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INSIGHT INTO THE CHEMOTAXONOMY OF *THYMUS* SPECIES IN SOUTHEASTERN EUROPE

Gjoshe Stefkov, Svetlana Kulevanova

Faculty of Pharmacy, Ss. Cyril and Methodius University in Skopje, North Macedonia

e-mail: gstefkov@yahoo.com

Thymus L. is one of the most important and polymorphic genera in the *Lamiaceae* family, comprising approximately 350 species distributed across Europe, Asia, North and East Africa, and southern Greenland, with the majority found in the Mediterranean region. *Thymus* plants and their essential oils are well-regarded in traditional medicine and culinary practices in Southeastern Europe. The essential oils of *Thymus* species exhibit high chemical variability due to various intrinsic and extrinsic factors, including genetic variations and environmental influences. Despite broad scientific interest in the taxonomy, chemotypes, and biological activities of its secondary metabolites, there is limited information available about this genus in Southeastern Europe. The aim of this review is to present the essential oil composition of versatile *Thymus* species from Southeastern Europe and to compile knowledge on the occurrence, essential oil composition, and biological activities of *Thymus* species in this region (including Croatia, Bosnia and Herzegovina, Serbia, Montenegro, Bulgaria, Romania, Kosovo, Albania, North Macedonia, Hungary, Moldova, Turkey, and Greece). This is crucial for enhancing our understanding of their chemotaxonomy. In this context, this review seeks to provide an in-depth insight into the chemotype variations present among 263 different *Thymus* samples from Southeastern Europe, highlighting their major essential oil constituents and paving the way for further investigation into the biological properties of *Thymus* L. and its essential oils.

Key words: Wild Thyme; Easter Europe; essential oil composition; chemotypes; multivariate statistical analysis

INTRODUCTION

Thyme (*Thymus*) is a genus within the *Lamiaceae* family, comprising roughly 350 species of fragrant perennial herbaceous plants and subshrubs native to Europe, North Africa, and Asia, with a significant presence in Southeastern Europe [1]. According to Karl Ronniger, 417 specific names for these species are valid, while Jalas estimates there are 150 species [1, 2]. Approximately 110 species thrive in the Mediterranean region and are widespread. Some species have evergreen leaves that are grouped in opposing pairs, are tiny, oval, whole, and often scented, with stems that are slender or even wiry. Thyme flowers appear in dense terminal heads with an irregular calyx and three lobes on the top lip that can be yellow, white, or purple [1].

The Balkan Peninsula boasts a wealth of *Thymus* plant habitats. In Serbia, 31 *Thymus* species with over 60 varieties are recorded, thriving mainly in meadows, pastures, and dry, sunny, rocky areas on both limestone and serpentine [3]. Bosnia and Herzegovina also feature several *Thymus* species [4], including the endemic *T. jankae* and *T. brateoscus* [5]. The entire *T. teucrioides* section is unique to the Balkan Peninsula, with prominent species such as *T. teucrioides*, *T. hartvigii*, and *T. leucospermus* [6]. Additionally, several species from the *Hyphodromi* section, including *T. atticus*, *T. dolopicus*, *T. leucotrichus*, *T. parnassicus*, and *T. striatus*, are widespread in this region. Bulgarian flora includes 21 species from the *Hyphodromi* and *Serpyllum* sections, six of which are endemic to the Balkan Peninsula [7, 8].

This genus presents significant complexity in taxonomy and systematics, exhibiting notable polymorphism in both morphological traits and essential oil composition [9]. Chemotypes may also vary across several species. *Thymus* plants and their essential oils are well-regarded in traditional medicine and culinary practices, often used to treat respiratory conditions, including infections, through various forms such as tinctures, tisanes, salves, syrups, or steam inhalation [10]. They offer a broad range of pharmacological properties, including antimicrobial, gastrointestinal, and nervous system benefits, as well as anti-inflammatory, antioxidative, spasmolytic, secretolytic, and tonifying effects. Most of these pharmacological effects are attributed to the highly complex composition of the essential oil [10].

Thymus species are distinguished by their essential oils, which are complex mixtures of monoterpenes, sesquiterpenes, and other volatile compounds. The primary components of *Thymus* essential oils are monoterpenes, especially aromatic and oxygenated monoterpenes [1]. Major constituents—thymol, carvacrol, linalool, and geraniol—vary considerably between species and within species across different geographical regions. The value of thyme oil is largely influenced by its phenol content, particularly thymol, making it essential to measure these components accurately, as thymol extraction is relatively common. The essential oil of common thyme (*T. vulgaris*) contains 20–55 % thymo*l*. Thymol, known for its antiseptic properties, is the active ingredient in many well-known mouthwashes and was historically used to treat bandages before the development of modern antibiotics [10].

It is well known that secondary metabolites are not directly involved in plant growth and development but serve as attractants, repellents, toxins, and antibiotics, or as precursors to such bioactive compounds [11]. The concept of secondary metabolism, which differentiates these processes from primary metabolism, emerged in the late 19th century [12]. Terpenoid emissions facilitate plant communication, playing crucial roles in interactions with insects, pathogens, and other plants [13, 14]. They attract pollinators and predators of herbivores, protect against photooxidative stress, mediate thermotolerance, and provide direct defense against microbes and insects [15, 16]. The polyphenolic pattern has been found to be a useful additional chemotaxonomic tool for classification purposes and determining the locality of origin. Within the genus *Thymus*, the influence of environmental conditions on the pattern of essential oil components and flavonoids has been investigated [17–29]. Abiotic environmental factors (temperature, moisture, soil and climatic conditions, elevation, etc.), as well as biotic effects (human disturbance, herbivores, etc.), have been shown to influence both the essential oil and polyphenol production of *Thymus* species and the chemical composition of coenopopulations over time [18, 30, 31]. It has been established that phenolic essential oil compounds (thymol, carvacrol) and polyphenols (e.g., flavonoids) are favored in warmer and drier climatic zones, while other non-phenolic substances typically accumulate in higher quantities in cooler and more humid areas.

Chemotaxonomy can provide valuable insights into the diversity and evolutionary relationships within the genus *Thymus* in Southeastern Europe. This study investigates the essential oil composition of various *Thymus* species, aiming to contribute to the elucidation of their taxonomic status and phylogenetic relationships.

Essential oils constituents of Thymus species from Southeastern Europe

The essential oils of *Thymus* species exhibit high chemical variability due to various intrinsic (genetic variation) and extrinsic (ecological and environmental) factors [32]. Additionally, the chemical composition of these essential oils depends on several parameters, including the season in which the aromatic plants are collected, the dehydration procedure, the storage conditions prior to essential oil extraction, the method used for essential oil isolation, and the analysis conditions [33].

Table 1 compiles literature data on the essential oil composition of *Thymus* species from Southeastern Europe, covering the following countries: Croatia, Bosnia and Herzegovina, Serbia, Montenegro, Bulgaria, Romania, Kosovo, Albania, North Macedonia, and Greece. Among all recorded *Thymus* species, the most abundant chemotypes are the aromatic thymol, carvacrol, and *p*-cymene types, followed by linalool and geraniol chemotypes (Figure 1). The highest levels of thymol (92.0 %) and carvacrol (93.4 %) are found in *T. leucospermus* from Greece [34]. The second most abundant constituents in essential oils from phenolic chemotypes are *p*-cymene and γ-terpinene, reflecting the fact that these monoterpenes, both aromatic and non-aromatic, are linked through their biosynthetic pathways [32]. Notably, *p*-cymene chemotypes vary significantly between species: *T. teucrioides* spp. *alpinus* and *T. teucrioides* spp. *teucrioides* are rich in borneol, whereas *T. teucri-*

oides spp. *candilicus* has γ-terpinene as its second most abundant constituent [35].

Thymus species rich in linalool and geraniol are found in the southern part of the Balkan Peninsula, primarily in Macedonia, where eight populations belong to *T. jankae* [25, 36]. Additionally, species such as *T. hartvigii* ssp. *macrocalyx* from Greece have the highest linalool content (89.2 %) [35]. Geraniol chemotypes are distributed across the Balkan Peninsula, though their geraniol content is generally low compared to other *Thymus* chemotypes [32]. The highest geraniol levels have been recorded in Greek *T. longicaulis* (56.8 %) [37] and Romanian *T. glabrescens* (55.5 %) [38].

In Albania, *T. capitatus* was identified as a carvacrol chemotype, with carvacrol content ranging from 57.8 % to 78.0 %, and *p*-cymene and γ-terpinene as minor constituents [39]. *T. vulgaris* samples were found to be of the thymol chemotype, with thymol content ranging from 32.3 % to 53.0 %, and *p*-cymene and γ-terpinene as minor constituents [40]. In another study, samples of *T. vulgaris*, *T. capitatus*, and *T. serpyllum* from various areas of Southeastern Albania (Pogradec, Korca, Librazhd, and Kolonja) showed *p*-cymene, γ-terpinene, thymol, and carvacrol as main constituents. *P*-Cymene was the predominant constituent in *T. vulgaris*. Carvacrol was found in higher percentages in *T. capitatus* (29.1 %) and *T. serpyllum*, while thymol was more abundant in *T. vulgaris* and *T. serpyllum*. The combined content of thymol and carvacrol was highest in *T. serpyllum*.

In all analyzed essential oils from *Thymus* samples in Albania, *p*-cymene, γ-terpinene, thymol, and carvacrol were identified as primary constituents. *P*-Cymene (40.1 %) was the main constituent in *T. vulgaris* samples. Carvacrol was found in higher percentages in *T. capitatus* (29.2 %) and *T. serpyllum* (18.4 %). Thymol was more prevalent in *T. vulgaris* (28.2 %) and *T. serpyllum* (17.1 %). The total content of thymol and carvacrol was highest in *T. serpyllum* samples (45.3 %) [1].

Analysis of the essential oil composition from *T. sibthorpii* Bentham collected in northern Greece and *T. striatus* Vahl. collected in southern Albania revealed α-terpinyl acetate (68.9 %), α-terpineol (11.0 %), and thymol (7.9 %) as the major compounds in *T. sibthorpii*, while thymol (53.6 %), *p*-cymene (18.6 %), and γ-terpinene (9.4 %) were the major compounds in *T. striatus* [41].

Thymus holosericeus Čelak. is a taxonomically isolated and endangered local endemic thyme species, geographically limited to four Ionian Islands in western Greece. The essential oil composition of this species is dominated by linalool, carvacrol, geraniol, thymol, and *p*-cymene [42].

Kakouri et al. investigated the phytochemical composition of volatile compounds in five *Thymus* species (*T. parnassicus*, *T. leucotrichus*, *T. atticus*, *T. holosericeus*, *T. laconicus*), native to Greece. These species were found to be rich in varying levels of α-cadinol, β-caryophyllene, elemol, eudesmol, β-bisabolene, linalool, geraniol, carvacrol, and *p*-cymene [43].

T. sibthorpii and *T. striatus* differed in essential oil yield—approximately 1.33 % and 2.12 %, respectively. The essential oil of *T. sibthorpii* was mainly composed of esters, with α-terpinyl acetate (68.9 %) being the dominant compound. The fraction of oxygenated monoterpenes was 24.4 %, with the main components being α-terpineol (11.0 %) and thymol (7.9 %). The fractions of monoterpene hydrocarbons and sesquiterpene components were very low. Previous studies show that *T. sibthorpii* Benth., growing wild in northern Greece, appears to occur in two chemotypes: one geraniol-thymol-*p*-cymene type and one geraniol-linalool-citronellyl acetate type [44], while the essential oil from Turkey was found to be rich in thymol (34.8 %) [45]. Comparative analyses of the winter and summer leaf essential oils of *T. sibthorpii* from northern Greece revealed that the winter leaves have a higher essential oil yield (1.20 %, i.e., 1.20 ml/100 g leaf, dry weight) compared to the summer leaves (1.11 %). The principal components of both types of oils were *p*-cymene, linalool, borneol, terpinen-4-ol, thymol, and β-caryophyllene, with linalool (42.4 %) being the dominant compound in winter leaves and *p*-cymene (25.0 %) being the dominant compound in summer leaves, followed by linalool (19.1 %) [46]. It can be suggested that different chemotypes exist in these species, and results indicate the presence of a new chemotype in northern Greece: α-terpinyl acetate - α-terpineol. Finally, the essential oil of *T. striatus* was mainly composed of monoterpene oxygenated compounds, with thymol (53.6 %) being the dominant compound [41].

A study from Turkey analyzed essential oils from 91 samples representing 34 out of 64 *Thymus* taxa found in Turkey. According to Stahl-Biskup's classification of *Thymus* oils into three terpene groups [47], the majority of the analyzed species belong to the terpene group in which the following terpenes are found in notably high concentrations: thymol, carvacrol, linalool, linalyl acetate, borneol, *p*-cymene, 1,8-cineole, γ-terpinene, and camphor. In fact, thymol is the main compound in most *Thymus* species growing in Turkey. Among them, 20 species (59 %) have thymol content below the accepted limits. Two varieties of *T. longicaulis* subsp. *chaubardii* are the richest in thymol: var. *alterrantus* (70.0 %) and var. *chaubardii* (67.0 %). The highest carvacrol content was found in the oil of *T. eigii* (65.0 %).

The second group consists of species with high concentrations of geranyl acetate, α-terpineol, α-terpinyl acetate, dihydrocarvone, citronellol, geranyl butyrate, hedicaryol, and carvone [47]. In this group, α-terpineol and α-terpinyl acetate are the main components of the essential oil from *T. praecox* ssp. *skorpilli* var. *skorpilli*. α-Terpinyl acetate is the main compound in the oil of *T. longicaulis* ssp. *longicaulis* var. *longicaulis*.

The third group is highly diverse and consists of minor components of *Thymus* essential oils, such as terpinen-4-ol, β-caryophyllene, geraniol, bornyl acetate, trans-sabinene hydrate, α-humulene, caryophyllene epoxide, β-bisabolene, 1-octen-3-ol, neryl acetate, nerolidol, carvacrol methyl ester, thymol methyl ester, germacrene D, and β-terpineol. Although these components are regarded as minor, geraniol was found to be the major compound in the oils of *T. longicaulis* ssp. *longicaulis* var. *longicaulis* and *T. thracicus* var. *longidens*, while β-caryophyllene and terpinen-4-ol were the major components in the oil of *T. striatus* var. *interruptus* [2].

A study of the essential oil composition of five *Thymus* species, belonging to Sect. *Hyphodromi* (A. Kerner) Halácsy – *T. atticus* Čelak., *T. leucotrichus* Halácsy, *T. striatus* Vahl, *T. zygioides* Griseb., and *T. perinicus* (Velen.) Jalas from Bulgaria, revealed high amounts of sesquiterpenoids (57.7 %, 78.9 %, and 79.7 %, respectively), with β-caryophyllene and caryophyllene oxide as the main constituents in *T. atticus*, *T. leucotrichus*, and *T. striatus*. Aromatic compounds (61.2 %) were the most abundant group in *T. zygioides* essential oil, with thymol (51.2 %) as the principal component. The essential oil from the endemic species *T. perinicus* contained almost equal amounts of monoterpenoids (37.8 %) and aromatic compounds (36.0 %), with borneol (17.9 %) and thymol (20.9 %) as the major components. The obtained results revealed the existence of new chemotypes of *T. atticus* (caryophyllene oxide/β-caryophyllene), *T. leucotrichus* (β-caryophyllene/elemol/germacrene D), and *T. striatus* (β-caryophyllene/germacrene D/caryophyllene oxide). The essential oil content of the endemic *T. perinicus* is reported for the first time [48].

In a recent study, the analysis of the essential oils of 10 *Thymus* species (*T. moesiacus*, *T. jankae*, *T. vandasii*, *T. longicaulis*, *T. sibthorpii*, *T. pulegioides*, *T. glabrescens*, *T. callieri*, *T. pannonicus*, *T. thracicus*), belonging to Sect. *Serpyllum*, led to the identification of 118 compounds, with dominant linalool, terpinyl acetate, thymol, carvacrol, germacrene D, and β-myrcene [49]. On the other hand, in the essential oil composition of the Balkan endemic *Thymus longedentatus* (Degen & Urum.) Ronniger, citral isomers, neral and geranial, were the principal ones [50].

The studies on the essential oil composition of *T. atticus* from Turkey and Greece revealed the existence of five chemotypes: thymol/p-cymene, terpinen-4-ol/caryophyllene oxide [2], E-nerolidol/caryophyllene/germacrene D/myrcene [51], 1,8-cineole/myrcene/caryophyllene, and camphene/caryophyllene oxide/α-pinene [51]. There is only one report on the essential oil content of *T. leucotrichus* from two Greek populations so far [52]. β-Caryophyllene was the principal component in both populations, while the other two main compounds were different: 1,8-cineole/borneol and linalool/α-phellandrene.

The investigations on the volatile constituents of *T. striatus* and its varieties from the Balkan region (Turkey, Greece, Croatia, and Bosnia and Herzegovina) have shown a high level of polymorphism with 7 chemotypes: thymol; thymol/1,8-cineole/p-cymene; thymol/β-caryophyllene; β-caryophyllene; terpinen-4-ol; γ-terpinene; 6α-hydroxygermacra-1(10),4-diene; β-cubebene/β-caryophyllene; and caryophyllene oxide/α-elemol/α-cadinol [2, 45, 53–55]. Additionally, Kulevanova et al. [21] reported another chemotype from *T. pseudoatticus* (syn. of *T. striatus*) – borneol/caryophyllene/β-cubebene. Similarly, collections of *T. zygioides* var. *lycaonicus* from different localities in Turkey [2, 56] and Greece [57] displayed significant variability in the essential oil composition, resulting in 7 different chemotypes: geraniol; carvacrol; α-terpinyl acetate; thymol; thymol/geraniol; limonene/cis-linalool oxide; and p-cymene/thymol/γ-terpinene. Analysis of the essential oil of *T. zygioides* var. *lycaonicus* revealed an abundance of p-cymene (19.4 %), thymol (19.5 %), and γ-terpinene (17.2 %), three terpenes closely connected by biogenetic processes, with p-cymene and γ-terpinene serving as precursors of thymol in the biochemical pathway [57]. Furthermore, analysis of the essential oil of *T. zygioides* var. *lycaonicus* growing wild in Turkey revealed that it contains mainly monoterpenes and oxygenated monoterpenoids, with limonene (24.11 %) and cis-linalool oxide (22.91 %) as major constituents, and eucalyptol (8.65 %), 3-octanol (7.04 %), nerol (4.47 %), geranyl acetate (3.19 %), carvacrol (2.74 %), linalyl propanoate (2.95 %), and sabinene (2.23 %) as minor constituents. Thus, the essential oil of *T. zygioides* from Turkey belonged to the limonene and cis-linalool oxide-rich type [56].

In a Moldavian study, essential oils of five Moldavian *Thymus* species (*T. vulgaris, T.* × *citriodorus*, *T. calcareus*) and cultivars (*T. vulgaris* 'Faustini', *T. citriodorus* 'Aureus') were examined. The main compounds were: thymol in *T. vulgaris* and *T. calcareus* (55.44 % and 55.45 %, respectively), lavandulol in *T.* × *citriodorus* (54.27 %), and geraniol in *T. citriodorus* 'Aureus' and *T. vulgaris* 'Faustini' (60.31 % and 31.45 %, respectively) [58].

Numerous studies have been conducted on *Thymus* species in North Macedonia, their secondary metabolites, and especially essential oil yield, composition, and variability. The essential oil of several taxa of the genus *Thymus* L. (*T. tosevii* Velen. ssp. *tosevii* – var. *tosevii*, var. *degenii* and var. *longifrons*, and *T. tosevii* Velen. ssp. *substriatus*, *T. alsarensis*, *T. macedonicus*, *T. moesiacus*, *T. jankae* – var. *jankae*, var. *pantotrichus* and var. *patentipilus*, *T. longidens* Velen. var. *lanicaulis* Ronn., and var. *dassareticus* Ronn., *T. rohlenae*, *T. balcanus*, *T. albanus*, *T. ciliatopubescens*, *T. pseudoatticus*) from North Macedonia and the environmental influences were studied. In most of the samples, thymol, carvacrol, linalool, α-terpineol, terpinyl acetate, p-cymene, and γ-terpinene were found to be the prevalent components. In the remaining samples, geraniol, linalool, and sabinene hydrate were present in higher amounts [19–29, 59].

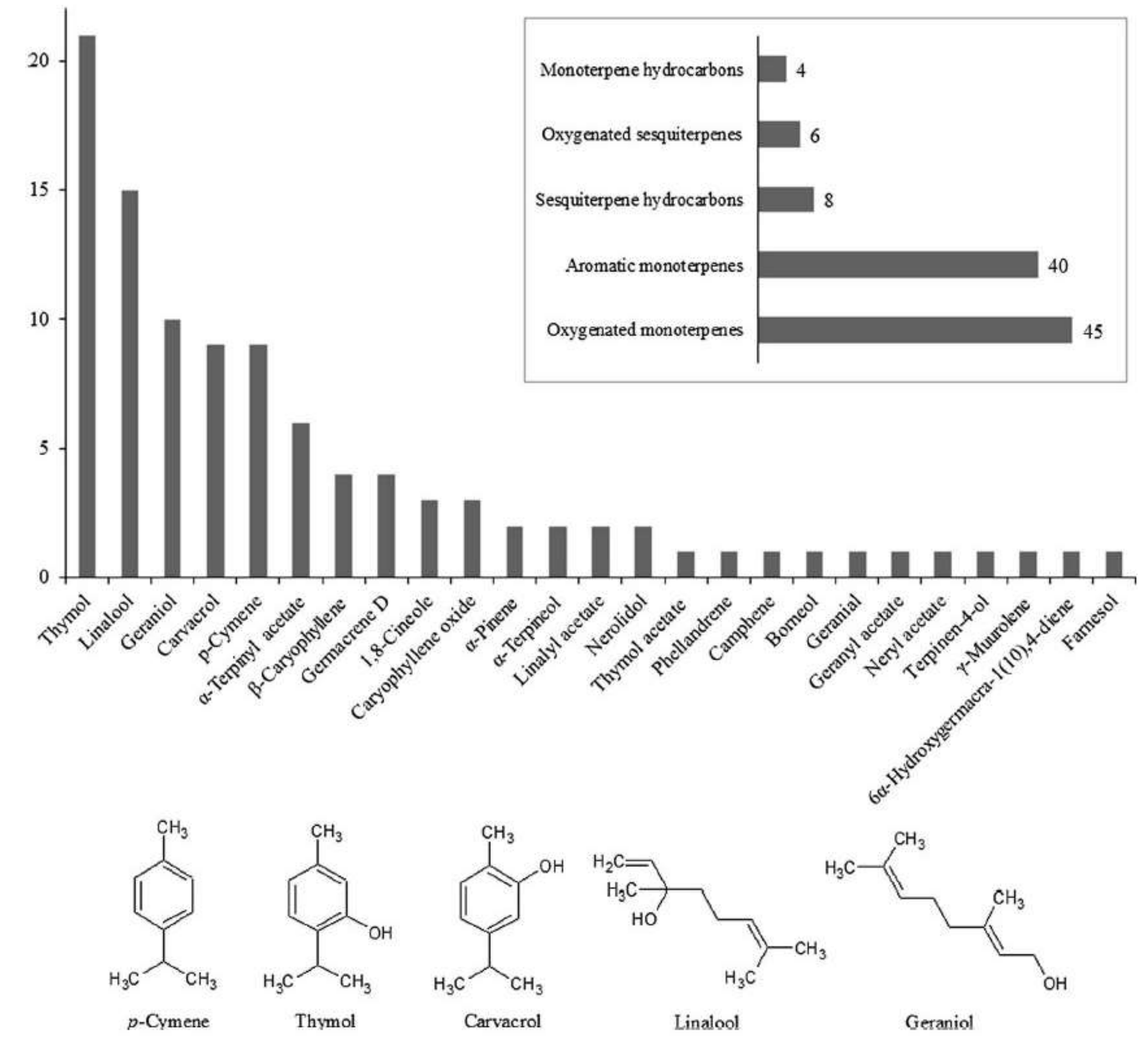

Figure 1. The most abundant essential oil constituents of genus *Thymus* from Southeastern Europe (modified from [32])

γ-Terpinene, thymol, β-caryophyllene, geraniol, and linalyl acetate were found to be the most abundant components in the essential oil of *T. glabrescens* Willd., *T. praecox* Opiz subsp. *jankae* (Čelak) Jalas (from two localities), and *T. pulegioides* from Serbia [60].

Sesquiterpenes are generally present in very low quantities in *Thymus* species [32], but several sesquiterpenoid chemotypes are found in Southeastern Europe. β-Caryophyllene, germacrene D, and caryophyllene oxide chemotypes are present in the southern parts with a Mediterranean climate, as well as *T. comosus* in Romania, which contains 54.8 % caryophyllene oxide as a major constituent [38].

In terms of *Thymus* essential oil composition, widespread chemical polymorphism, not limited only to *comosus* constituents, is evident (Table 1). Some species occur with only a few chemotypes, such as *T. pulegoides*, *T. vulgaris*, and *T. mastichina*, while others have more, or even an uncertain number of chemotypes [32]. According to the presented results, *T. tosevii* has the highest polymorphism, with 12 different chemotypes, followed by *T. longicaulis*, *T. glabrescens*, and *T. moesiacus*, with eight, six, and six chemotypes, respectively. The differences in chemical composition may be due to different geographical origins, but also to various environmental factors, different chemotypes, and the nutritional status of the plants [56].

The variability in essential oil composition among *Thymus* species has significant ecological and evolutionary implications. The presence of specific chemotypes in certain regions suggests adaptive strategies to local environmental conditions, such as climate, soil type, and biotic interactions.

Multivariate analysis in chemotaxonomy

The major components of the essential oils were used to determine the chemical relationships between 263 different *Thymus* spp. essential oil samples through multivariate statistical techniques, including Principal Component Analysis (PCA), Hierarchical Cluster Analysis (HCA), and Partial Least Squares Discriminant Analysis (PLS-DA), using SIMCA v14.1 (Umetrics, Sweden). This approach allowed for the identification of patterns within the *Thymus* genus in Southeastern Europe. PCA was employed to reduce the data's dimensionality, highlighting the main sources of variation in essential oil composition. Cluster Analysis was used to group *Thymus* species based on their chemical profiles, providing insights into their taxonomic relationships.

Table 1. Essential oils' main components of *Thymus* taxa from Southeastern Europe and hierarchical cluster analysis (HCA) groups' assemblage

Code	Thymus taxa	Country	Main compound	Component 2	Component 3	HCA group	Ref.
T1	*T. citriodorus*	Moldavia	Lavandulol	Geranial	Neral	3	[58]
T2	*T. citriodorus “Aureus”*	Moldavia	Geraniol	Neral	*p*-Cymene	4	
T3	*T. marschallianus*	Bosnia and Herzegovina	Thymol	*p*-Cymene	Carvacrol	6	[53]
T4	*T. teucrioides* ssp. *candilicus*	Greece	*p*-Cymene	γ-Terpinene	Thymol	7	[35]
T5	*T. teucrioides* ssp. *candilicus*	Greece	*p*-Cymene	γ-Terpinene	Borneol	7	
T6	*T. teucrioides* ssp. *candilicus*	Greece	*p*-Cymene	γ-Terpinene	Thymol	7	
T7	*T. teucrioides* ssp. *candilicus*	Greece	*p*-Cymene	γ-Terpinene	Borneol	7	
T8	*T. teucrioides* ssp. *candilicus*	Greece	*p*-Cymene	Thymol	γ-Terpinene	7	
T9	*T. teucrioides* ssp. *candilicus*	Greece	*p*-Cymene	Borneol	Caryophyllene oxide	7	
T10	*T. teucrioides* ssp. *candilicus*	Greece	Thymol	*p*-Cymene	γ-Terpinene	6	
T11	*T. teucrioides* ssp. *teucrioides*	Greece	*p*-Cymene	Borneol	β-Caryophyllene	7	
T12	*T. teucrioides* ssp. *teucrioides*	Greece	*p*-Cymene	Linalool	Carvacrol methyl ether	7	
T13	*T. teucrioides* ssp. *teucrioides*	Greece	*p*-Cymene	Borneol	Caryophyllene oxide	7	

Table 1 continuous

T14	*T. teucrioides* ssp. *teucrioides*	Greece	*p*-Cymene	Borneol	Caryophyllene oxide	7	[35]
T15	*T. tosevii* ssp. *substriatus*	Macedonia	Thymol	Carvacrol	Linalool	7	[36]
T16	*T. tosevii* ssp. *substriatus*	Macedonia	Thymol	Linalool	γ-Terpinene	6	
T17	*T. tosevii* ssp. *substriatus*	Macedonia	Thymol	Linalool	*p*-Cymene	7	
T18	*T. tosevii* ssp. *tosevii*	Macedonia	Carvacrol	Thymol	Terpinyl acetate	7	[61]
T19	*T. tosevii* ssp. *tosevii*	Macedonia	Carvacrol	*p*-Cymene	Linalool	7	
T20	*T. tosevii* ssp. *tosevii*	Macedonia	Carvacrol	Linalool	Geraniol	7	[36]
T21	*T. tosevii* ssp. *tosevii*	Macedonia	Geraniol	Terpinyl acetate	Sabinene hy-drate	4	[61]
T22	*T. tosevii* ssp. *tosevii*	Macedonia	Geraniol	Thymol	Geranyl acetate	4	
T23	*T. tosevii* ssp. *tosevii*	Macedonia	Linalool	Terpinyl acetate	Geraniol	3	
T24	*T. tosevii* ssp. *tosevii*	Macedonia	Thymol	Linalool	γ-Terpinene	6	
T25	*T. tosevii* ssp. *tosevii*	Macedonia	Thymol	Linalool	*p*-Cymene	7	
T26	*T. tosevii* ssp. *tosevii*	Macedonia	Thymol	Carvacrol	*p*-Cymene	7	
T27	*T. tosevii* ssp. *tosevii*	Macedonia	α-Terpinyl ace-tate	Thymol	Linalool	4	
T28	*T. tosevii* ssp. *tosevii*	Macedonia	α-Terpinyl ace-tate	Linalool	Carvacrol	4	
T29	*T. transcaucasicus*	Turkey	Germacrene D	β-Caryophyllene	ND	5	[2]
T30	*T. zygioides* var. *lycaonicus*	Greece	*p*-Cymene	Thymol	γ-Terpinene	7	[51]
T31	*T. zygioides* var. *lycaonicus*	Greece	Thymol	*p*-Cymene	γ-Terpinene	6	[57]
T32	*T. zygioides* var. *lycaonicus*	Turkey	Thymol	*p*-Cymene	β-Bisabolene	6	[2]
T33	*T. zygioides* var. *lycaonicus*	Turkey	Thymol	ND	ND	7	
T34	*T. zygioides* var. *lycaonicus*	Turkey	Carvacrol	ND	ND	7	
T35	*T. zygioides* var. *lycaonicus*	Turkey	Geraniol	ND	ND	4	
T36	*T. albanus* ssp. *albanus*	Macedonia	*(E)*-Nerolidol	β-Caryophyllene	Geraniol	5	[23]
T37	*T. albanus* ssp. *albanus*	Macedonia	*(E)*-Nerolidol	β-Caryophyllene	Geranyl acetate	5	
T38	*T. alsarensis*	Macedonia	Carvacrol	Thymol	*p*-Cymene	7	[24]
T39	*T. alsarensis*	Macedonia	Linalool	Carvacrol	Thymol	3	[36]
T40	*T. argaeus*	Turkey	Linalyl acetate	Linalool	ND	4	[2]
T41	*T. atticus*	Greece	*(E)*-Nerolidol	β-Caryophyllene	Germacrene D	5	[51]
T42	*T. atticus*	Greece	1,8-Cineole	Myrcene	β-Caryophyllene	4	
T43	*T. atticus*	Greece	Camphene	α-Pinene	Caryophyllene oxide	7	
T44	*T. atticus*	Turkey	Caryophyllene oxide	Terpinen-4-ol	ND	7	[2]
T45	*T. atticus*	Turkey	Thymol	*p*-Cymene	ND	6	
T46	*T. atticus*	Bulgaria	Caryophyllene oxide	β-Caryophyllene	Germacrene D	7	[48]
T47	*T. aureopunctatus*	Bosnia and Herzegovina	Thymol	Thymol methyl ether	*p*-Cymene	7	[62]
T48	*T. balcanus*	Bosnia and Herzegovina	Linalyl acetate	Linalool	α-Terpineol	4	[63]
T49	*T. balcanus*	Macedonia	β-Caryophyllene	β-Pinene	Linalool	2	[21]
T50	*T. balcanus*	Romania	α-Terpineol	Linalool	Linalyl acetate	4	[64]

Table 1 continuous

T51	*T. balcanus*	Romania	Germacrene D	β-Caryophyllene	Thymol	5	[65]
T52	*T. balcanus*	Romania	Thymol	Linalool	Germacrene D	7	
T53	*T. balcanus*	Romania	Thymol	Linalool	Linalyl acetate	7	
T54	*T. balcanus*	Romania	Thymol	Carvacrol	β-Caryophyllene	7	
T55	*T. balcanus*	Romania	Thymol	Linalool	Linalyl acetate	7	
T56	*T. balcanus*	Romania	Thymol	Linalyl acetate	Linalool	7	
T57	*T. balcanus*	Romania	Thymol	Linalool	Estragol	7	
T58	*T. bornmuelleri*	Turkey	Thymol	*p*-Cymene	ND	6	[2]
T59	*T. bracteosus*	Croatia	β-Caryophyllene	Germacrene D	Caryophyllene oxide	2	[66]
T60	*T. bracteosus*	Croatia	Germacrene D	β-Caryophyllene	Myrcene	5	[67]
T61	*T. bracteosus*	Croatia	Germacrene D	β-Caryophyllene	1,8-Cineole	5	[66]
T62	*T. bracteosus*	Montenegro	Germacrene D	β-Caryophyllene	*p*-Cymene	5	[68]
T63	*T. calcareus*	Moldavia	Thymol	γ-Terpinene	*o*-Cymene	7	[58]
T64	*T. capitatus*	Albania	Carvacrol	*p*-Cymene	γ-Terpinene	6	[39]
T65	*T. capitatus*	Albania	Carvacrol	*p*-Cymene	γ-Terpinene	6	
T66	*T. capitatus*	Albania	Carvacrol	*p*-Cymene	γ-Terpinene	6	
T67	*T. capitatus*	Albania	Carvacrol	*p*-Cymene	γ-Terpinene	6	
T68	*T. capitatus*	Albania	Carvacrol	*p*-Cymene	Linalool	7	[69]
T69	*T. capitatus*	Croatia	Carvacrol	1,8-Cineole	Limonene	7	[70]
T70	*T. capitatus*	Greece	Carvacrol	*p*-Cymene	γ-Terpinene	6	[71]
T71	*T. capitatus*	Greece	Carvacrol	Thymol	Borneol	7	[72]
T72	*T. cariensis*	Turkey	Borneol	1,8-Cineole	α-Pinene	7	[2]
T73	*T. ciliatopubescens*	Macedonia	1,8-Cineole	α-Pinene	Camphene	4	[21]
T74	*T. cillicus*	Turkey	α-Pinene	1,8-Cineole	ND	7	[2]
T75	*T. comosus*	Romania	Caryophyllene oxide	Camphene	β-Bourbene	1	[38]
T76	*T. comosus*	Romania	Neryl acetate	Carvacrol	Thymol	7	[64]
T77	*T. comptus*	Turkey	Thymol	ND	ND	7	[2]
T78	*T. dacicus*	Romania	Carvacrol	Thymol	Nerol	4	[64]
T79	*T. eigii*	Turkey	Carvacrol	ND	ND	7	[2]
T80	*T. glabrescens*	Croatia	1,8-Cineole	Myrcene	Camphene	4	[70]
T81	*T. glabrescens*	Bosnia and Herzegovina	α-Terpinyl acetate	Terpinen-4-ol	ND	4	[53]
T82	*T. glabrescens*	Serbia	γ-Terpinene	Thymol	*p*-Cymene	4	[73]
T83	*T. glabrescens*	Serbia	γ-Terpinene	Thymol	*p*-Cymene	4	[74]
T84	*T. glabrescens*	Serbia	γ-Terpinene	Thymol	*p*-Cymene	4	[73]
T85	*T. glabrescens*	Romania	Farnesol	*(E)*-Nerolidol	Terpinen-4-ol	3	[75]
T86	*T. glabrescens*	Romania	Geraniol	Neryl acetate	β-Caryophyllene	4	[38]
T87	*T. glabrescens*	Serbia	Geraniol	Geranyl acetate	Linalool	4	[76]
T88	*T. glabrescens*	Serbia	Thymol	γ-Terpinene	*p*-Cymene	7	[74]
T89	*T. glabrescens*	Serbia	Thymol	*p*-Cymene	γ-Terpinene	6	[74]
T90	*T. glabrescens*	Serbia	Thymol	γ-Terpinene	*p*-Cymene	7	[73]
T91	*T. glabrescens*	Serbia	Thymol	*p*-Cymene	γ-Terpinene	6	[74]
T92	*T. glabrescens*	Serbia	Thymol	γ-Terpinene	*p*-Cymene	7	[77]
T93	*T. glabrescens*	Croatia	Thymol acetate	Carvacrol	*p*-Cymene	7	[70]
T94	*T. hartvigii* ssp. *hartvigii*	Greece	Thymol	*p*-Cymene	γ-Terpinene	6	[35]

Table 1 continuous

T95	*T. hartvigii* ssp. *macrocalyx*	Greece	Linalool	β-Caryophyllene	β-Bisabolene	7	[35]
T96	*T. haussknechtii*	Turkey	Linalool	Caryophyllene oxide	Borneol	3	[2]
T97	*T. jankae* ssp. *jankae*	Macedonia	Linalool	Geranial	α-Terpinyl acetate	3	[25,36]
T98	*T. jankae* var. *jankae*	Macedonia	Linalool	Geranial	β-Caryophyllene	3	
T99	*T. jankae* var. *pantotrichus*	Macedonia	Linalool	Geranial	β-Pinene	3	[25]
T100	*T. jankae* var. *pantotrichus*	Macedonia	Linalool	Geranial	β-Pinene	3	
T101	*T. jankae* var. *patentipilus*	Macedonia	Linalool	Geranial	β-Pinene	3	[25,36]
T102	*T. jankae*	Bosnia and Herzegovina	Linalool	*(E)*-Nerolidol	β-Caryophyllene	3	[63]
T103	*T. jankae*	Bosnia and Herzegovina	*p*-Cymene	Carvacrol	Geraniol	7	[53]
T104	*T. jankae*	Kosovo	β-Caryophyllene	α-Pinene	α-Humulene	2	Hatipi Ibrahimi et al. (un-published results)
T105	*T. jankae*	Kosovo	Thymol	α-Terpinene	Borneol	6	
T106	*T. kotschyanus* var. *argillaceus*	Turkey	Thymol	Carvacrol	Borneol	7	[2]
T107	*T. kotschyanus* var. *eriophorus*	Turkey	Carvacrol	Thymol	*p*-Cymene	7	
T108	*T. kotschyanus* var. *glabrescens*	Turkey	Carvacrol	ND	ND	7	
T109	*T. kotschyanus* var. *kotschyanus*	Turkey	Carvacrol	ND	ND	7	
T110	*T. kotschyanus* var. *leucostomus*	Turkey	Carvacrol	*p*-Cymene	Thymol	7	
T111	*T. leucospermus*	Greece	Carvacrol	Thymol	Carvacrol acetate	7	[34]
T112	*T. leucospermus*	Greece	*p*-Cymene	Thymol	γ-Terpinene	7	[35]
T113	*T. leucospermus*	Greece	*p*-Cymene	γ-Terpinene	Thymol	7	
T114	*T. leucospermus*	Greece	*p*-Cymene	γ-Terpinene	Thymol	7	
T115	*T. leucospermus*	Greece	Thymol	*p*-Cymene	γ-Terpinene	6	
T116	*T. leucospermus*	Greece	Thymol	Carvacrol	Thymol acetate	6	[34]
T117	*T. leucospermus*	Greece	Thymol	γ-Terpinene	*p*-Cymene	7	
T118	*T. leucospermus*	Greece	Thymol	Carvacrol	γ-Terpinene	6	
T119	*T. leucospermus*	Greece	Thymol	Carvacrol	Thymol acetate	6	
T120	*T. leucotrichus*	Bulgaria	β-Caryophyllene	Germacrene D	Elemol	2	[48]
T121	*T. longicaulis*	Croatia	Thymol	γ-Terpinene	Thymol methyl ether	7	[78]
T122	*T. longicaulis*	Croatia	Thymol	*p*-Cymene	Carvacrol	6	[70]
T123	*T. longicaulis*	Greece	Carvacrol	*p*-Cymene	γ-Terpinene	6	[79]
T124	*T. longicaulis*	Greece	Geraniol	Thymol	Carvacrol	4	
T125	*T. longicaulis*	Greece	Geraniol	Geranyl acetate	Nerol	4	[51]
T126	*T. longicaulis*	Greece	Linalool	α-Terpinyl acetate	α-Terpineol	3	
T127	*T. longicaulis*	Greece	Thymol	Limonene	Borneol	6	
T128	*T. longicaulis*	Kosovo	α-Phellandrene	Linalool	β-Caryophyllene	4	[80]
T129	*T. longicaulis*	Kosovo	α-Terpineol	α-Terpinyl acetate	Linalool	3	
T130	*T. longicaulis*	Kosovo	Thymol	Carvacrol	α-Terpinyl acetate	7	

Table 1 continuous

T131	*T. longicaulis*	Serbia	α-Terpinyl acetate	Thymol	Linalool	4	[81]
T132	*T. longicaulis* ssp. *chaubardii* var. *alternatus*	Turkey	Thymol	ND	ND	7	[2]
T133	*T. longicaulis* ssp. *chaubardii* var. *chaubardii*	Turkey	Thymol	ND	ND	7	
T134	*T. longicaulis* ssp. *chaubardii* var. *chaubardii*	Turkey	Carvacrol	Thymol	ND	7	
T135	*T. longicaulis* ssp. *chaubardii* var. *chaubardii*	Turkey	Linalool	Carvacrol	Thymol	3	
T136	*T. longicaulis* ssp. *longicaulis* var. *longicaulis*	Turkey	α-Terpinyl acetate	ND	ND	4	
T137	*T. longicaulis* ssp. *longicaulis* var. *longicaulis*	Turkey	Geraniol	Geranyl acetate	ND	4	
T138	*T. longicaulis* ssp. *longicaulis* var. *longicaulis*	Turkey	Thymol	*p*-Cymene	ND	6	
T139	*T. longicaulis* ssp. *longicaulis* var. *subisophyllus*	Turkey	Thymol	Carvacrol	γ-Terpinene	6	
T140	*T. longicaulis* ssp. *longicaulis* var. *subisophyllus*	Turkey	Linalyl acetate	Linalool	ND	4	
T141	*T. longidens* var. *lanicaulis*	Macedonia	Thymol	Geraniol	Carvacrol	7	[22,36]
T142	*T. longidens* var. *lanicaulis*	Macedonia	Geraniol	Linalool	Carvacrol	4	
T143	*T. longidens* var. *dassareticus*	Macedonia	Linalool	Geraniol	Citral	3	[19,20]
T144	*T. macedonicus* spp. *Macedonicus*	Macedonia	Linalool	α-Terpinyl acetate	Geraniol	3	
T145	*T. macedonicus* spp. *macedonicus*	Macedonia	Linalool	Carvacrol	Geranial	3	
T146	*T. macedonicus* spp. *macedonicus*	Macedonia	α-Terpinyl acetate	α-Terpineol	Linalool	4	
T147	*T. macedonicus* spp. *macedonicus*	Macedonia	α-Terpinyl acetate	Linalool	α-Terpineol	4	
T148	*T. macedonicus* spp. *macedonicus*	Macedonia	α-Terpinyl acetate	Linalool	α-Terpineol	4	
T149	*T. macedonicus* spp. *macedonicus*	Macedonia	Geraniol	Linalool	ND	4	
T150	*T. macedonicus* spp. *macedonicus*	Macedonia	Geraniol	α-Terpineol	Linalool	4	
T151	*T. macedonicus* spp. *macedonicus*	Macedonia	Geraniol	Geranyl acetate	Linalool	4	
T152	*T. moesiacus*	Bosnia and Herzegovina	γ-Murolene	Thymol	Borneol	7	[82]
T153	*T. moesiacus*	Bosnia and Herzegovina	Thymol	Linalool	Terpinen-4-ol	4	
T154	*T. moesiacus*	Bosnia and Herzegovina	α-Terpinyl acetate	α-pinene	Geraniol	4	
T155	*T. moesiacus*	Bulgaria	Linalyl acetate	epi-α-cadinol	Linalool	4	[82]
T156	*T. moesiacus*	Macedonia	Geraniol	Geranyl acetate	Carvacrol	4	[36]
T157	*T. moesiacus*	Macedonia	Geraniol	Geranyl acetate	Carvacrol	4	
T158	*T. moesiacus*	Macedonia	Linalool	Geraniol	Carvacrol	3	
T159	*T. pannonicus*	Serbia	α-Pinene	*(E)*-β-Ocimene	Limonene	3	[83]

Table 1 continues

T160	*T. pannonicus*	Serbia	Geraniol	Neral	Terpinen-4-ol	4	[84]
T161	*T. pannonicus*	Serbia	Geraniol	Neral	3-octenol	4	[83]
T162	*T. pannonicus*	Serbia	Germacrene D	α-Pinene	Myrcene	5	
T163	*T. pannonicus*	Bosnia and Herzegovina	α-Terpinyl acetate	Terpinen-4-ol	Carvacrol	4	[53]
T164	*T. parnassicus*	Greece	β-Caryophyllene	*epi*-α-Muurolol	δ-cadinene	2	[51]
T165	*T. parnassicus*	Greece	β-Caryophyllene	(*2Z*, *6E*)-Farnesol	Germacrene-D-4-ol	2	
T166	*T. parnassicus*	Greece	β-Caryophyllene	Linalyl acetate	γ-Terpinene	2	
T167	*T. pectinatus* var. *pectinatus*	Turkey	Thymol	*p*-Cymene	Borneol	6	[2]
T168	*T. perinicus*	Bulgaria	Thymol	Borneol	γ-Terpinene	7	[48]
T169	*T. praecox* ssp. *gorssheimii* var. *grossheimii*	Turkey	Carvacrol	*p*-Cymene	ND	7	[2]
T170	*T. praecox* ssp. *gorssheimii* var. *grossheimii*	Turkey	Thymol	*p*-Cymene	ND	6	
T171	*T. praecox* ssp. *skorpilli* var. *langier*	Turkey	α-Terpineol	α-Terpinyl acetate	Geraniol	3	
T172	*T. pseudoatticus*	Macedonia	*exo*-Borneol	β-Caryophyllene	β-Cubebene	5	[85]
T173	*T. pseudopulegioides*	Turkey	Linalool	α-Terpinyl acetate	ND	3	[2]
T174	*T. pulegioides*	Croatia	Geraniol	Thymol	Linalool	4	[86]
T175	*T. pulegioides*	Croatia	Linalool	Geraniol	Thymol methyl ether	3	
T176	*T. pulegioides*	Croatia	Linalool	Geraniol	Thymol methyl ether	3	
T177	*T. pulegioides*	Croatia	Carvacrol	*p*-Cymene	γ-Terpinene	6	[70]
T178	*T. pulegioides*	Romania	Carvacrol	Thymol	*p*-Cymene	7	[64]
T179	*T. pulegioides*	Romania	Carvacrol	γ-Terpinene	*p*-Cymene	7	[38]
T180	*T. pulegioides*	Romania	Carvacrol	γ-Terpinene	*p*-Cymene	7	
T181	*T. pulegioides*	Romania	Carvacrol	Linalool	Thymol	7	[75]
T182	*T. pulegioides*	Bosnia and Herzegovina	Geraniol	Linalool	Thymol	4	[53]
T183	*T. pulegioides* ssp. *montanus*	Kosovo	Geraniol	α-Terpinyl acetate	Thymol	3	Hatipi Ibrahimi et al. (un-published results)
T184	*T. pulvinatus*	Turkey	Borneol	ND	ND	7	[2]
T185	*T. revolutus*	Turkey	*p*-Cymene	Borneol	ND	7	[2]
T186	*T. roegneri*	Turkey	Thymol	*p*-Cymene	ND	6	[2]
T187	*T. rohlenae*	Macedonia	*p*-Cymene	γ-Terpinene	Linalool	7	[26]
T188	*T. samius*	Greece	Germacrene D	β-Bisabolene	β-Caryophyllene	5	[51]
T189	*T. serpyllum*	Bosnia and Herzegovina	Thymol	Borneol	Linalool	7	[82]
T190	*T. serpyllum*	Croatia	Carvacrol	Thymol	γ-Terpinene	7	[87]
T191	*T. serpyllum*	Greece	Linalool	*(E)*-Nerolidol	Limonene	3	[88]
T192	*T. serpyllum*	Greece	Thymol	*p*-Cymene	γ-Terpinene	6	[89]
T193	*T. serpyllum*	Albania	*p*-Cymene	Linalool	Carvacrol	7	[69]
T194	*T. sipyleus* ssp. *rosulans*	Turkey	Thymol	Carvacrol	ND	6	[2]
T195	*T. sipyleus* ssp. *rosulans*	Turkey	1,8-Cineole	ND	ND	4	

Table 1 continues

T196	*T. sipyleus* ssp. *sipyleus* var. *sipyleus*	Turkey	Geranial	Neral	ND	4	[2]
T197	*T. sipyleus* ssp. *sipyleus* var. *sipyleus*	Turkey	Linalool	Geranial	Neral	3	[2]
T198	*T. striatus*	Bosnia and Herzegovina	6α-Hydroxygerma-cra-1(10),4-diene	1,8-Cineole	Germacrene D	7	[54]
T199	*T. striatus*	Bulgaria	β-Caryophyllene	Germacrene D	Caryophyllene oxide	2	[48]
T200	*T. striatus*	Bosnia and Herzegovina	Thymol	Caryophyllene oxide	Carvacrol	7	[54]
T201	*T. striatus*	Bosnia and Herzegovina	Terpinen-4-ol	α-Terpinyl acetate	Linalool	3	[53]
T202	*T. striatus*	Croatia	Caryophyllene oxide	Elemol	α-cadinol	1	[54]
T203	*T. striatus*	Greece	Thymol	γ-Terpinene	*p*-Cymene	7	[55]
T204	*T. striatus*	Greece	Thymol	*p*-Cymene	Linalool	6	[41]
T205	*T. striatus* var. *interruptus*	Turkey	β-Caryophyllene	Terpinen-4-ol	ND	2	[2]
T206	*T. striatus* var. *interruptus*	Turkey	Thymol	ND	ND	7	[2]
T207	*T. striatus* var. *interruptus*	Turkey	*p*-Cymene	1,8-Cineole	Thymol	7	[2]
T208	*T. sibthorpii*	Greece	Geraniol	Linalool	Citronelyl acetate	4	[44]
T209	*T. sibthorpii*	Greece	Geraniol	Thymol	Geranyl acetate	4	[44]
T210	*T. sibthorpii*	Greece	α-Terpinyl acetate	α-Terpineol	Geraniol	4	[41]
T211	*T. sibthorpii*	Turkey	Thymol	*p*-Cymene	ND	6	[2]
T212	*T. sibthorpii*	Turkey	Carvacrol	*p*-Cymene	Thymol	7	[2]
T213	*T. syriacus*	Turkey	Thymol	Carvacrol	ND	6	[2]
T214	*T. teucrioides* ssp. *alpinus*	Greece	*p*-Cymene	Borneol	β-Caryophyllene	7	[35]
T215	*T. teucrioides* ssp. *alpinus*	Greece	*p*-Cymene	Borneol	β-Caryophyllene	7	[35]
T216	*T. teucrioides* ssp. *alpinus*	Greece	*p*-Cymene	Borneol	β-Caryophyllene	7	[35]
T217	*T. teucrioides* ssp. *alpinus*	Greece	*p*-Cymene	β-Caryophyllene	Caryophyllene oxide	7	[35]
T218	*T. thracicus* var. *longidens*	Turkey	Geraniol	ND	ND	4	[2]
T219	*T. tosevii*	Greece	Linalool	Geraniol	Thymol	3	[90]
T220	*T. tosevii*	Kosovo	α-Pinene	Caryophyllene oxide	*p*-Cymene	7	[91]
T221	*T. tosevii*	Kosovo	Caryophyllene oxide	γ-Terpinene	α-Pinene	7	[91]
T222	*T. tosevii*	Kosovo	Caryophyllene oxide	γ-Terpinene	α-Terpineol	7	[91]
T223	*T. tosevii*	Kosovo	γ-Terpinene	Geranyl acetate	β-Caryophyllene	4	[91]
T224	*T. tosevii*	Kosovo	γ-Terpinene	Thymol methyl ether	Camphene	4	[91]
T225	*T. tosevii*	Kosovo	*p*-Cymene	*(E)*-β-Farnesene	β-Caryophyllene	7	[91]
T226	*T. tosevii*	Kosovo	Thymol	γ-Terpinene	*p*-Cymene	7	[91]
T227	*T. tosevii*	Serbia	Geranyl acetate	Carvacrol	α-Terpinyl acetate	3	[92]
T228	*T. tosevii* ssp. *degenii*	Macedonia	Thymol	Carvacrol	Geraniol	7	[36]
T229	*T. tosevii* ssp. *degenii*	Macedonia	Thymol	Carvacrol	Linalool	7	[36]
T230	*T. tosevii* ssp. *longifrons*	Macedonia	Carvacrol	Thymol	Geraniol	7	[36]

Table 1 continues

T231	*T. tosevii* ssp. *longifrons*	Macedonia	Carvacrol	Thymol	Linalool	7	[36]
T232	*T. tosevii* ssp. *longifrons*	Macedonia	Carvacrol	Thymol	*p*-Cymene	7	
T233	*T. tosevii* ssp. *longifrons*	Macedonia	Geraniol	Linalool	Carvacrol	4	
T234	*T. vulgaris "Faustini"*	Moldavia	Geraniol	Linalool	Neral	3	[58]
T235	*T. vulgaris*	Albania	Thymol	*p*-Cymene	γ-Terpinene	6	[40]
T236	*T. vulgaris*	Albania	Thymol	*p*-Cymene	γ-Terpinene	6	
T237	*T. vulgaris*	Albania	Thymol	*p*-Cymene	γ-Terpinene	6	
T238	*T. vulgaris*	Albania	Thymol	*p*-Cymene	γ-Terpinene	6	
T239	*T. vulgaris*	Albania	Thymol	*p*-Cymene	γ-Terpinene	6	
T240	*T. vulgaris*	Albania	*p*-Cymene	Thymol	γ-Terpinene	7	[69]
T241	*T. vulgaris*	Croatia	Linalool	Thymol	*p*-Cymene	7	[93]
T242	*T. vulgaris*	Croatia	*p*-Cymene	Thymol	1,8-Cineole	7	[94]
T243	*T. vulgaris*	Croatia	Thymol	*p*-Cymene	γ-Terpinene	6	[93]
T244	*T. vulgaris*	Croatia	Thymol	*p*-Cymene	γ-Terpinene	6	[87]
T245	*T. vulgaris*	Greece	Thymol	γ-Terpinene	γ-Terpinene	6	[95]
T246	*T. vulgaris*	Turkey	Thymol	*p*-Cymene	ND	6	[2]
T247	*T. vulgaris*	Moldavia	Thymol	*m*-Cymene	γ-Terpinene	6	[58]
T248	*T. vulgaris*	Serbia	Thymol	*p*-Cymene	Carvacrol	6	[96]
T249	*T. vulgaris*	Serbia	Thymol	Carvacrol	β-Caryophyllene	7	[97]
T250	*T. vulgaris*	Serbia	Thymol	*p*-Cymene	γ-Terpinene	6	[98]
T251	*T. vulgaris*	Serbia	Thymol	ND	ND	7	[77]
T252	*T. vulgaris*	Serbia	Thymol	*p*-Cymene	Carvacrol	6	[99]
T253	*T. vulgaris*	Serbia	Thymol	*p*-Cymene	γ-Terpinene	6	[92]
T254	*T. vulgaris*	Serbia	Thymol	ND	ND	7	[89]
T255	*T. vulgaris*	Serbia	Thymol	ND	ND	7	[100]
T256	*T. vulgaris*	Serbia	Thymol	ND	ND	7	[101]
T257	*T. zygioides*	Bulgaria	Thymol	Borneol	*p*-Cymene	7	[48]
T258	*T. zygioides* var. *lycaonicus*	Greece	Thymol	*p*-Cymene	γ-Terpinene	6	[51]
T259	*T. zygioides* var. *lycaonicus*	Greece	*p*-Cymene	Thymol	γ-Terpinene	7	[57]
T260	*T. zygioides* var. *lycaonicus*	Turkey	Thymol	*p*-Cymene	β-Bisabolene	6	[2]
T261	*T. zygioides* var. *lycaonicus*	Turkey	Thymol	ND	ND	7	
T262	*T. zygioides* var. *lycaonicus*	Turkey	Carvacrol	ND	ND	7	
T263	*T. zygioides* var. *lycaonicus*	Turkey	Geraniol	ND	ND	4	
T264 *	*T. glabrescens*	Serbia	Thymol	γ-Terpinene	*p*-Cymene	NI	[60]
T265 *	*T. praecox* subsp. *jankae*	Serbia	β-Caryophyllene	Thymol	Linalool	NI	
T266 *	*T. pulegioides*	Serbia	Linalyl acetate	Thymol	γ-Terpinene	NI	
T267 *	*T. parnassicus*	Greece	α-Cadinol	β-Caryophyllene	β-bisabolene	NI	[43]
T268 *	*T. leucotrichus*	Greece	Elemol	α-Eudesmol	β-Eudesmol	NI	
T269 *	*T. atticus*	Greece	Linalool	*p*-Cymene	ND	NI	

Table 1 continues

T270 *	*T. holosericeus*	Greece	Geraniol	*p*-Cymene	ND	NI	[43]
T271 *	*T. laconicus*	Greece	Carvacrol	*p*-Cymene	ND	NI	
T272 *	*T. longedentatus*	Bulgaria	Geranial	Neral	Eucalyptol	NI	[50]
T273 *	*T. moesiacus*	Bulgaria	Linalool	Geraniol	Geranyl acetate	NI	[49]
T274 *	*T. jankae*	Bulgaria	Linalool	Linalyl acetate	τ-Cadinol	NI	
T275 *	*T. vandasii*	Bulgaria	Linalool	Linalyl acetate	β-Caryophyllene	NI	
T276 *	*T. longicaulis*	Bulgaria	Geraniol	α-Terpinyl acetate	Linalool	NI	
T277 *	*T. sibthorpii*	Bulgaria	Myrcen-8-yl acetate	Linalool	Myrcen-8-ol	NI	
T278 *	*T. pulegioides*	Bulgaria	α-Terpinyl acetate	Geraniol	Thymol	NI	
T279 *	*T. glabrescens*	Bulgaria	Thymol	*p*-Cymene	γ-Terpinene	NI	
T280 *	*T. callieri*	Bulgaria	Carvacrol	Thymol	γ-Terpinene	NI	
T281 *	*T. pannonicus*	Bulgaria	Germacrene D	β-Caryophyllene	ND	NI	
T282 *	*T. thracicus*	Bulgaria	β-Myrcene	*cis*-Sabinene hydrate	τ-Cadinol	NI	
T283 *	*T. holosericeus*	Greece	Linalool	Carvacrol	Geraniol	NI	[42]

*Resent studies not included in the multivariate analysis (NI)

A total of 263 different *Thymus* spp. samples and their essential oil compositions were used to perform Principal Component Analysis (PCA), followed by Hierarchical Cluster Analysis (HCA). Ward's method of HCA was applied based on each sample's scores in the first five components of the PCA model. The HCA dendrogram (Figure 2) revealed seven groups, which were used to develop a subsequent Partial Least Squares Discriminant Analysis (PLS-DA) model based on the affiliation of each sample to the seven primary clustering groups. The statistical descriptors of the PLS-DA model (R2X = 0.132, R2Y = 0.864, Q2 = 0.657) indicate satisfactory predictive capabilities for *Thymus* chemotaxonomic differentiation based on essential oil composition. The score scatter plot reveals a distinctive grouping pattern of samples based on the main compounds in the essential oil (Figure 3).

The coefficient plots derived from the PLS-DA model for *Thymus* spp. demonstrate the compounds in the essential oil that determine the chemotype group assignment for each sample (Figures S1 and S2). The discriminant presence or absence of the major component, along with components 2 and 3, in each group are represented in Table 2. The cluster analysis revealed seven main chemotypes, and their characteristics are provided in Table 2.

Group 7 comprises the majority of the analyzed samples (107) and is characterized by the presence of *p*-cymene and borneol, along with carvacrol and thymol, as predominant components in the essential oil composition, resembling the well-known *p*-cymene/thymol chemotype [102]. Another previously recognized chemotype is the geraniol chemotype, which corresponds to the second largest cluster in the dendrogram, encompassing 53 representative samples in group 4 (including some *T. vulgaris* samples from Serbia). In addition to geraniol, α-terpinyl acetate, γ-terpinene, 1,8-cineole, and linalyl acetate can also be present as predominant compounds in the essential oils.

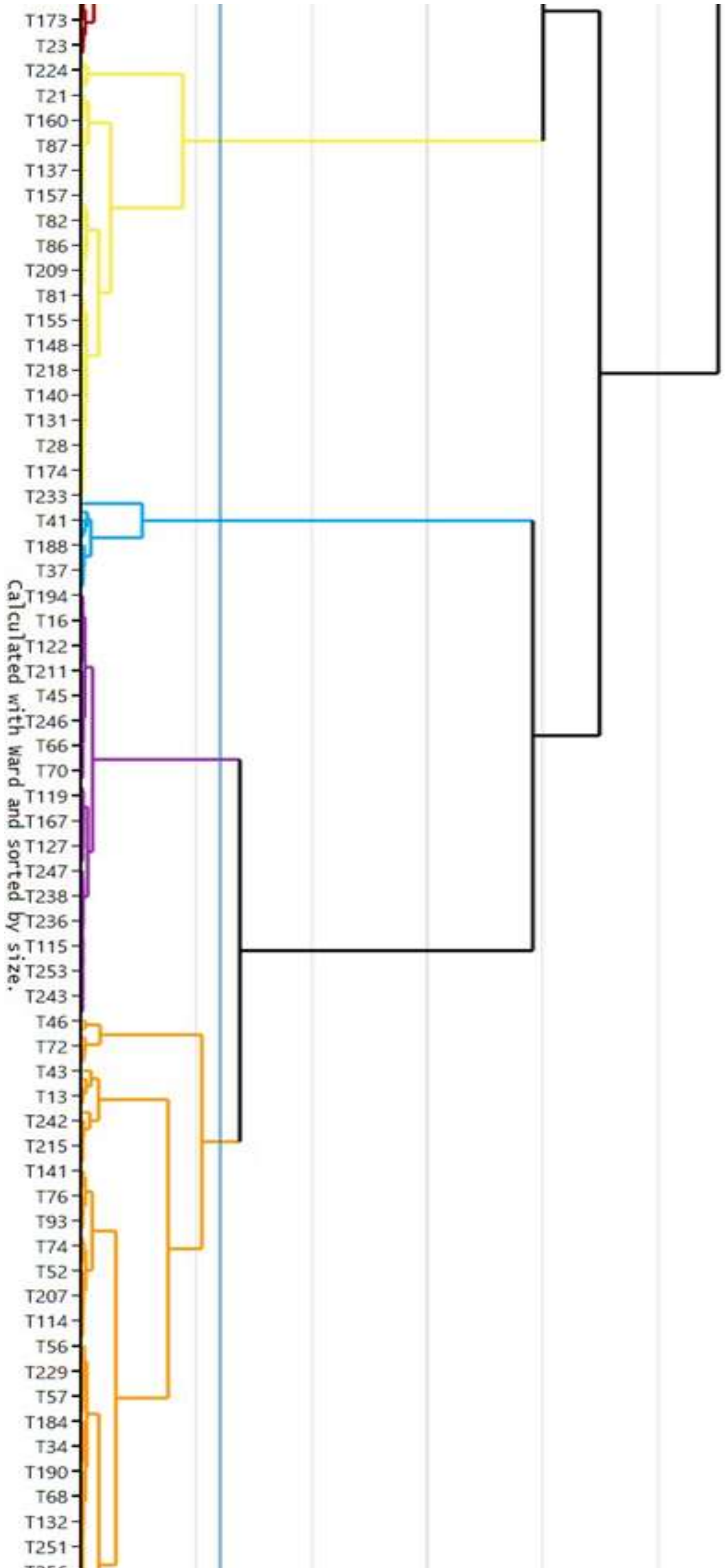

Figure 2. Dendrogram obtained by hierarchical cluster analysis using Ward's method revealing the essential oils polymorphism of *Thymus* taxa

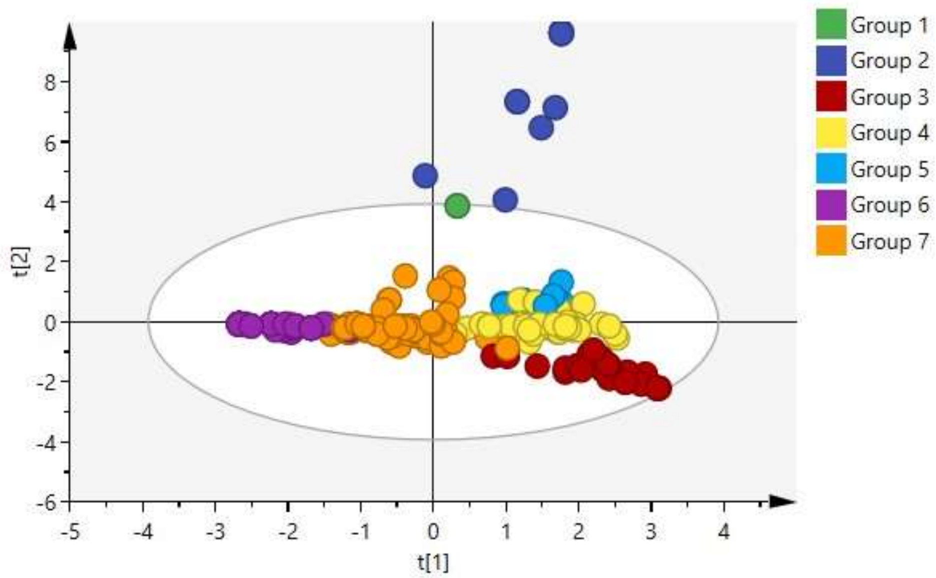

Figure 3. Score scatter plot from the PLS-DA model for *Thymus* spp. chemotaxonomic differentiation based on essential oils; main components, colored according to group assignment

Group 6, the third largest cluster with 51 samples, is a classic thymol chemotype that had been recognized previously [103–106]. A characteristic of this chemotype is that p-cymene is always present as a second major compound, serving as a discriminatory compound that differentiates it from group 4, where p-cymene is absent as a major compound. The absence of p-cymene as a second major compound is also typical for Group 2 (9 samples), which is a β-caryophyllene chemotype. All samples from *T. striatus* and *T. parnassicus* are included in this group.

Group 3 (30 samples) is distinguished by the presence of linalool as one of the major compounds. The smallest group is Group 1 (2 samples), typified by the predominance of camphene, elemol, and caryophyllene oxide. Group 5 (11 samples) is characterized by the predominance of germacrene D, (E)-nerolidol, and borneol, with β-caryophyllene as a secondary major component.

Applying multivariate statistical techniques was essential for integrating chemical data with chorological information, leading to a more comprehensive understanding of *Thymus* chemotaxonomy. In this way, chemical profiles can be further used to accurately identify and classify *Thymus* species, especially those that are morphologically similar, and to assist in phylogenetic studies to understand the evolutionary relationships among *Thymus* species from Southeastern Europe, revealing patterns of divergence and speciation.

Table 2. Discriminant essential components in each chemotaxonomic group based on the PLS-DA coefficients

HCA GROUP	MAJOR COMPOUND HIGH PRESENCE	MAJOR COMPOUND INSIGNIFICANT PRESENCE/ ABSENCE	OTHER DOMINANT COMPOUNDS HIGH PRESENCE	OTHER DOMINANT COMPOUNDS LOW PRESENCE/ ABSENCE	*THYMUS* SPP. SAMPLES
1	Camphene, Elemol, Caryophyllene oxide	Thymol & Carvacrol	α-cadinol, β-Bourbene		T75, T202
2	β-Caryophyllene	Thymol & Carvacrol	Germacrene D	*p*-Cymene	T49, T59, T104, T120, T164, T165, T166, T199, T205

3	Linalool, Lavandulol, Geranyl acetate	Thymol & Carvacrol, *p*-Cymene	Geranial, Geraniol, α-Terpenyl acetate	*p*-Cymene, γ-Terpinene	T1, T23, T39, T85, T96, T97, T98, T99, T100, T101, T102, T126, T129, T135, T143, T144, T145, T158, T159, T171, T173, T175, T176, T183, T191, T197, T201, T219, T227, T234
4	Geraniol, α-Terpenyl acetate, γ-Terpinene, 1,8-Cineole, Linalyl acetate	Thymol & Carvacrol	Geranyl acetate, Linalool, Neral	*p*-Cymene	T2, T21, T22, T27, T28, T35, T40, T42, T48, T50, T73, T78, T80, T81, T82, T83, T84, T86, T87, T124, T125, T128, T131, T136, T137, T140, T142, T146, T147, T148, T149, T150, T151, T153, T154, T155, T156, T157, T160, T161, T163, T174, T182, T195, T196, T208, T209, T210, T218, T223, T224, T233, T263
5	Germacrene D, *(E)*-Nerolidol, Borneol	Thymol & Carvacrol	β-Caryophyllene, β-Bisabolene, Myrcene, β-Cubebene	Thymol & Carvacrol, γ-Terpinene, Linalool	T29, T36, T37, T41, T51, T60, T61, T62, T162, T172, T188
6	Thymol	*p*-Cymene, Geraniol, Linalool, Caryophyllene oxide	*p*-Cymene, γ-Terpinene, Thymol acetate, Limonene		T3, T10, T16, T24, T31, T32, T45, T58, T64, T65, T66, T67, T70, T89, T91, T94, T105, T115, T116, T118, T119, T122, T123, T127, T138, T139, T167, T170, T177, T186, T192, T194, T204, T211, T213, T235, T236, T237, T238, T239, T243, T244, T245, T246, T247, T248, T250, T252, T253, T258, T260
7	P-Cymene, Carvacrol, Thymol, Borneol	Geraniol, α-Terpenyl acetate, γ-Terpinene, β-Caryophyllene, Linalool, 1,8-Cineole	γ-Terpinene, *p*-Cymene, Borneol, Thymol		T4, T5, T6, T7, T8, T9, T11, T12, T13, T14, T15, T17, T18, T19, T20, T25, T26, T30, T33, T34, T38, T43, T44, T46, T47, T52, T53, T54, T55, T56, T57, T63, T68, T69, T71, T72, T74, T76, T77, T79, T88, T90, T92, T93, T95, T103, T106, T107, T108, T109, T110, T111, T112, T113, T114,

	T117, T121, T130, T132, T133, T134, T141, T152, T168, T169, T178, T179, T180, T181, T184, T185, T187, T189, T190, T193, T198, T200, T203, T206, T207, T212, T214, T215, T216, T217, T220, T221, T222, T225, T226, T228, T229, T230, T231, T232, T240, T241, T242, T249, T251, T254, T255, T256, T257, T259, T261, T262

CONCLUSION

This review synthesizes current knowledge on the chemical diversity of *Thymus* species from Southeastern Europe, primarily focusing on the composition of their essential oils. It highlights the variability in chemical constituents, the importance of chemotypes, and the application of multivariate statistical techniques in chemotaxonomic studies. In this context, the review provides a thorough insight into the seven main chemotype groups present among 263 different *Thymus* spp. samples from Southeastern Europe, along with their major chemical constituents. It also suggests further investigation into the biological properties of *Thymus* species and their essential oils, including the selection of rare species, standardization, and clinical trials using molecular, cellular, and animal models to demonstrate the valuable significance of *Thymus* oils. In conclusion, the theory regarding the effect of environmental factors and ecological interactions on the evolution of chemotypes is not entirely applicable to the known chemotypes of *Thymus* species growing in Southeastern Europe, as evolutionary relationships and classical systematics play a crucial role.

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УВИД ВО ХЕМОТАКСОНОМИЈАТА НА ВИДОВИТЕ ОД РОДОТ *THYMUS* ВО ЈУГОИСТОЧНА ЕВРОПА

Ѓоше Стефков, Светлана Кулеванова

Фармацевтски факултет, Универзитет „Св. Кирил и Методиј“ – Скопје, Северна Македонија

Родот *Thymus* L. претставува еден од најзначајните и најполиморфни родови во семејството *Lamiaceae*, опфаќајќи приближно 350 видови распространети низ Европа, Азија, Северна и Источна Африка, и јужниот дел на Гренланд, при што најголемиот број се среќаваат во Медитеранскиот регион. Растенијата од родот *Thymus* и нивните етерични масла се високо ценети во традиционалната медицина и кулинарството во Југоисточна Европа. Етеричните масла на видовите од *Thymus* покажуваат значајна хемиска варијабилност, како резултат на различни внатрешни и надворешни фактори, меѓу кои се генетските варијации и влијанијата на животната средина.

И покрај широко распространетиот научен интерес за таксономијата, хемотиповите и биолошката активност на нивните секундарни метаболити, достапната литература за родот *Thymus* во Југоисточна Европа е ограничена. Целта на овој преглед е да се прикаже составот на етеричните масла кај различни видови од овој род, присутни во Југоисточна Европа, и да се систематизираат постоечките податоци за распространетоста, составот на етеричните масла и биолошките активности на *Thymus* видовите во регионот (вклучувајќи ги Хрватска, Босна и Херцеговина, Србија, Црна Гора, Бугарија, Романија, Косово, Албанија, Северна Македонија, Унгарија, Молдавија, Турција и Грција). Овие сознанија се од особено значење за подобро разбирање на нивната хемотаксономија.

Во таа насока, овој труд има за цел да понуди сеопфатен увид во варијациите на хемотиповите кај 263 примероци од *Thymus* собрани во Југоисточна Европа, со акцент на главните компоненти на нивните етерични масла, и да отвори пат за понатамошни истражувања на биолошките својства на родот *Thymus* L. и неговите етерични масла.

Клучни зборови: див мајчина душица; Југоисточна Европа; состав на етерични масла; хемотипови; мултиваријантна статистичка анализа