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Aromatic biodiversity among the flowering plant taxa of Turkey*

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Abstract: *Flora of Turkey* is rich and diverse with well over 11 000 flowering taxa recorded in the 9-volume set of Prof. Davis's monumental work and its two supplements. Chemical diversity among the flowering plants of Turkey is well documented in the recently published volume 11 of the *Flora of Turkey and the East Aegean Islands*.

Among the aromatic taxa, remarkable examples can be found in families such as Labiatae, Compositae, Umbelliferae, etc. The occurrence of volatile chemicals in aromatic plants is not only an indication of chemical diversity but may also help solve taxonomical problems is comprehensively studied genera. Aromatic diversity is illustrated with examples from genera such as Sideritis, Salvia, Thymus, Origanum, Satureja, Thymbra, Mentha, Micromeria, Ziziphora, Calamintha, Cyclotrichium, Acinos, Echinophora, Ferulago, Heracleum, Pimpinella, Tanacetum, and Betula.

The economic implications of aromatic biodiversity and the importance of bioprospecting are highlighted.

GEOGRAPHY

Turkey is a large peninsula, rectangular in shape, and situated at the southwestern corner of Asia meeting Europe across the Aegean and Marmara seas to the west with land in Europe, named Thrace. Therefore, Turkey with its land mass of 780 600 km^2 embraces both Asia and Europe and is a natural passageway between these continents. It is surrounded by four seas, namely the Black Sea to the north, the Mediterranean Sea to the south, the Aegean Sea to the west, and the Marmara Sea to the northwest. The land mass of Turkey lies between 42 °N and 36 °N latitudes at a transsect between the sea level and over 5500 m.

CLIMATE

Turkey is under the influence of three different climates, namely, Mediterranean, continental, and oceanic. Most of Turkey is under the Mediterranean influence. The Central Anatolian Plateau and the more eastern mountainous parts enjoy continental climate. Oceanic climate occurs only in an enclave in the northeastern part around the Rize province [1].

PHYTOGEOGRAPHY

Turkey is situated at the junction of three important phytogeographic regions, namely Mediterranean, Irano-Turanian, and Euro-Siberian. The Black Sea's coastal areas are in the Euro-Siberian region. Areas

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surrounding the Mediterranean, Aegean, and Marmara Seas enjoy the characteristics of the Mediterranean regions, and finally, the large part of Turkey stretching from the Central Anatolian Plateau to the borders with Iran and Iraq to the east and southeast lies in the Irano-Turanian region. Endemic species are largely found in the Mediterranean and Irano-Turanian regions. The Anatolian flora, especially in the more arid areas, is said to be in an active state of diversification [2].

FLORA OF TURKEY

The wide biodiversity of the flowering plants of Turkey is reflected in the 11-volume set of books titled *Flora of Turkey and the East Aegean Islands*. The series had been the initiative of the late Prof. P. H. Davis of Edinburgh University. Based on his numerous visits to Anatolia since 1938, Prof. Davis started publishing his monumental work in 1965. Publication of the flora was completed in 1985 with the 9th volume [3]. However, new developments in the taxonomy of vascular plants of Turkey had deemed the publication of the first supplement (Vol. 10) in 1988 [4]. Finally, 12 years after the publication of the first supplement, a second supplement (Vol. 11) was published in April 2001 [5]. The new volume was edited by four Turkish scientists with contributions from national and international collaborators. The latest status of the flora of Turkey and the East Aegean Islands is shown in Tables 1 and 2.

Table 1 Statistical data on the flora of Turkey [5].

	Native	Endemic	%	Alien	Cultivated	Total
Families	163	0	0.0	2	8	174
Genera	1168	16	1.4	31	52	1251
Species	8988	2991	33.3	96	138	9222
Subspecies	1683	497	29.5	6	8	1702
Varieties	1074	390	36.3	1	11	1086
Hybrids	298	160	53.7	1	8	307
Total infrageneric taxa	10 754	3708	34.5	101	159	11 014*

*532 new taxa have been included in Vol. 11.

Table 2 Distribution of total infrageneric taxa in the flora of Turkey [5].

	Native	Endemic	%	Alien	Cultivated	Total
Pteridophytes	101	1	1.0	0	0	101
Gymnosperms	35	3	9.1	0	0	35
Dicotyledons	8887	3319	37.3	79	97	9063
Monocotyledons	1731	389	22.5	22	62	1815
Total	10 754	3708	34.5	101	159	11 014

According to the tables, the flora contains just over 11 000 infrageneric taxa, of which 34.5 % are endemic. Two hundred taxa have been recorded only from the Aegean islands belonging to Greece. However, it has been pointed out that most of them can be found in Turkey in the course of careful field studies. The flora of Turkey is estimated to contain over 3000 aromatic plants.

The second supplement (Vol. 11) reported 532 new taxa for the flora region. A unique feature of this new volume has been the inclusion of a chapter on the chemical constituents of the plants of Turkey. Information in the chapter was compiled from 935 research papers published until the end of June 1999. Papers published on taxa growing in the Aegean islands were not included in this treatise. As the chapter was hoped to provide an easy reference for plant taxonomists and other related plant scientists, for the sake of simplicity and to facilitate the use of this chapter by non-chemists, instead of citing names of chemical compounds, chemical groups that they belong to have been indicated. The information is presented in table form alphabetically under each family, and each record contains location and herbarium data with full references.

The designated chemical groups used in the chapter are as follows: alkaloid, amino acid, anthocyanin, anthraquinone, benzofuran, carbohydrate, cardiac glycoside, coumarin, cyanogenic glycoside, diterpenoid, flavonoid, glucosinolate, hydrocarbon, iridoid, lignan, meroterpenoid, monoterpenoid, naphthaquinone, organic acid, phenylethanoid, phenylpropanoid, phloroglucinol, polysaccharide, protein, saponin, sesquiterpenoid, steroid, sulfur compounds, tannin, and triterpenoid. Furthermore, essential oils and fixed oils were treated as such. Since these complex mixtures contain different classes of chemical compounds breaking them down to their components would really cause great confusion.

The results indicated that until the end of June 1999 over 930 papers were published reporting the chemical compositions of 830 taxa belonging to 237 genera included in 58 families, meaning only 7.7 % of the flora of Turkey has been investigated chemically. This is almost half of that estimated for the world. It has been estimated that out of ca. 250 000 species of flowering plants only about 15 % have been studied phytochemically [6].

The study has revealed that essential oils were the most widely studied chemical group with 279 taxa which belonged to 74 genera in 21 families. Two hundred fifty-seven papers were published on essential oils.

Families extensively studied for essential oils were Labiatae, Umbelliferae, and Compositae (Table 3).

Table 3 Essential oil studies in Turkey.

Family	Genus	Taxon	Publications
Labiatae	23	199	156
Umbelliferae	16	33	34
Compositae	8	33	36

Terpenoids constituted the largest single group of chemical constituents. Two hundred twenty-seven taxa belonging to 88 genera in 35 families contained terpenoids and 265 papers were published in this group of constituents. Since essential oils consist mainly of mono-, sesqui-, and diterpenoids, together they represent the largest group reported in 55 %, that is over half of the published papers on phytochemical constituents of Turkey. Fifty-eight percent of all taxa, 57 % of all genera, and 74 % of all the families studied contained terpenoids + essential oils.

The *Dictionary of Natural Products* is the largest inventory of natural chemicals. According to the August 1999 edition, 145 000 naturally occurring chemicals have been reported. Each year about 4000 new structures are reported. The largest group of natural chemicals is terpenoids, comprising 37 500 compounds [7].

Over 30 % of the flora of Turkey contain aromatic plants with high percentage of endemism.

At the Medicinal and Aromatic Plant and Drug Research Centre (TBAM), extensive research has been carried out into studying the chemical composition of essential oils of the aromatic plants of Turkey. So far, essential oils of over 484 taxa belonging to 94 genera in 23 families have been investigated.

In some genera, such as *Acinos, Betula, Echinophora, Lavandula, Melissa, Origanum, Satureja, Sideritis, Thymbra,* and *Ziziphora,* all the existing taxa have been studied for essential oils. Chemical profiles of the essential oils of *Abies, Cyclotrichium, Ferulago, Mentha, Micromeria, Pimpinella, Ruta, Thymus, Tilia, Wiedemannia*, etc. are nearing completion. Extensive research is carried out into essential oils of A*chillea, Ajuga, Anthemis, Anthriscus, Artemisia, Calamintha, Chaerophyllum, Citrus,* *Eucalyptus*, *Heracleum*, *Hypericum*, *Juniperus*, *Laserpitium*, *Marrubium*, *Nepeta*, *Pinus*, *Pistachia*, *Prangos*, *Salvia*, *Stachys*, *Seseli*, *Smyrnium*, *Teucrium*, and *Tordylium*.

Essential oils of the following single species aromatic genera of Turkey have also been studied: *Anethum graveolens*, *Artedia squamata*, *Coridothymus capitatus*, *Cuminum cyminum*, *Dictamnus albus*, *Dorystoechas hastata*, *Ekimia bornmuelleri*, *Foeniculum vulgare*, *Gentiana lutea*, *Glaucosciadium cordifolium*, *Lagoecia cuminoides*, *Laser trilobum*, *Laurus nobilis*, *Liquidambar orientalis*, *Mandragora autumnalis*, *Morina persica*, *Ocimum basilicum*, *Olymposciadium caespitosum*, *Orthurus heterocarpus*, *Petroselinum sativum*, *Rosa damascena*, *Rosmarinus officinalis*, *Santolina chamaecyparissus*, *Vitex agnus castus*, *Xanthogalum purpurascens*, and *Zosima absinthifolia*.

Chemistry of a plant is regulated by biosynthetic and metabolic processes. The so-called primary metabolites such as carbohydrates, amino acids, proteins, etc., which are essential for the plant, are biosynthesized first. The so-called secondary metabolites are responsible for chemodiversity. These compounds are biosynthesized from primary compounds and are not necessary for life. They have secondary functions, and their occurrence in plants varies widely. In other words, they may have a role to improve the quality of life of a plant.

Chemical diversity may occur at infrageneric and infraspecific levels. Each taxon is believed to have acquired the ability to biosynthesize certain chemicals during its evolutionary history. Although those characters are generally inherited, plants are capable of adapting themselves to changing climatic and edaphic conditions. Such changes may, in the long run, lead to the evolution of new taxa. The occurrence of different chemotypes of the same species within certain polymorphic genera is not uncommon [8,9].

Now, I shall try to illustrate the diverse phytochemistry of the aromatic flora of Turkey with worked examples:

Sideritis

Sideritis (Labiatae) is represented in Turkey by 52 taxa belonging to 44 species of which 34 are endemic to Turkey. Such a high rate of endemism (79.5 %) is due to the fact that Turkey is one of the two main gene centers of the genus. The other center is the Iberic peninsula in southwestern Europe with ca. 50 species belonging to section Sideritis. All the Turkish species belong to section Empedoclia. We have been conducting a large research program into studying not only the essential oils but also taxonomical, anatomical, morphological, caryological, palinological, and genetical aspects of all the *Sideritis* species growing in Turkey. The first results are summarized in Table 4 in order to classify them according to the groups of main components in their oils. The majority of *Sideritis* taxa contain monoterpene hydrocarbons as main constituents. Dried inflorescenses of *Sideritis* species are used as a popular herbal tea in Turkey and Greece.

Table 4 Classification of Turkish *Sideritis* species in order of main components [10,11].

Monoterpene hydrocarbons	*amasiaca, argyrea, armeniaca, athoa, bilgerana, brevidens, congesta, dichotoma, erythrantha* var. *erythrantha*, *erythrantha* var. *cedretorum, galatica, germanicapolitana* ssp. *germanicapolitana, germanicapolitana* ssp. *viridis, gulendamii, hispida, huber-morathii, libanotica* ssp. *libanotica, libanotica* ssp. *kurdica, lycia, niveotomentosa, phrygia, rubriflora, scardica* ssp. *scardica, serratifolia. sipylea, stricta, syriaca* ssp. *nusairiensis, trojana, vuralii*
Oxygenated monoterpenes	*arguta, libanotica* ssp. *microchlamys, romana* ssp. *romana*

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Table 4 (*Continued*)

Sesquiterpene hydrocarbons	*akmanii, albiflora, brevibracteata, caesarea, cilicica, condensata, curvidens, hololeuca, leptoclada, libanotica* ssp. *linearis, libanotica* ssp. *violascens, montana* ssp. *montana, montana* ssp. *remota, ozturkii, pisidica, tmolea, vulcanica*
Oxygenated sesquiterpenes	*phlomoides, taurica*
Diterpenes	*perfoliata*
Others	*lanata*

Salvia

Salvia (Labiatae) is represented in Turkey by 94 taxa belonging to 89 species with 50 % endemism. Sixty-four percent of the *Salvia* taxa (41) have been studied at TBAM. Most *Salvia* species (69 %) are moderately rich in oil (0.1–1.0 %). Nine taxa (14 %), which comprise commercial species, contained >1 % oil.

Salvia taxa of Turkey were classifed by us according to main components in their respective essential oils as shown in Table 5 [12–19].

Commercial *Salvia* species belong to the following groups:

- CiCa group: *S. fruticosa* (syn. *S. triloba*)
- Pinene group: *S. tomentosa*
- Thujone group: *S. officinalis*, *S. pomifera* (syn. *S. calycina*).

Table 5 Main groups of constituents in *Salvia* oils.

Chemical group	*Taxa* (oil yield) % component
α/β-Pinene	*tomentosa*[a] (0.6–1.3) 6–29/5–33 *wiedemannii* (0.4–0.6) 23–33/14–30 *potentillifolia* (0.4) 10/8
Camphor/1,8-Cineole (CaCi)[b]	*recognita* (0.6) 37/8 *aytachii* (0.9) 31/27 *tchihatcheffii* (0.6–1.9) 20–23/16 *aucheri/aucheri* (0.7) 21/20 *multicaulis* (tr) 19/8 *blepharochlaena* (tr) 18/14
1,8-Cineole/Camphor (CiCa)	*fruticosa* (0.9–2.8) 35–51/7–13 *cryptantha*[b,c] (0.6–0.9) 16–37/6–13 *aucheri/canescens* (0.4–0.8) 15–25/14–18
1,8-Cineole/Cryptone	*cadmica* (0.2) 22/12 *smyrnaea* (0.4) 18/18
α/β-Thujone	*pomifera* [1.0; 2.7 (Leaf)] 16–20/16–51 *caespitosa* (0.6) 24 (α+β)
Linalyl acetate/Linalool (LaLi)	*sclarea*[d] (0.3–1.3) 16–49/6–29 *palaestina* (0.3) 24/12 *trichoclada* (0.3) 24/26 *multicaulis* (0.1) 21/12
Other monoterpene esters	*pisidica* (0.4–1.1) sabinyl acetate 16–33 *chrysophylla* (0.4) α-terpinyl acetate 26 *euphratica/euphratica* (0.04) *trans*-pinocarvyl acetate 17 *suffruticosa* (0.2) bornyl acetate 10

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Table 5 (*Continued*)

Other oxygenated monoterpenes	*halophila* (0.01) carvacrol 36 *aethiopis*[e] (tr) linalool 20 *candidissima/occidentalis* (0.2) linalool 9 *cyanescens* (0.4) borneol + isoborneol 10 *albimaculata* (0.3) *trans*-verbenol + β-selinene 11
Sesquiterpene hydrocarbons	***β-caryophyllene*** *virgata* (tr-0.02) 28–55 *dichroantha* (tr-0.2) 23 *bracteata* (0.2) 21 *napifolia* (0.4) 20 *microphylla* (0.4–0.5) 14–17 *verticillata/amasiaca* (0.1) 17 *yosgadensis* (0.3) 13 ***germacrene D*** *chionantha* (0.02) 38 *syriaca*[f] (0.1) 34 *argentea* (0.2) 27 *candidissima/candidissima* (0.2) 21 *verticillata/verticillata* (0.06–0.07) 10–16 *forskahlei* (0.05) 15 *candidissima/occidentalis* (0.1) 13 *hypargeia* (0.02) 11 *cilicica* (0.04) 10 ***others*** *aethiopis*[g] (0.2) α-copaene 25 *albimaculata* (0.3) β-selinene 11 (with *trans*-verbenol)
Oxygenated sesquiterpenes	***Spathulenol*** *syriaca*[h] (0.03–0.08) 11–20 *heldreichiana*[i] (0.2) 9 *microstegia* (0.1) 5
Phenylpropanoid	*viridis* (0.02) methylchavicol 28

[a]Exceptions: one sample (1.4) CaCi 36/15; one sample (1.3) borneol 27
[b]CaCi: *tomentosa* [pinene gr.] (1.4) 36/15; *pisidica* [ester gr.] (0.4) 30/6; *aramiensis* (3.0) camphor 17, α-terpineol 11; *cryptantha* (0.9) 24/10
[c]one sample (0.6) borneol 25
[d]one sample (1.1) LaLi 14/24
[e]one sample (0.2) α-copaene 25
[f]two samples (0.03–0.08) spathulenol 11–20
[g]one sample (tr) linalool 20
[h]one sample (0.1) germacrene D 24
[i]one sample (tr) borneol 15

Thymus

Thymus (Labiatae) is a polymorphic genus with 60 taxa belonging to 39 species in Turkey. The ratio of endemism is 45 %. One hundred eighty-one specimens belonging to 51 taxa have been studied at TBAM for essential oils [20–46]. This constitutes that 85 % of the *Thymus* taxa of Turkey have been investigated for essential oil. The studies have indicated that 49 % of all *Thymus* taxa are considered as oil-rich (>1 %). Thirty-three percent which yield 0.1–1.0 % oil are considered moderate-rich, and only 18 % contained less than 0.1 % oil. The survey has revealed that 24 *Thymus* taxa contained thymol and 11 taxa contained carvacrol as main constituents (Table 6). The highest thymol content (85 %) was encountered in the oil of *Thymus migricus*. Over 3 % oil and up to 70 % thymol were found in *T. long-*

icaulis subsp. *chaubardii* var. *chaubardii* and var. *alternatus*. Highest carvacrol content was found in the oil of *T. migricus* (78 %). *T. kotschyanus* var. *glabrescens* contained over 3 % oil with 53–70 % carvacrol.

Table 6 Main components in *Thymus* essential oils.

Omt	Taxa	Mthc	Taxa
Thymol	24	*p*-Cymene	3
Carvacrol	11	α-Pinene	2
Linalool	7		
α-Terpinyl acetate	4	Sthc	Taxa
1,8-Cineole	3	β-Caryophyllene	10
Geraniol	3	Germacrene D	2
Linalyl acetate	2		
Citral	2	Ost	Taxa
Borneol	2	Caryophyllene Oxide	3
α-Terpineol	1	(*E*)-Nerolidol	1
Camphor	1	Elemol	1

The following chemotype patterns are common among the *Thymus* taxa in Turkey (Table 7).

Table 7 Pure chemotype patterns among *Thymus* taxa in Turkey.

1. Carvacrol *and/or* thymol, *p*-cymene, γ-terpinene (*oregano or thyme smell*)
2. Geraniol, geranyl acetate (*rose smell*)
3. Geranial, neral (*lemon smell*)
4. Linalool, linalyl acetate (*lavender smell*)
5. α-Terpineol, α-terpinyl acetate (*lavender smell*)
6. 1,8-Cineole, α-terpineol, α-terpinyl acetate, borneol, camphor, α/β-pinenes, limonene may come together (e.g., *Thymus cariensis*, *T.cilicicus*)
7. β-Caryophyllene, germacrene D, caryophyllene oxide
8. Other sesquiterpenes

Several chemotypes may occur withing a dense population of the same taxon, e.g., *Thymus longicaulis* subsp. *longicaulis* var. *longicaulis* (Table 8) or in several populations of a taxon growing nearby, e.g., *T. zygioides* (Table 9).

Table 8 *Thymus longicaulis* subsp. *longicaulis* var. *longicaulis* 3 chemotypes growing into each other in 1 m^2 area [25].

Odor type	Oil yield	Main components (%)
Thyme	0.3	Thymol (53), *p*-Cymene (18)
Rose	0.8	Geraniol (69), Geranyl acetate (16)
Lavender	1.7	α-Terpinyl acetate (82)

Table 9 *Thymus zygioides* var. *lycaonicus* growing in the same vicinity [35].

Odor type	Oil yield (%)	Main components (%)
Lavender	1.7	α-Terpinyl acetate (36), α-Terpineol (19)
Oregano	1.0	Carvacrol (48), γ-Terpinene (12), Thymol (10)
Rose	0.2	Geraniol (69), Geranyl acetate (7)
Thyme (4 samples)	1.0–1.9	Thymol (42–57), γ-Terpinene (4–19), Carvacrol (4–10)

Linalool ranks third in components occurring most in *Thymus* oils of Turkey. Enantiomeric analysis of linalool showed the occurrence of (–)-enantiomer in the oils of all ten taxa studied. Pure (100 % ee) enantiomer of (–)-linalool was encountered in the oils of *T. zygioides* var. *zygioides* (linalool content—33.7 %), *T. sibthorpii* (20.4 %), *T. revolutus* (15.5 %), *T. fedschenkoi* var. *handelii* (12.9 %), *T. migricus* (9.7 %).

Origanum

The genus *Origanum* (Labiatae) is represented in Turkey by 22 species or 32 taxa, 21 being endemic to Turkey. Out of 52 known taxa of *Origanum*, 60 % are recorded to grow in Turkey. This high rate is suggestive that the gene center of *Origanum* is in Turkey .

Twenty-six *Origanum* taxa growing in Turkey have been studied for their essential oils [47,48]. *Origanum* species according to main components in their oils are shown in Table 10.

O. sipyleum is a polymorphic endemic species growing in western provinces of Turkey. The analysis of twelve samples collected from different localities showed that no single chemical could characterize the species. Although carvacrol and thymol were present in all the samples, main components were variously found in different samples as shown in Table 11. Oil yields varied between 0.1–1.7 % [49].

Table 10 Yields and main constituents in the *Origanum* oils of Turkey.

Group	*Taxa* (oil yield) % component
Carvacrol	*majorana* (5.2–7.8) 32–84
	onites (1.1–4.7) 67–82
	minutiflorum (1.1–3.8) 42–82
	vulgare subsp. *hirtum* (1.1–6.5) 23–79[a]
	syriacum var. *bevanii* (0.4–3.7) 43–79
	acutidens (1.4) 66
	bilgeri (1.3) 66
	hypericifolium (0.9–2.5) 34–64[b]
	x*intercedens* (4.3) 46[c]
	x*adanense* (0.2) 17[d]
	bargyli (1.1) 15
p-Cymene	*saccatum* (1.3–1.4) 61–84
	solymicum (0.2) 53
	leptocladum (0.2) 48
	boissieri (0.3) 43
	haussknechtii (0.2) 16
Other monoterpenes	*husnucan-baseri* (0.1) borneol 20
	onites (2.6–4.0) linalool 80–92[e]
	vulgare subsp. *viride* (0.08) linalool 21[f]
	micranthum (0.4–0.5) linalyl acetate 10–12[g]
	majorana (1.1–2.3) *cis*-sabinene hydrate 30–44[h]
	x*majoricum* (0.7–1.9) *cis*-sabinene hydrate 24–37[i]
	rotundifolium (0.3) *cis*-sabinene hydrate 22
Sesquiterpenes	*vulgare* subsp. *gracile* (0.04) β-caryophyllene 18–20
	vulgare subsp. *vulgare* (0.08) germacrene D 18–22, β-caryophylene 18–20
	vulgare subsp. *viride* (0.1) germacrene D 16[j]
	laevigatum (0.03) bicyclogermacrene 38, germacrene D 22
	x*dolichosiphon* (0.04) bicyclogermacrene 20, β-caryophyllene 13, germacrene D 11[k]

[a]The ratios of carvacrol + thymol (A) were correlated with those of *p*-cymene + γ-terpinene (B) (A/B) against the yield of oil. The conclusion was *the larger the ratio, the higher the carvacrol (+ thymol) content, the better the oil yield*.

[b]Plants collected before flowering and budding stages yielded oils with high carvacrol content. Flowering plants had poor oil yields with *p*-cymene (36–48) and γ-terpinene (up to 40 %) as main constituents. No wonder that people collect this species before flowering.
[c]It is a natural hybrid of *O. onites* and *O. vulgare* subsp. *hirtum*.
[d]It is a natural hybrid of *O. laevigatum* and *O. bargyli*.
[e]Linalool chemotype is encountered in Antalya and Burdur provinces.
[f]Other major component was germacrene D (11 %).
[g]Other major components were linalool (9–11 %), α-terpineol (10–11), carvacrol (0.1–11 %).
[h]This is sweet marjoram. Carvacrol rich *O. majorana* grows wild in Antalya. This species was previously known as *O. dubium*.
[i]It is a cultivated hybrid of *O. majorana* and *O.vulgare* subsp. *virens*, not a native plant of Turkey.
[j]In one sample linalool (21 %) and germacrene D (11 %) were main constituents.
[k]This is a natural hybrid of *O. laevigatum* and *O. amanum*.

Table 11 Main components of the essential oil of *O. sipyleum*

Main Components (%)	Samples studied
p-Cymene (28–40)	4
γ-Terpinene (23–34)	4
β-Caryophyllene (17–22)	2
Myrcene (37)	1
Thymol methylether (20)	1
Thymol (tr–16)	12
Carvacrol (1–12)	12

Thymbra

Thymbra (Labiatae) is represented in Turkey by four taxa belonging to two species. Carvacrol was found as the main constituent in all the oil samples [48,50–52].

Table 12 Yields and main constituents in the *Thymbra* oils of Turkey.

Thymbra taxon	Part	Yield (%)	Main compounds %	No. samples studied
spicata var. *spicata*	Herb	1.0–3.4	Carvacrol 56–71	9
	Leaf	1.6–5.2	Carvacrol 59–70	2
	Flower	4.1	Carvacrol 77	1
spicata var. *intricata*	Herb	1.4–2.7	Carvacrol 49–71	6
	Herb	2.0	Thymol 51	1
sintenisii subsp. *sintenisii*	Herb	1.5	Carvacrol 43, thymol 33, γ-terpinene 9	1
sintenisii subsp. *isaurica*	Herb	1.6	Carvacrol 39, *p*-cymene 26, γ-terpinene 13	1

Satureja

Satureja (Labiatae) is represented in Turkey by 15 taxa. All but *S. amani* have been studied at TBAM for essential oil [48,53–62]. The results are summarized in Table 13 .

Carvacrol and/or thymol were found as the main components in all but four taxa of *Satureja* in Turkey. All the oils from cultivated form of *Satureja hortensis* contained carvacrol as the main constituent. Carvacrol was also the main component in the oils of *S. hortensis* growing wild in western parts of Turkey including the Eastern Mediterranean province, Adana. On the other hand, except for one collection from Artvin in the northeastern corner of Turkey, in which the percentages of carvacrol and thymol were even (16 % and 17 %, respectively), all the other materials collected from the east contained thymol (29–43 %) as the main constituent in their oils [63].

Table 13 Yields and main components in the *Satureja* oils of Turkey.

Satureja taxon	End	Part	Yield (%)	Main compounds %
*aintabensis**	E	Herb	2.8	*p*-Cymene 32, Carvacrol 28, γ-Terpinene 21
*boissieri**	E	Herb	2.1	Carvacrol 41, γ-Terpinene 27, *p*-Cymene 15
cilicica	E	Herb	0.9	Carvacrol 38, *p*-Cymene 15, γ-Terpinene 14
coerulea		Herb	0.02–0.09	Germacrene D 13–21
cuneifolia		Herb	0.3–3.6	Carvacrol 26–72 [*11 samples*]
		Herb	0.6–2.8	Thymol 17–43 [*8 samples*]
hortensis		Herb	1.3–2.7	Carvacrol 42–63 [*13 samples*]
		Herb	1.3–4.8	Thymol 17–43 [*7 samples*]
icarica		Herb	0.8–1.1	Carvacrol 52–56, *p*-Cymene 13–17
*macrantha**		Herb	1.7	Carvacrol 54
montana	C	Herb	1.5	Carvacrol 63
	C	Leaf	2.8	Carvacrol 63
parnassica subsp. *sipylea*[a]	E	Herb	0.1–0.2	Linalool 21–23
(preflowering)	E	Herb	0.2	Linalool 44
pilosa		Herb	1.1–2.7	Carvacrol 38–53, *p*-Cymene 7–17, γ-Terpinene 4–14
spicigera		Herb	0.2–1.5	Thymol 20–35, *p*-Cymene 9–34, Carvacrol 2–26, Methyl Carvacrol 6–21, γ-Terpinene 3–15 [*5 samples*]
spinosa (flowering)*		Herb	0.1	Linalool 47
(preflowering)		Herb	0.5	Linalool 62
*thymbra**		Herb	0.9–1.0	Carvacrol 44–45, γ-Terpinene 18–25, *p*-Cymene 7–13
		Leaf	2.9–4.3	Carvacrol 30–40, γ-Terpinene 23–25, *p*-Cymene 14–16
wiedemanniana[b]	E	Herb	0.8–3.0	Carvacrol 21–62 [*8 samples*]

E: Endemic, C: Cultivated
* not yet published
[a]one sample (<0.01) spathulenol 17
[b]three samples: (0.9) thymol 40; (0.4) borneol 16; (0.1) spathulenol 13, borneol 11

Mentha

Mentha (Labiatae) is represented in Turkey by 8 species, and altogether 15 taxa of which 8 taxa belonging to 6 species were investigated by our group for their essential oils. Eighty-five out of 272 samples collected from 181 stations in northern Turkey were water-distilled and analyzed by GC/MS. The taxa investigated were *M. aquatica*, *M. longifolia* subsp. *longifolia*, *M. longifolia* subsp. *typhoides*, *M. pulegium*, *M. spicata var. spicata*, *M. suaveolens*, *M.* x *dumetorum*, and *M.* x *villosa-nervata*.

The study revealed the diverse chemistry of the genus *Mentha* with the occurrence of several chemotypes in each taxon. In conclusion, 67 % of the wild *Mentha* oils analyzed by us were found to contain 3-oxo monoterpenoids including 1,2-epoxy derivatives such as menthone, isomenthone, pulegone, and menthofuran.

In the case of *M. pulegium*, pennyroyal, an interesting pattern was observed in the occurrence of main constituents in the oil based on geographical distribution of the plant from west to east Anatolia. Pulegone was the main component in plants collected from Izmir to Bilecik. Piperitone-rich oils were obtained from plants collected in areas stretching from Zonguldak to Samsun. Between Samsun and Rize, menthone/isomenthone group of plants were present. From Rize to Artvin, pulegone-rich oil-bearing plants reappeared. The validity of this information and its ecological or evolutionary significance has yet to be proven [64].

Ziziphora

Ziziphora (Labiatae) is represented in Turkey by six taxa belonging to five species. Essential oils of all the taxa have been studied. *Z. capitata* contained no oil [65–68]. Except for the oil-poor species, *Z. persica*, all the other oils contained pulegone as main constituent. Table 14 summarizes the results.

Table 14 Yields and main constituents in the *Ziziphora* oils of Turkey.

Ziziphora taxon	Yield (%)	Main constituent (%)
tenuior	2.0–2.3	Pulegone(85–87)
taurica subsp. *cleonioides*	1.0–1.6	Pulegone (66–78)
taurica subsp. *taurica*	0.8–1.1	Pulegone (65)
clinopodioides	0.3	Pulegone (22)
persica	0.1	Thymol (31)
capitata	No oil	–

Micromeria

Micromeria (Labiatae) is represented in the flora of Turkey by 22 taxa belonging to 14 species. Essential oils of 13 taxa have been investigated at TBAM [68–78]. The summary of results are shown in Table 15.

Table 15 Yields and main constituents in the *Micromeria* oils of Turkey.

Micromeria taxon	Yield (%)	Main compounds (%)
fruticosa subsp. *barbata*	2.5–4.0	Pulegone (57–81)
fruticosa subsp. *brachycalyx*	1.6–3.1	Pulegone (26–57), Isomenthone (9–12)
fruticosa subsp. *giresunica* (E)	2.0	Pulegone (40), Menthol (24), Menthone (24)
fruticosa subsp. *serpyllifolia*	0.7	Pulegone (33), Piperitenone (33)
congesta	0.8–1.3	Piperitenone oxide (45), Pulegone (10), Verbenone (9)
dolichodontha (E)	1.3	Isomenthone (24), *cis*-Piperitone oxide (17), Pulegone (15), Piperitone (10)
elliptica	0.02	*cis*-Piperitone oxide (44), Piperitenone oxide (17)
cristata subsp. *phrygia* (E)	0.03–0.2	Borneol (27–40), Camphor (10–13)
cristata subsp. *xyllorrhiza* (E)	0.1	Borneol (26), Camphor (9)
cristata subsp. *carminea* (E)	0.1	Borneol (26)
cristata subsp. *orientalis*	0.2	Borneol (13)
mollis	0.2	Hexadecanoic acid (9), Borneol (8), Caryophyllene oxide (7)
myrtifolia	0.5	β-Caryophyllene (43)
juliana	0.05–0.06	β-Caryophyllene (7–10), Caryophyllene oxide (7–9)

E = Endemic

Pulegone-rich oil of *M. fruticosa* subsp. *brachycalyx* and subsp. *barbata* was produced and exported (3 tons) as pennyroyal oil from wild crafted plants collected in South Anatolia in 1994. These plants have development potential as agricultural crops due to their high oil yield and pulegone content.

Calamintha

Twelve taxa of *Calamintha* (Labiatae) are recorded in Turkey belonging to 9 species including 4 endemic taxa. Five taxa were studied for their essential oils. The results are shown in Table 16 [79–82].

Table 16 Yields and main constituents in the *Calamintha* oils of Turkey.

Calamintha taxon	Part	Yield (%)	Main compounds (%)
grandiflora	Herb	0.2	Isopinocamphone (49–56)
	Leaf	0.6	Isopinocamphone (53)
incana	Herb	1.5	Piperitenone oxide (67)
nepeta subsp. *glandulosa*	Herb	0.4–2.0	*trans*-Piperitone oxide (25–58), Piperitenone oxide (18–46)
pamphylica subsp. *pamphylica*	Herb	0.9	Pulegone (36), Menthyl acetate (28), Menthol (9)
pamphylica subsp. *davisii*	Herb	0.3	Pulegone (38), Menthone (10), Menthyl acetate (9), Menthol (9)

Cyclotrichium

Cyclotrichium (Labiatae) is represented in Turkey by five species. We have analyzed all of them as shown in Table 17 [83,84]. Chemodiversity in this genus seems to be complementary in taxonomical identification of the species. However, studies are needed with more samples to prove this point.

Table 17 Yields and main constituents in the *Cyclotrichium* oils of Turkey.

Cyclotrichium taxon	Yield (%)	Main compounds (%)
niveum (E)	1.5	Pulegone (56), Isomenthone (35)
origanifolium (E)	0.4–1.2	*cis*-Isopulegone (4–52), Pulegone (7–37), Isomenthone (2–31), Isomenthol (0.3–11)
stamineum	1.5	Pinocamphone (34), Isopinocamphone (14)
leucotrichum	0.2	Terpinen-4-ol (11), Linalool (9), Myrcene (8), 1,8-Cineole (6)
glabrescens	0.8	1,8-Cineole (37), Cubenol (13), T-Cadinol (12)

E = Endemic

Acinos

Acinos (Labiatae) is represented in Turkey by six taxa belonging to five species. All of them have been analyzed for essential oil [85–87]. As Table 18 clearly shows, *A. suaveolens* was singled out as the only species with high pulegone content in its oil.

Table 18 Yields and main constituents in the *Acinos* oils of Turkey.

Acinos taxon	Yield (%)	Main compounds (%)
suaveolens	0.6–1.2	Pulegone (23–81), Isomenthone (1–54)
rotundifolius	0.02–0.03	Germacrene D (14–73), Hexadecanoic acid (18–30)
alpinus	0.01–0.08	Germacrene D (4–40), Hexadecanoic acid (4–24), Thymol (10–15)
troodi subsp. *grandiflorus* (E)	0.03–0.05	Germacrene D (14–30), Hexadecanoic acid (15–22)
troodi subsp. vardaranus (E)	0.01–0.06	Germacrene D (10–15), Hexadecanoic acid (8–18)
arvensis	0.02	Germacrene D (14), Hexadecanoic acid (14)

E = Endemic

Echinophora

Echinophora (Umbelliferae) is represented in Turkey by seven species. Fruits of all the species were analyzed for their respective oils at TBAM [88–90]. A diverse picture was obtained with oil of each species characterized by a different compound. Table 19 summarizes the results.

Table 19 Yields and main constituents in the *Echinophora* oils of Turkey.

Echinophora taxon	Yield (%)	Main compounds (%)
tenuifolia subsp. sibthorpiana	1.0–2.2	Methyl eugenol (18–59), α-Phellandrene (16–52), *p*-Cymene (11–15)
chrysantha (E)	0.7–1.4	α-Phellandrene (48–61)
lamondiana (E)	1.6	δ-3-Carene (48), α-phellandrene (28)
trichophylla (E)	1.4	Sabinene (27), Terpinen-4-ol (16), 2,6-Dimethyl-1,3(E),5(E),7-Octatetraene (14)
orientalis	0.7	Myrcene (34), *p*-Cymene (19)
carvifolia (E)	0.5	Germacrene D (31), β-Caryophyllene (5)
tournefortii	0.2	Caryophyllene oxide (13), α-Pinene (10)

E = Endemic

Ferulago

Ferulago (Umbelliferae) is represented in Turkey by 30 species, of which 16 are endemic to Turkey. Twelve species have been studied at TBAM for the composition of their essential oils. The results are shown cumulatively in Table 20 [91–93].

Table 20 Yields and main constituents in the *Ferulago* oils of Turkey.

Ferulago taxa	Part	Yield (%)	Dist.	Main components (%)
asparagifolia	Fruit	7.0	WD	2,3,6-Trimethylbenzaldehyde (39), Myrcene (18)
			MD	2,3,6-Trimethylbenzaldehyde (42, α-Pinene (11)
idaea (E)	Fruit		MD	*p*-Cymene (18), α-Pinene (16), 2,3,6-Trimethyl-benzaldehyde (14), Carvacrol methylether (13), 2,5-Dimethoxy *p*-cymene (13)
sylvatica	Fruit		MD	*p*-Cymene (46), 2,5-Dimethoxy *p*-cymene (40)
confusa	Fruit		MD	2,5-Dimethoxy *p*-cymene (63), *p*-Cymene (24)
galbanifera	Fruit		MD	*cis*-Chrysanthenyl acetate (17), *p*-Cymene (12), α-Phellandrene (11), Limonene (10)
		1.3	WD	α-Pinene (32), Sabinene (16), Limonene (7), α-Phellandrene (6)
silaifolia (E)	Fruit		MD	*cis*-Chrysanthenyl acetate (84), α-Pinene (6)
humilis (E)	Fruit		MD	(*Z*)-β-Ocimene (32), Limonene (31)
trachycarpa	Fruit	7.3	WD	(*Z*)-β-Ocimene (31), Myrcene (28)
	Herb	0.6	WD	(*Z*)-β-Ocimene (34), α-Pinene (8)
	Root	0.02	WD	Octanal (10), (E)-2-Decenal (7)
	Fruit		MD	γ-Terpinene (28), *p*-Cymene (22), Myrcene (20)
			MD	α-Pinene (41), Germacrene D (8), α-Humulene (6), *trans*-Chrysanthenyl acetate (5)
aucheri (E)	Fruit		MD	α-Pinene (21), Caryophyllene oxide (8), Spathulenol (7)
			MD	α-Pinene (36), Humulene epoxide II (7), *trans*-Verbenol (6)
mughlae (E)	Fruit		MD	α-Pinene (25), Cubenol (13), β-Phellandrene (6)
macrosciadia (E)	Fruit		MD	Carvacrol methylether (78–92, *p*-Cymene (19–38)

E: Endemic, MD: Micro distillation, WD: Water distillation

Heracleum

Heracleum (Umbelliferae) is represented by 22 species belonging to 17 species in Turkey. The fruit oils of all the four species analyzed contained fatty acid esters as main components (Table 24). Indeed, fatty acid esters, e.g., octyl esters in fruit oils can be considered as marker compounds for *Heracleum* [94–96] and related species such as *Zosima* [97]. They are easily recognizable by the rancid butter-like smell which appears after crushing the fruits.

Table 21 Yields and main constituents in the *Heracleum* oils of Turkey.

Heracleum taxon	Yield (%)	Main compounds (%)
argaeum (E)	1.2	Hexyl butyrate (40), Octyl hexanoate (9)
paphlagonicum (E)	4.9–7.4	Octyl acetate (27–95), Hexyl butyrate (17–25)
platytaenium (E)	5.2–6.8	Octyl acetate (72–77), Octyl butyrate (8–17)
sphondylium subsp. *ternatum*	2.0	Octyl acetate (55), Octyl butyrate (11)
Zosima absinthifolia	0.9	Octyl acetate (38), Octyl hexanoate (32)

E = Endemic

Pimpinella

Pimpinella (Umbelliferae) is represented in Turkey by 28 taxa belonging to 23 species including 3 endemics. Work on the essential oils of all the *Pimpinella* taxa of Turkey is ongoing. Table 22 summarizes some published results [98–99].

Table 22 Yields and main constituents in the *Pimpinella* oils of Turkey.

Pimpinella taxa	Part	Yield (%)	Main components (%)
anisum	Fruit	1.6	*trans*-Anethole (96)
anisetum (E)	Fruit	5.3	*trans*-Anethole (77), Methylchavicol (22)
	Herb	3.0	*trans*-anethole (55), Methylchavicol (42)
aromatica	Herb	6.1	Methylchavicol (92), *trans*-Anethole (7)
	Root	4.2	*trans*-Epoxypseudoeugenyl-2-methyl butyrate (40), 4,10-Dihydro-1,4-dimethylazulene (17), 1,4-Dimethylazulene (9), Pregeijerene (5)
cappadocica (E)	Fruit	0.3	Caryophyllene oxide (26)
	Herb	0.7	Himachalol (16)
corymbosa	Fruit	0.2	β-Caryophyllene (14), Caryophyllene oxide (11)
	Herb	0.1	β-Caryophyllene (38), Caryophyllene oxide (17)
isaurica (E)	Herb	1.3	Chavicyl angelate (44)
tragium ssp. *lithophila*	Fruit	7.1	Limonene (36), β-Pinene (27), Sabinene (16)

E = Endemic

P. anisum is the cultivated aniseed, a commercial crop. It is one of the main export crops of Turkey. Annually, ca. 11 000 tons of aniseed is produced in Turkey, 7000 tons of which is used in manufacturing the famous Turkish alcoholic beverage, Raki. In 2000, Turkey exported 3800 tons of aniseed for a return of $6.4 million [100].

The fruits of wild-growing *P. anisetum*, an endemic species, yielded 5.3 % essential oil with *trans*-anethol (77 %) and methyl chavicol (22 %) as main constituents. Its oil yield is twice as much as that of *P. anisum*. This species seems to be a promising alternative to common aniseed with agronomic development potential.

Tanacetum

Tanacetum (Compositae) is represented in Turkey by 60 taxa belonging to 45 species including 17 endemics. We have so far investigated the essential oil composition of eight taxa. The results are summarized in Table 23 [101–102].

Table 23 Yields and main constituents in the *Tanacetum* oils of Turkey.

Tanacetum taxa	Part	Yield (%)	Main components (%)
argenteum subsp. *canum var canum*	Leaf	0.04	Caryophyllene oxide (13), α-Thujone (12)
argyrophyllum var. *argyrophyllum*	Leaf	1.0	α-Thujone (52), 1,8-Cineole (11), β-Thujone (5)
	Flower	1.0	α-Thujone (63), 1,8-Cineole (4), β-Thujone (4)
armenum	Leaf	0.6	1,8-Cineole (31), Camphor (9)[a]
	Herb	0.7	Camphor (27)[b], 1,8-Cineole (11)
balsamita	Herb	0.4	Carvone (54)[c], α-Thujone (12)
chiliophyllum var. *chiliophyllum*	Flower	0.4	Camphor (17)[d], *trans*-Chrysanthenyl acetate (16)
haradjani	Leaf	0.6	Camphor (16)[a], 1,8-Cineole (10)
praeteritum subsp. *praeteritum*	Herb	1.1	Borneol (28), 1,8-Cineole (12), Bornyl acetate (10)
praeteritum subsp. *massicyticum*	Herb	0.9	α-Thujone (51), β-Thujone (10)

[a](–)-camphor (100 % ee),
[b](–)-camphor (99.97 % ee),
[c](–)-carvone (99.8 % ee)
[d](+)-camphor (79.2 % ee) and (–)-camphor (20.8 % ee)

Betula

Betula (Betulaceae) is represented in Turkey by five species including one endemic. We have analyzed the leaf, bud, and leafless branch oils of all the *Betula* species of Turkey. Tables 24 and 25 summarize the results on leaf and bud oils. The major component 14-hydroxy-4,5-dihydro-β-caryophyllene and several other caryophyllene derivatives were isolated as new compounds from *Betula* oils in the course of this investigation [103–105].

Table 24 Yields and main constituents in the bud oils of *Betula* species of Turkey.

Betula species	Yield (%)	Main compounds (%)
litwinowii	6.3	14-Hydroxy-4,5-dihydro-β-caryophyllene (37), 14-Hydroxy-β-caryophyllene (α-betulenol) (22)
pendula	3.8	14-Hydroxy-β-caryophyllene (α-betulenol) (25), 14-Hydroxy-4,5-dihydro-β-caryophyllene (37)
browicziana (E)	L–N	14-Hydroxy-β-caryophyllene (α-betulenol) (25), 14-Hydroxy-4,5-dihydro-β-caryophyllene (16)
recurvata	L–N	14-Hydroxy-β-caryophyllene (α-betulenol) (38), 14-Hydroxy-4,5-dihydro-β-caryophyllene (37)
medwediewii	0.1	Methyl salicylate (68)

E = Endemic; L–N = Likens–Nickerson simultaneous distillation-extraction

Table 25 Yields and main constituents in the leaf oils of *Betula* species of Turkey.

Betula species	Yield (%)	Main compounds (%)
litwinowii	0.2	14-Hydroxy-4,5-dihydro-β-caryophyllene (19), 14-Hydroxy-β-caryophyllene (α-betulenol) (13)
pendula	0.6	14-Hydroxy-β-caryophyllene (α-betulenol) (29), 14-Hydroxy-4,5-dihydro-β-caryophyllene (21)
browicziana (E)	0.1	14-Hydroxy-4,5-dihydro-β-caryophyllene (25), 14-Hydroxy-β-caryophyllene (α-betulenol) (13)
recurvata	0.6	14-Hydroxy-4,5-dihydro-β-caryophyllene (25), 14-Hydroxy-β-caryophyllene (α-betulenol) (21)
medwediewii	0.1	Methyl salicylate (50)

E = Endemic

BIOPROSPECTING

Bioprospecting is described as tapping the potential of bioresources for the welfare of humanity and to improve the quality of life in a sustainable manner [106]. It is an environment-friendly exploitation of biological resources. It is also described as the search for valuable compounds in nature.

Wild crafting, that is harvesting biological materials from wild sources, is mainly practiced in developing countries where people resort to it either to earn extra income or for their health needs. In Turkey, like many developing countries, wild crafting of several plant materials is common practice.

In the wild flora, over millions of years, plants have evolved capabilities to biosynthesize chemicals with highly diverse structures for their survival. Among thousands of natural chemicals only a relatively small number has been utilized by industry. Perfumery companies are in search of novel resources of natural aromachemicals. Nature is the only source to exploit such a potential. Systematic screening of aromatic biodiversity often leads to the discovery of new leads with development potential. It is then either the work of agronomists to use them as sources of genetic material for the development of new crops or for improving existing ones, or chemists to synthesize them. If both fails then only wild crafting becomes the only way of exploitation.

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