\mu$ g/mL, respectively. The possible toxicity was tested on the

RAW 264.7 macrophage cell line that showed an LC<sub>50</sub> of 3.64 µg/mL. The same activity was tested for the main component (56%) of the oil, carvacrol, and for other significantly represented compounds, such as β-caryophyllene and geraniol, all of them showing remarkable activity with IC<sub>50</sub> values < 10 µg/mL.

An interesting activity was disclosed for the EO of *T. ramosissimum* (Tunisia) that was active against the *Acanthamoeba*, an infective agent responsible for a rare human keratitis that lacks definitive successful pharmacological approaches [277]. The oil showed a remarkable IC<sub>50</sub> value of 25.7 µg/mL. The authors speculated that the presence of a relevant amount of sesquiterpenes in the oil may explain the observed activity and supported this claim with literature data concerning active pure sesquiterpene compounds that, however, were not present in their sample.

## Conclusions

In this review, a complete recognition of the volatile secondary metabolites occurring in the *Teucrium* genus has been carried out. Some relevant studies on several biological activities have been reported that include antioxidant, anti-inflammatory, antibacterial, antifungal, antitumor, and antidiabetic, justifying the widespread implementation reported in the ethnomedicine of several countries.

## Contributors' Statement

Conception and design of the work: M. Bruno, S. Rosselli, G. Fontana, R. Gagliano Candela. Data collection: M. Bruno, S. Rosselli, R. Gagliano Candela, G. Fontana. Analysis and interpretation of the data: M. Bruno, S. Rosselli, G. Fontana, R. Gagliano Candela. Drafting the manuscript: M. Bruno, S. Rosselli, G. Fontana. Critical revision of the manuscript: M. Bruno, S. Rosselli, G. Fontana, R. Gagliano Candela.

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## Conflict of Interest

The authors declare that they have no conflict of interest.

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