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REVIEW

Essential Oils of *Achillea* Species of Turkey

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Abstract

The genus *Achillea* L.(Asteraceae) is represented by 115 species in the Northern Hemisphere. In the flora of Turkey, 48 species and altogether 54 taxa have been recorded, 24 being endemic. So far, 31 *Achillea* taxa growing wild in Turkey have been studied for their essential oils. Most have been characterized by the occurrence of camphor and 1,8-cineole as main constituents in their oils.
This paper reviews the essential oil compositions of *A. aleppica* subsp*. aleppica, A. biebersteinii, A. biserrata, A. cretica, A. coarctata, A. cucullata, A. falcata, A. filipendulina, A. formosa* subsp*. amanica, A.goniocephala, A. gypsicola, A. hamzaoglui, A. ketenoglui, A. kotschyi* subsp*. kotschyi, A. lycaonica, A. magnifica, A. millefolium subsp. millefolium, A. multifida, A. nobilis subsp. neilreichii, A. oligocephala, A. phrygia, A. pseudoaleppica, A. salicifolia subsp. salicifolia, A. schischkinii, A. setacea, A. sieheana, A. sintenisii, A.tenuifolia, A. teretifolia, A. vermicularis, A. wilhelmsii.*

Keywords: *Achillea*, Essential oil, Asteraceae, activity

Introduction

Achillea L. (Asteraceae) is represented in the World by 110-140 species, centred in South West Asia and South East Europe with extensions through Eurasia to North America. The genus is represented in Turkey by 48 species belonging to 54 taxa, 24 of which endemic in Turkey. Endemism ratio is 50%. The species are classified into 4 sections: Otanthus (1 species), Babounya (30 species, 2 subspecies), Ptarmica (4 species), Achillea (13 species, 4 subspecies).

Table 1. *Achillea* taxa recorded in the flora of Turkey (Arabaci, 2012)

1. *A. aleppica* DC. subsp. *aleppica* subsp. *zederbaueri* (Hayek) Hub-Mor. 2. *A. armenorum* Boiss. & Hausskn. 3. *A. arabica* Kotschy. 4. *A. biserrata* M.Bieb. 5. *A. boissieri* Hausskn. ex Boiss. 6. *A. brachyphylla* Boiss. & Hausskn. 7. *A. cappadocica* Hausskn. & Bornm. 8. *A. clypeolata* Sibth. & Sm. 9. *A. coarctata* Poir. 10. *A. cretica* L. 11. *A. crithmifolia* Waldst. & Kit. 12. *A. cucullata* Bornm 13. *A. falcata* L. 14. *A. filipendulina* Lam. 15. *A. formosa* (Boiss.) Sch.Bip. subsp. *formosa* subsp. *amanica* (Rech.f.) Ehrend &Y. Guo 16. *A. fraasii* Sch.Bip. 17. *A. goniocephala* Boiss. & Balansa 18. *A. grandifolia* Friv. 19. *A. gypsicola* Hub.-Mor.	20. *A. hamzaoglui* Arabacı & Budak 21. *A. ketenoglui* H.Duman 22. *A. kotschyi* Boiss. subsp. *kotschyi* subsp. *canescens* Bässler 23. *A. latiloba* Ledeb. ex. Nordm. 24. *A. lycaonica* Boiss. & Heldr. 25. *A. magnifica* Heimerl ex Hub.-Mor. 26. *A. maritima* (L.) Ehrend. & Y.P.Guo subsp. *maritima* 27. *A. membranacea* (Labill.) DC. 28. *A. millefolium* L. subsp. *millefolium* 29. *A. milliana* H.Duman 30. *A. monocephala* Boiss. & Balansa 31. *A. multifida* (DC.) Griseb. 32. A. *nobilis* L. subsp. *densissima* (O. Schwarz ex Bässler) Hub-Mor. subsp. *kurdica* Hub-Mor. subsp. *neilreichii* (A. Kern.) Velen subsp. *sipylea* (O.Schwarz) Bässler	33. A. *oligocephala* DC. 34. A. *pannonica* Scheele 35. A. *phrygia* Boiss. & Balansa 36. A. *pseudoaleppica* Hausskn. ex Hub-Mor. 37.A. *salicifolia* Besser subsp. *salicifolia* 38. *A. santolinoides* Lag. subsp. *wilhelmsii* (K. Koch.) Greuter 39. *A. schischkinii* Sosn. 40. *A. setacea* Waldst. & Kit. 41. *A. sieheana* Stapf 42. *A. sintenisii* Hub.-Mor 43. *A. sipikorensis* Hausskn. & Bornm. 44. *A. sivasica* Çelik & Akpulat 45. *A. spinulifolia* Fenzl ex Boiss. 46. *A. tenuifolia* Lam. 47. *A. teretifolia* Willd. 48. *A. vermicularis* Trin.

31 *Achillea* species of Turkey have been studied for their essential oil yield and composition. Dried aerial parts were water distilled to obtain essential oil. In some oil-poor species essential oil was recovered by trapping the oil in *n*-hexane during distillation. Oil yields varied between <0.01% (*kotschyi* subsp. *kotschyi*, *setacea*) and 1.2% (*A. pseudoaleppica, A. sieheana, A. biebersteinii*). Most oils yielded less than 1% essential oil. Five species yielded more than 1% essential oil (*A. multifida, A. oligocephala*) (Table 2). Some of these oils have been subjected to various biological activity testing. The *Achillea* taxa studied will be treated in alphabetical order.

Table 2. Essential oil yields of *Achillea* species

***Achillea* L.**	**Essential oil yield (%)**
aleppica subsp. *aleppica*	0.1-0.6
biebersteinii	0.2-1.2
biserrata	0.07
coarctata	0.9
cretica	<0.1
cucullata	0.4
falcata	0.3-0.8
filipendulina	0.8
formosa subsp. *amanica*	<0.1
goniocephala	0.4
gypsicola	0.65
hamzaoglui	0.07
ketenoglui	0.1
kotschyi subsp. *kotschyi*	<0.01
lycaonica	0.9
magnifica	0.5-0.9
millefolium subsp. *millefolium*	0.6
multifida	1.06
nobilis subsp. *neilreichii*	0.3
oligocephala	1.0
phrygia	0.7
pseudoaleppica	1.2
salicifolia subsp. *salicifolia*	0.08
schischkinii	0.3
setacea	<0.01
sieheana	0.3-1.2
sintenisii	0.6
tenuifolia	0.2-0.6
teretifolia	0.5-0.6
vermicularis	0.3
wilhelmsii	0.3

Achillea aleppica subsp. *aleppica*

Oils obtained from plants collected from three different localities were analyzed. Camphor and 1,8-cineole were main constituents in the Hazar and Keban regions of Elazığ, 34% and 20%, and 33% and 26%, resp. Hazar sample also contained *p*-cymene (14%) and Keban sample, α–pinene (4%) as other main constituents.

In the sample from Gaziantep, 1,8-cineole (26%) was the main constituent with α-terpineol (9%), α-bisabolol oxide (4%), T-cadinol (4%), caryophyllene oxide (3%), spathulenol (3%) and camphor (3%).

Antimicrobial, antiinflammatory, antinociceptive activities were also detected in the oils (Toncer et al. 2010 and Iscan et al., 2006)

Achillea biebersteinii

As the Table 2, clearly shows, most *A. biebersteinii* oils contained camphor and 1,8-cineole as main constituents with five samples containing piperitone as the third most occurring constituent. In one Ankara sample (Ankara C) piperitone (50%) was the main constituent. □a-terpinyl acetate (7%) was also encountered in this oil. Another third constituent encountered in five oils was p-cymene. It was the main constituent in Ankara B sample (27%). Borneol (7%) was the third main constituent in Ankara A sample. A sample from Sivas contained α-thujone (13%), p-cymene (5%), β-thujone (3%), borneol (3%) as other significant constituents.

It was interesting to see ascaridol (62%) and p-cymene (16%) as main constituents in one sample from Siirt with nocamphoror 1,8-cineole. Although, ascaridol is a known component of this species, it is early to name it as a chemotype (Oskay & Yesilada, 1984). Antioxidant, insecticidal, herbicidal activities of the oils were reported (Techen et al., 2009; Tabanca et al., 2011; Kordali et al., 2009; Küsmenoğlu et al, 1995; Toncer et al., 2010; Demirci et al., 2011; Polatoğlu et al., 2013).

Table 2. Summarized results of the essential oil samples of *A. biebersteinii* from different locations.

Locality	**Camphor**	**1,8-cineole**	**Others**	**Reference**
Ankara A	30	36	borneol 7	Tabanca et al, 2011
Ankara B	25	9	*p*-cymene 27	Tabanca et al, 2011
Ankara C	9	11	piperitone 50 α-terpinyl acetate 7	Kusmenoglu et al., 1995
Ankara D	12	17	*p*-cymene 19	Turkmenoglu et al, 2015
Erzurum	17	30	piperitone 3	Kusmenoglu et al, 1995
Bingöl	15	15	piperitone 13	Toncer et al., 2010
Mardin	28	32	piperitone 12	Toncer et al., 2010
Ağrı	12	31	piperitone 29	Polatoglu et al., 2013
Konya C	16	37	piperitone 11	Tabanca et al., 2011
Konya D	22	36	*p*-cymene 13	Tabanca et al., 2011
Isparta	22	34	*p*-cymene 13	Tabanca et al., 2011
Elazığ	16	42	*p*-cymene 6	Toncer et al, 2010
Sivas	14	31	α-thujone 13, p-cymene 5, β-thujone 3, borneol 3	Polatoglu et al., 2013
Siirt	-	-	ascaridol 62, *p*-cymene 16	Toncer et al., 2010

Achillea biserrata

There is only one publication on the essential oil of this species in which camphor (37%), 1,8-cineole (19%), camphene (16%) and artemisia alcohol (14%) were reported as main constituents. Antimicrobial properties of the oil was also determined and showed mild inhbitory activity against most of the microorganisms tested (Azaz et al., 2009).

Achillea coarctata

Essential oil from aerial parts yielded 0.9% oil which showed 1,8-cineole (20%), camphor (16%) and viridiflorol (12%) as main constituents (Toker et al., 2003). In another study, viridiflorol (26%), camphor (10%), caryophyllene oxide (10%), 15-hexadecanolide (9%), hexadecanoic acid (8%) and β-eudesmol (7%) were reported as main constituents (Turkmenoglu et al., 2015).

Achillea cretica

Caryophylladienol-II (13%), β-maaliene (6%), neo-intermedeol (6%), carvone (5%), spathulenol (5%), palmitic acid (3%), selina-3,11-dien-6-ol (3%) were characterized as main constituents of the essential oil of this species (Kucukbay et al., 2012).

Achillea cucullata

Aerial parts of this endemic species contained camphor (33%), 1,8-cineole (29%) and isoborneol (4%) as main constituents in its hydrodistilled essential oil (Toncer et al., 2010).

Achillea falcata

Essential oils of this plant collected from two localities in Antalya, Turkey yielded 1,8-cineole (14-24%), camphor (2-24%) and α-pinene (2-12%) as main constituents. The enantiomeric distribution of 1S (−) camphor was measured as 93.3% and 99.6% in the two oils. Both enantiomers of camphor arefound in nature. However, the S(−) enantiomer is less frequently found than the R (+) enantiomer (Kurkcuoglu et al., 2003).

Achillea filipendulina

This oil contained santolina alcohol (44%), 1,8-cineole (15%) and cis-chrysanthenyl acetate (13%) as main constituents. *A. filipendulina* oil showed strong antimalarial activity against chloroquine sensitive D6 (IC_{50} = 0.68 mg/mL) and chloroquine resistant W2 (IC_{50}= 0.9 mg/mL) strains of*Plasmodium falciparum* without cytotoxicity to mammalian cells. It also demonstrated weak non-selective antifungal activity against filamentous fungal plant pathogens *Colletotrichum acutatum, C. fragariae*, and *C. gloeosporioides* (Demirci, et al., 2009).

Achillea formosa subsp*. amanica*

Borneol (13%), hexadecanoic acid (12%), caryophyllene oxide (6%), camphor (5%), elemol (5%), β-eudesmol (5%), α-terpineol (5%) were reported as main constituents in the oil of this endemic species. Antimicrobial activity of the oil was tested against 6 microorganisms. The essential oil was particularly effective against the yeasts *Candida albicans* and *Candida tropicalis* with the lowestMIC value (12.5 μg/ml), and moderately active against the Gram-positive bacteria *Staphylococcus aureus* and *Enterococcus faecalis*, and the Gram-negative *Pseudomonas aeruginosa* and *Escherichia coli* (Kucukbay et al., 2011).

Achillea goniocephala

Camphor (33%) and 1,8-cineole (23%) were reported as main constituents in the essential oil of *A. goniocephala* collected from Kahraman Maras (Baser et al., 2001).

Achillea gypsicola

Camphor (40%), 1,8-cineole (22%), piperitone (11%), borneol (10%), α-terpineol (2%), sabinaketone (2%) were found as major compounds in the oil of this species obtained in 0.65% yield (Kordali et al., 2009; Tozlu et al., 2011).

Achillea hamzaoglui

This endemic species yielded 0.07% essential oil which contained 1,8-cineole (24%), linalool (12%), camphor (7%), germacrene D (6%) as main constituents. The oil showed strong radical scavenging, antioxidant and antibacterial activities (Turkmenoglu et al., 2015)

Achillea ketenoglui

Borneol (6-14%) and α-terpineol (3-15%) were main constituents of the essential oil of this endemic species (Baser et al., 2001).

Achillea kotschyi subsp. *kotschyi*

The oil of this species was rich in 1,8-cineole (23%), caryophyllene oxide (10%), p-cymene (8%), hexadecanoic acid (8%) (Turkmenoglu et al., 2015).

Achillea lycaonica

Three contradicting reports are available for this endemic species. The essential oil from Karaman sample contained trans-sabinene hydrate (9%), terpinen-4-ol (9%), linalool (5%), cis-sabinene hydrate 4%, trans-pinocarveol 3%), 1,8-cineole (3%) and camphor (2%) as main constituents while major components in the oil from Sivas sample were reported as camphor (43%), artemisia alcohol (21%) and 1,8-cineole (17%). The oil inhibited most microorganisms but the activity of the Sivas oil against *Alternaria brassicola* was particularly strong (Baser et al., 2001; Azaz et al., 2008). Another sample from Sivas:Ulas yielded <0.01 % oil with only alkanes (Nonacosane 11%, heptacosane 9%, pentacosane 6%) as main constituents (Turkmenoglu et al., 2015). This species needs to be reexamined in order to solve the apparent discrepancy.

Achillea magnifica

There are two reports on the essential oil composition of this endemic species. One reported 1,8-cineole (30%), camphor (23%) and a-pinene (5%) as main constituents. Mild antifungal activity of the oil was also determined (Demirci et al., 2009). In the other study, however, linalool (28%), spathulenol (6%), terpinen-4-ol (6%), α-terpineol (5%), β-eudesmol (5%) were reported as main constituents oddly with no camphor and 1,8-cineole (Toncer et al., 2010).

Achillea millefolium subsp. *millefolium*

There are only three reports from Turkey on this commercially important species. One paper reports on the essential oil composition and antioxidant and antimicrobial activities. Main constituents were characterized as 1,8-cineole (25%), camphor (17%), α-terpineol (10%) (Candan et al., 2003).

Another paper reported the main constituents of the oil as δ-cadinene (19%), limonene oxide (10%), alloaromadendrene (6%), caryophyllene oxide (6%),β-caryophyllene (5%) (Kocak et al., 2010). α-bisabolol (12%), caryophyllene oxide (8%), muurolo-4,10(14)-dien-1-ol (7%) were reported as main constituents from another sample (Turkmenoglu et al., 2015).

According to European Pharmacopoeia ”whole or cut, flowering tops of *Achillea millefolium* L.” should contain “not less than 2 ml/kg of essential oil and not less than 0.02 per cent of proazulenes, expressed as chamazulene, both calculated with reference to the dried drug” (Eur.Pharm., 2014). None of the two studies seem not to take into account the occurrence of azulenes, since the recovery of a blue oil is not mentioned. Therefore, the information reported here cannot be regarded as representative of the official drug.

The oil of the first study showed antimicrobial activity against *Streptococcus pneumoniae, Clostridium perfringens*, *Candida albicans*, *Mycobacterium smegmatis, Acinetobacter lwoffii* and *Candida krusei* (Candan et al., 2003).

Achillea multifida

α-Thujone (61%), β-thujone (9%), sabinene (4%) and camphor (4%) were characterized as main components in the oil of this endemic species collected from Uludag mountain in Bursa. The oil was tested against human pathogenic bacteria and yeast. Good inhibitory activity was observed against Gram-negative human pathogens *Enterobacter aerogenes* (MIC 62.5 μg/ml), *Pseudomonas aeruginosa* (MIC 125 μg/ml), and the yeast *Candida albicans* (MIC 62.5 μg/ml) (Baser et al., 2002).

Achillea nobilis subsp. neilreichii

Fragranyl acetate (32%), fragranol (24%) and β-eudesmol (8%) were identified as the main components of *A. nobilis*subsp. *neilreichii* essential oil. Antioxidant and weak antimicrobial activities were observed (Demirci et al., 2009).

Achillea oligocephala

1,8-cineole (19%), α-terpineol (7%) and linalool (6%) were main components of this oil (Toker et al., 2003).

Achillea phrygia

Aerial parts of this endemic species were subjected to distillation and chemical analysis by two independent groups. Both studies gave quantitative and qualitative compositions of the oils. Oils from two localities in Eskisehir showed the occurrence of cis-piperitol (11-31%), camphor (15%), trans-p-menth-2-en-1-ol (11-15%), 1,8-cineole (9-10%), cis-p-menth-2-en-1-ol (7-10%) as main constituents (Baser et al., 2000). In the other study, however, the oil of Nevsehir sample gave a different composition with camphor (36%), 2-furaldehyde (=furfural) (17%) and 1,8-cineole (10%) as major components. This oil also reportedly showed antioxidant, and a broad antimicrobial activity against most of the microorganisms tested (Akcin et al., 2014).

Achillea pseudoaleppica

Aerial parts of this species yielded 1.2% essential oil rich in camphor (29%), 1,8-cineole (18%) and artemisia ketone (10%) as main constituents (Ozen et al., 2003).

Achillea salicifolia* subsp. *salicifolia

Main constituents in the essential oil of this species were found as camphor (55%), 1,8-cineole (23%), camphene (3%) and artemisia alcohol (3%). The oil showed mild antimicrobial activity (Azaz et al., 2009).

Achillea schischkinii

There are three papers on the essential oils of this endemic species. The sample from Erzincan yielded 0.3% oil containing 1,8-cineole (26%), camphor (8%), β-eudesmol (6%), β-pinene (5%), artemisia ketone (4%), piperitone (4%) as main constituents. It showed weak antimicrobial activity (Iscan et al., 2006). The Sivas sample, on the other hand, contained 1,8-cineole (31%) and camphor (20%) as major components in the oil (Donmez et al., 2005). In a recent paper, caryophyllene oxide (18%), spathulenol (9%), *p*-cymene (9%), (E)-nerolidol (6%) were reported as main constituents (Turkmenoglu et al., 2015).

Achillea sieheana

Both authors studied essential oils of this endemic species from the same region (Kayseri: Develi) but with different oil yields (0.3% and 1.2%). The oil with lesser yield contained *(1S)(-)*-camphor (40%), 1,8-cineole

(16%) and camphene (8%) as main constituents (Tabanca et al., 2004). The other oil contained camphor (43%), artemisia ketone (26%), 1,8-cineole (6%) and camphene (5%) as major components. This oil showed high antioxidant effect, and strong antimicrobial activity against 13 bacterial and two yeasts (Albayrak, 2013).

Achillea setacea

α-bisabolon oxide A (27%) and hexadecanoic acid (16%) were reported as main components in the essential oil of the endemic *Achillea setacea* (Turkmenoglu et al., 2015).

Achillea sintenisii

There are two studies on this endemic species. While one study showed a camphor-cineole type profile commonly characteristic for many *Achillea* oils with camphor (15%), 1,8-cineole (13%), β-pinene (13%), borneol (11%), piperitone (10%) (Sokmen et al., 2003), the other study presented a completely different picture with β-eudesmol (26%), hexadecanoic acid (23%), caryophyllene oxide (8%) as main constituents (Turkmenoglu et al., 2015).

Achillea teretifolia

Several authors reported on the essential oil of this endemic species. Demirci reported 1,8-cineole (34%), camphor (11%), terpinen-4-ol (8%) and α-thujone (5%) as main components of the essential oil which showed antimicrobial, antioxidant and antiangiogenic activities but no embryotoxicity (Demirci et al., 2009 and 2011). Polatoglu reported 1,8-cineole (16%), borneol (8%), camphor (7%), T-cadinol (6%), terpinen-4-ol (5%), *(E)*-nerolidol (5%) and caryophyllene oxide (4%) as main components of the oil which exhibited high antioxidant activity and low insecticidal fumigant toxicity against *Sitophilus granarius* (Polatoglu et al. 2013). A completely different oil composition was published in which 3-cyclohexen-1-one (22%), linalool (14%), 1,8-cineole (13%), chrysanthenone (9%), trans-chrysanthenol (8%), δ-cadinene (4%) were reported as main constituents. Since 3-cyclohexen-1-one is not found in nature, its identity requires reconfirmation (Kocak et al., 2010).

Achillea vermicularis

Aerial parts of this species yielded 0.3% oil in which 1,8-cineole (29%), camphor (26%), borneol (5%), piperitone (5%), camphene (4%) were main constituents. The oil showed high antioxidant and insecticidal fumigant toxicity against *Sitophilus granarius* (Polatoglu et al., 2013). In another study, 15-hexadecanolide (20%), camphor (7%), heptacosane (6%), bornyl acetate (5%) were characterized as main constituents (Turkmenoglu et al., 2015).

Achillea wilhelmsii subsp. wilhelmsii

Camphor (40%), artemisia alcohol (18%), 2,5,5-trimethyl-3,6-heptadien-2-ol (=Yomogi alcohol)(16%), and 1,8-cineole (7%) were reported as main constituents in this oil. Antimicrobial activity of the oil was tested against several microorganisms. Strong inhibitory activity was observed against *Enterobacter aerogenes, Proteus vulgaris* and *Alternaria brassicola* (Azaz et al., 2008). Camphor (41%) was also the main constituent in another study together with caryophylladienol II (6%), borneol (6%), camphene (6%) (Turkmenoglu et al., 2015).

Results and Discussion

1,8-cineole and camphor were main constituents in the essential oils of 19 *Achillea* species of Turkey, namely, *aleppica* subsp. *aleppica*, *biebersteinii, biserrata, coarctata, cucullata, falcata, goniocephala, gypsicola, kotschyi subsp. kotschyi, lycaonica, magnifica, phrygia, pseudoaleppica, salicifolia* subsp. *salicifolia, schischkinii, sintenisii, teretifolia, vermicularis, wilhelmsii* (Table 3). Alongside, these components, piperitone (*biebersteinii* 50%), ascaridol (*biebersteinii* 62%), *cis*-piperitol (*phrygia* 11-31%), p-cymene (*biebersteinii* 27% and 19%) rich oils were also encountered. *A. nobilis* subsp. *neilreichii* was unique in containing fragranyl acetate (32%) and fragranol (24%) and *A. multifida* was rich in α-thujone (61%) and β-thujone (9%) in their essential oils. *A. magnifica* oil was rich in linalool (28%); *A. millefolium* subsp. *millefolium* in δ-cadinene and other sesquiterpenes (19%), α-bisabolol (12%); *A.ketenoglui* in borneol (6-14%) and terpinen-4-ol (3-15%); *A. formosa* subsp. *amanica* and *A. ketenoglui* in borneol (13% and 6-14%); *A. filipendulina* in santolina alcohol (44%); *A. cretica* in caryophylladienol II (13%); *A. coarctata* in viridiflorol (26%); *A. lycaonica* in trans-sabinene hydrate (9%) and nonacosane (11%); *A. schischkinii* in caryophyllene oxide (18%); *A. setacea* in α-bisabolon oxide A (27%); *A. sintenisii* in β-eudesmol (26*%); A. tenuifolia* in Artemisia ketone (12%), isoascaridol (24%); *A. vermicularis* in 15-hexadecanolide (20%).

Previously, 1,8-cineole and camphor rich oils were reported by several authors from *Achillea* species growing outside Turkey (Bader et al., 2003; Boskovic et al.,2005; Feizbakhsh et al.,2003; Ghani et al., 2008; Kundakovic et al.,2007; Pavlovic et al., 2008; Rustaiyan et al., 1999; Suleimenov et al., 2001). Other main constituents reported were as follows: Borneol (Agnihotri et al., 2005; Kovacevic et al., 2005; Kundakovic et al., 2007; Rahimmalek et al., 2009; Simic et al., 2000; Tuberoso et al., 2005), α -thujone (Ghani et al., 2008; Tuberoso et al., 2005), β -thujone (Tampe et al., 2015; Tzakou and Loukis, 2009), β-pinene (Agnihotri et al., 2005; Boskovic et al.,2005; Kundakovic et al., 2007; Simic et al., 2005; Suleimenov et al., 2001), santolina alcohol (Rahimmalek et al., 2009, Tuberoso et al., 2005), germacrene D (Rahimmalek et al., 2009), β-caryophyllene (Agnihotri et al., 2005; Simic et al., 2002), chamazulene (Jianu et al., 2015, Stevanovic et al., 2015), spathulenol (Rahimmalek et al., 2009), trans-sabinol and esters (Radulovic et al., 2015). Chemotypes of *Achillea* oils were also reported (Agnihotri et al.,2005; Hofmann et al., 1992; Németh et al., 1999; Németh, 2005; Orav et al., 2006; Polatoglu et al., 2013; Rahimmalek et al., 2009; Rohloff et al., 2000; Stevanovic et al., 2015).

Biological activities of various *Achillea* species include angiogenic (Demirci et al., 2011), anxiolytic (Damiao et al., 2015), antifungal (Amjad et al., 2014; Kordali et al., 2009; Ristic et al., 2004; Tuberoso et al., 2005), antibacterial (Alafatemi et al, 2015; Barel & Yashphe, 1989; Filippi et al., 2006; Simic et al., 2005; Skocibusic et al., 2004), anti-inflammatory (Kazemi, 2015), antimicrobial (Barel et al., 1991; Baser, 2002a; Bezic et al., 2003; Candan et al., 2003; Demirci et al., 2009; Jianu et al., 2015; Ghasemi et al., 2008; Senatore et al., 2005; Sokmen et al., 2003, 2004; Unlu et al., 2002), genotoxicity (Sant'Anna et al., 2009), hepatoptotective (Al-Said et al., 2016) herbicidal (Kordali et al., 2009), insecticidal (Calmasur et al., 2006; Kepenekci & Saglam, 2015; Kesdek et al., 2015; Khani & Asghari, 2012; Song et al., 2016; Tabanca et al., 2011; Tampe et al., 2015; Tozlu et al., 2011) antioxidant (Al-Said et al., 2016; Dadkhah et al., 2015; Jianu et al., 2015; Mottaghipisheh et al., 2015; Nenaah, 2014, Nenaah et al., 2015) and antiradical (Candan et al., 2003; Demirci et al., 2009; Sökmen et al., 2004; Tuberoso et al., 2005).

In this short review, I have tried to compile the compositions and biological/pharmacological activities of essential oils of the *Achillea* species of Turkey with reference to important similar work outside Turkey. 31 out of 54 *Achillea* taxa have so far been studied for essential oils. As mentioned in the text, clarification is needed for the essential oil composition of some species due to conflicting reports.

Table 3. Main components found in *Achillea* essential oils

Compound	***Achillea* species**
allo-aromadendrene	*millefolium* ssp. *millefolium* 6
artemisia alcohol	*biserrata* 14, *salicifolia* ssp. *salicifolia* 3
artemisia ketone	*tenuifolia* 12, *pseudoaleppica* 10
ascaridol	*biebersteinii* 62
ascaridol, iso-	*tenuifolia* 24
α-bisabolol	*sintenisii* 26, *millefolium* subsp. *millefolium* 12
α-bisabolol oxide	*aleppica* ssp. *aleppica* 4
α-bisabolon oxide A	*setacea* 27
borneol	*ketenoglui* 6-14, *formosa* ssp. *amanica* 13, *borneol* 11, *gypsicola* 10, *teretifolia* 8, *biebersteinii* 3-7, *wilhelmsii* 6, *vermicularis* 5
borneol, iso-	*cucullata* 4, *biebersteinii* 6
bornyl acetate	*vermicularis* 5
δ-cadinene	*millefolium* ssp. *millefolium* 19, *teretifolia* 4
T-cadinol	*teretifolia* 5, *aleppica* ssp. *aleppica* 4
camphene	*biserrata* 16, *sieheana* 5-8, *wilhelmsii* 6, *salicifolia* ssp. *salicifolia* 3
camphor	*salicifolia* ssp. *salicifolia* 55, *lycaonica* 47, *sieheana* 40-43, *gypsicola* 40, *wilhelmsii* 40-41, *biserrata* 37, *phrygia* 15-36, *aleppica* ssp. *aleppica* 33-34, *goniocephala* 33, *cucullata* 33, *biebersteinii* 0-30, *pseudoaleppica* 29, *vermicularis* 7-26, *falcata* 4-24, *magnifica* 23, *schischkinii* 20, *coarctata* 16, *sintenisii* 15, *teretifolia* 7-11, *tenuifolia* 7, *hamzaoglui* 7, *multifida* 4
carvone	*cretica* 5
caryophylladienol II	*cretica* 13, *wilhelmsii* 6
β-caryophyllene	*millefolium* ssp. *millefolium* 5
caryophyllene oxide	*coarctata* 10, *kotschyi* subsp. *kotschyi* 10, *millefolium* ssp. *millefolium* 6-8, *sintenisii* 8, *tenuifolia* 5, *teretifolia* 4
trans-chrysanthenol	*teretifolia* 8
chrysanthenone	*teretifolia* 9
cis-chrysanthenyl acetate	*filipendulina* 13
1,8-cineole	*biebersteinii* 5-38, *teretifolia* 13-34, *aleppica* ssp. *aleppica* 20-33, *schischkinii* 31, *magnifica* 30, *cucullata* 29, *vermicularis* 29, *falcata* 14-24, *hamzaoglui* 24, *salicifolia* ssp. *salicifolia* 23, *goniocephala* 23, *kotschyi* subsp. *kotschyi* 23, *gypsicola* 22, *coarctata* 20, *biserrata* 19, *oligocephala* 19, *pseudoaleppica* 18, *lycaonica* 17, *sieheana* 6-16, *tenuifolia* 16, *filipendulina* 15, *sintenisii* 13, *phrygia* 10, *wilhelmsii* 7
3-cyclohexen-1-one	*teretifolia* 22
p-cymene	*biebersteinii* 6-27, *tenuifolia* 10-14
β-eudesmol	*biebersteinii* 10, *nobilis* ssp. *neilreichii* 8, *coarctata* 7
fragranol	*nobilis* ssp. *neilreichii* 24
fragranyl acetate	*nobilis* ssp. *neilreichii* 32
furfural	*phrygia* 17
germacrene D	*hamzaoglui* 6
heptacosane	*lycaonica* 9, *vermicularis* 6
hexadecanoic acid	*sintenisii* 23, *setacea* 16, *formosa* ssp. *amanica* 12, *biebersteinii* 11, *coarctata* 8, *kotschyi* subsp. *kotschyi* 8
15-hexadecanolide	*vermicularis* 20, *coarctata* 9
intermedeol, neo-	*cretica* 6
limoneneoxide	*millefolium* ssp. *millefolium* 10
linalool	*teretifolia* 14, *hamzaoglui* 12, *phrygia* 10, *oligocephala* 7

Table 3. *Continued*

β-maaliene	*cretica* 6
trans-p-menth-2-en-1-ol	*phrygia* 11-15
cis-p-ment-2-en-1-ol	*phrygia* 7-10
muurola-4,10(14)-dien-1-ol	*millefolium* subsp. *millefolium* 7
nonacosane	*lycaonica* 11
palmitic acid	*cretica* 3
α-pinene	*falcata* 2-12, *magnifica* 5, *tenuifolia* 5
pentacosane	*lycaonica* 6
β-pinene	*sintenisii* 13
cis-piperitol	*phrygia* 11-31
piperitone	*biebersteinii* 3-50, *gypsicola* 11, *sintenisii* 10, *vermicularis* 5
sabinene	*multifida* 4
trans-sabinenehydrate	*lycaonica* 9
sabinaketone	*gypsicola* 2
santolina alcohol	*filipendulina* 44
selina-3,11-dien-6-ol	*cretica* 3
spathulenol	*cretica* 5
α-terpineol	*aleppica* ssp. *aleppica* 9, *oligocephala* 7, *biebersteinii* 5, *gypsicola* 2
terpinen-4-ol	*ketenoglui* 3-15, *teretifolia* 5-8, *tenuifolia* 6
α-terpinyl acetate	*biebersteinii* 7
α-thujone	*multifida* 61, *biebersteinii* 13, *teretifolia* 5
β-thujone	*multifida* 9, *biebersteinii* 3
viridiflorol	*coarctata* 12-26
yomogi alcohol*(=2,5,5-trimethyl-3,6-heptadien-2-ol*)	*wilhelmsii* 16

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