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Review Article

# A systematic review on the ethnobotany, essential oils, bioactive compounds, and biological activities of *Tanacetum* species

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**ABSTRACT**

This review paper was designed in order to compile the chemical profiles of the essential oils (EOs) of a wide spectrum of *Tanacetum* species as well as to unify the data available in the literature concerning different aspects of this genus in ethnobotany of different countries worldwide. Biological activities and other bioactive compounds were presented, as well. In this regard, the literature and reliable scientific databases involving Scopus, Pubmed as well as all of the famous publishers involving Elsevier, Springer, Taylor and Francis, etc were systematically reviewed. As shown in this review, a variety of promising ethnobotanical and biological activities and properties have been reported for different species of this genus so far. In addition, a number of valuable bioactive compounds have been separated and characterized in different *Tanacetum* species.

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## 1. Introduction

Medicinal plants play a crucial role on our life and all of the living things (Mohammadhosseini et al., 2019a; Mohammadhosseini et al., 2019b). In fact, the life is absolutely impossible without these plants and there has been specific attention to explore new topics and uses of these materials in a variety of pharmaceutical and medical sciences (Mohammadhosseini et al., 2019c).

As the largest plant family, Asteraceae (Compositae) involves about 1600 herbal general and 2300 of relevant species (Abdolkarim et al., 2011). One of the most important herbal genera within this family and tribe Anthemideae and having the third largest rank only after two larger genera *Artemisia* L. and *Anthemis* L. is *Tanacetum* (formerly *Pyrethrum* (Zinn.) which consists of perennial herbaceous and aromatic plants having numerous sesquiterpenes and sesquiterpene lactones (Hendriks et al., 1990; Oberprieler et al., 2006; Lohani et al., 2012).

The chart indicating the number of publications per time interval over the years 1960 up to present has been displayed in Fig. 1 with the keyword of "*Tanacetum*" using the Scopus and Pubmed databases. Furthermore, to organize a comprehensive approach, a wide number of the relevant resources both in English and non-English books, papers etc. have been systematically reviewed. The keywords used for this research were: "*Tanacetum*", "*Tanacetum* species", "Asteraceae", "*Tanacetum* essential oils" and "feverfew".

The lack of adequate comprehensive report on numerous potentialities of the *Tanacetum* genus prompted us to organize this review article. At the first part of our undergoing review, the ethnobotany of *Tanacetum* medicinal plants, biological activity, and characterized bioactive compounds in different species of this genus are described, while at the second part,

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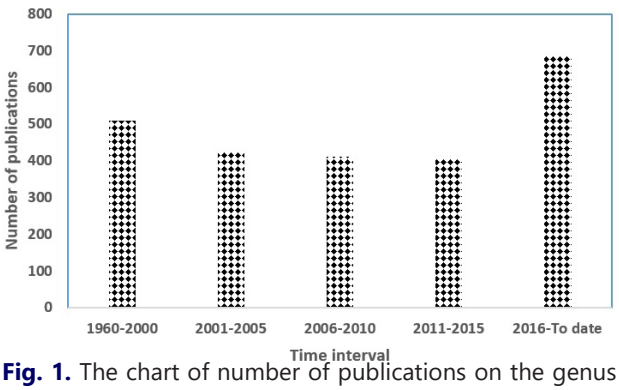


**Fig. 1.** The chart of number of publications on the genus *Tanacetum* as a function of time interval.

brief chemical compositions of the relevant essential oils (EOs) are discussed in detail.

## 2. Results and Discussion

### 2.1. Ethnobotany, biological activity and bioactive compounds of *Tanacetum* plants

It has been shown that *Tanacetum* species are of prime importance in the ethnobotany and local medicine of many Asian, African and European countries (Mozaffarian, 1996; Gören et al., 2001; El-Shazly et al., 2002; Mockute and Judzentiene, 2004; Mohammadhosseini, 2016). The endemic species of the genus *Tanacetum* are shown in Table 1 for those whose data are available in the literature. The photographs from the aerial parts of some of the important species of the genus *Tanacetum* have been presented in Fig. 2. Different *Tanacetum* species have diverse vernacular names in local folk medicine of different countries of the world. In Table 2, some of the most common names attributed to *Tanacetum* plants in different cultures and languages have been summarized.

Among the reported *Tanacetum* species up to present, two ones, namely *T. vulgare* L. and *T. parthenium* (L.) Schultz-Bip have been more investigated in the literature. In addition, a large number of medicinal species of *Tanacetum* are frequently found as tincture, herbal tea as well as capsules in the market. In fact, all of these herbaceous and perennial plants are of prime medicinal importance. The most important uses of *Tanacetum* species in the traditional and local folk medicine of different countries have been shown in Table 3. There has been many reports in the literature implying the capability of *Tanacetum* species as the potential source of a broad set of biopesticides possessing considerable insecticidal characteristics (Zengin et al., 2019; Magierowicz et al., 2020). The wide uses of *Tanacetum* species has a long history in many cultures. In fact, from time immemorial, *Tanacetum* plants have been traditionally used for the treatment of numerous diseases and disorders of the human body. In this relation, some antihistaminic, antitumor, cytotoxic, antiepileptic, antinociceptive, antiallergic and anticonvulsant characteristics have been attributed to some *Tanacetum* species (Jain and Kulkarni, 1999; Özek et al., 2007; Tabanca et al., 2007; Javidnia et al., 2008a).

These biological activities of *Tanacetum* directly depend on the main compounds:

i) Essential oil composition

ii) Sesquiterpene lactones and sesquiterpenoids (terpenoid group) (Gören et al., 2002):

- Germacranolides and seco germanolodes-The main compound is parthenolide
- Eudesmanolides-santamarine
- Guaianolides and seco guaianolides
- Farnesols
- Longipinane and derivatives
- Pyrethrins
- Triterpenes
- Other sesquiterpenoids-balsamiton, (+)-sesamin or chrysetunone.

iii) Polysaccharides-pectin polysaccharide-tanacetane (Polle et al., 2002a; Polle et al., 2002b).

iv) Phenolic compounds: flavonoids, phenolic acids and their derivatives (Long et al., 2003; Mahmood et al., 2003; Susurluk et al., 2007):

- Flavones-apigenin and luteolin and its glucosides and glucuronides;
- Flavonol derivatives-tanetin (6-hydroxykaempferol 3,7,4'-trimethylether); 6-hydroxykaempferol-3,6-dimethylether; santin; jaceidin and centauredin;
- Coumarin and coumarin derivatives-scopoletin, isofraxidin;
- Phenolic acids and derivatives of cinnamic and benzoic acids.

Some Indian people have used different species of *Tanacetum*, *e.g., T. dolichophyllum* to prepare incense and pungent fragrance in their holy shrines for a long time (Haider et al., 2011; Lohani et al., 2012).

The ethnobotanical knowledge, biological activities and chemical composition of some of the most important *Tanacetum* species, whose data are available in literature, are discussed in detail one by one as follows.

#### 2.1.1. *T. vulgare* L.

*T. vulgare* L. (tansy) is found in a wide range of geographical situations and gardens. The word "tansy" has been derived from a Greek word "athanasia" meaning immortality (Devrnja et al., 2017). Some authors have implied the use of tansy for culinary purposes and in the preparation of many local foods, cakes, spices, salads, goodies and confectionery industries, baked fish, meat flavoring, puddings, plant-based teas, beverages as well as omelettes and as a natural food preservative (Keskitalo et al., 2001; Gören et al., 2002). The other uses of tansy are in cosmetics, perfumery and dye industries (Gören et al., 2002; Javidnia et al., 2008b). This herbal species also serves as a powerful insecticide and balsam (Hussey, 1974; Keskitalo et al., 2001).

In the traditional medicine of many countries, tansy is highly recommended to address the symptoms of rheumatism, anorexia, sore throat, severe migraine and neuralgia (Hussey, 1974; Blumenthal, 1998; 2008b). It is known as an anthelmintic and an appetizer remedy (Blumenthal, 1998). A large number of investigations have recently confirmed the high potential of EO or extracts of tansy against a broad set of bacteria (Bączek et al., 2017), microbes (Mureşan et al., 2015;

**Table 1**
Some of the most important in indigenous and endemic species from the genus *Tanacetum* growing wild in different parts of the world.

| **Tanacetum species** **Number/name** | **Country** | **Ref.** |
|---|---|---|
| 44 species and totally 59 taxa* | Turkey | (Gören et al., 2001) |
| 6/ *T. arteminiodes*, *T. gracille*, *T. tibeticum*, *T. nubigeneum*, *T. senecoisis* and *T. longifolium* | Kumaun and Garhwa, India | (Beauchamp et al., 2001; Chanotiya et al., 2005; Mathela et al., 2008) |
| 1/ *T. santolinoides* (DC.) Feinbr. and Fertig | Egypt | (El-Shazly et al., 2002) |
| 1/ *T. vulgare* L. (syn. *Chrysanthenum vulgare* L.)** | Lithuania | (Mockute and Judzentiene, 2004) |
| 12/ *T. hololeucum* (Bornm.), Podlech, *T. stapfianum* (Rech.f.) Podlech, *T. khorasanicum*, *T. paradoxum* Bornm., *T. salsugineum* Podlech., *T. trifoliolatum* Podlech., *T. tenuisectum* (Boiss.) Podl., *T. archibald* Podl., *T. budjnurdense* (Rech.f.) Tzvel., *T. walteri* (C.Winkl.) Tzvelev, *T. lingulatum* (Boiss.) Bornm. and *T. domusum* | Iran | (Mozaffarian, 1996; Habibi et al., 2007b) |
| 6/ T. *larvatum* (Gris.) Kanitz, T. *serotinum* (L.) Shultz-Bip., *T. vulgare* (L.) Shultz-Bip., *T. macrophyllum* (L.) Shultz-Bip., *T. corymbosum* (Willd.) Shultz-Bip. and *T. parthenium* (L.) Shultz-Bip. | Serbia | (Tadić et al., 2010) |

* For the sake of brevity, the full names of the relevant species have not been mentioned here.
** With two endemic varieties, namely *T. vulgare* L. var. *vulgare* and *T. vulgare* L. var. *crispum*


**Fig. 2.** The photograph from the aerial parts of some *Tanacetum* species. (A: *T. parthenium* (L.) Schultz-Bip; B: *T. vulgare* L.; C: *T. cinerariifolium* (Trevir.) Sch.Bip.; D: *T. coccineum* (Willd.) Grierson; E: *T. balsamita* L. and F: *T. persicum* (Boiss.) Mozaff.).

**Table 2**
The vernacular and local names attributed to different herbal species of the genus *Tanacetum*.

| Tanacetum species | Vernacular name | Country/region | Ref. |
|---|---|---|---|
| *T. argyrophyllum* (C. Koch) Tvzel. var. *argyrophyllum* | Yavşan | Turkey | (Altundag and Ozturk, 2011; Yur et al., 2018) |
| *T. vulgare* L. | Tansy | Norway, Middle East, South American, African and many other European countries | (Lahlou et al., 2007) |
| | Panacea | Morocco | (Lahlou et al., 2007) |
| | Solucan otu | Turkey | (Baytop, 1999b; Yur et al., 2018) |
| | Shisha | Iran | (Goudarzi et al., 2015) |
| | Catinga-de-mulata | Brazil | (Godinho et al., 2014) |
| *T. longifolium* Wall | Guggle, Dhoop | Kashmir-Kumaon Himalaya | (Chauhan et al., 2016) |
| *T. parthenium* (L.) Schultz-Bip | Feverfew a | Brazil | (Benassi-Zanqueta et al., 2019) |
| | Santamaria | Mexico | (Avula et al., 2006) |
| | Feverfew; Midsummer Daisy | USA | (Sur et al., 2009) |
| | Babooneh Gavi, Babooneh Cheshm Gav | Iran | (Mozaffarian, 1996) |
| | Gümüşdügme | Turkey | (Baytop, 1999b; Yur et al., 2018) |
| *T. persicum* (Boiss.) Mozaff. | Golberenjas, Mokhalaseh | Iran | (Soleimani-Ahmadi et al., 2017) |
| *T. punctatum* (Desr.) Grierson | Sendel | Turkey | (Altundag and Ozturk, 2011; Yur et al., 2018) |
| *T. fisherae* Aitch. & Hemsl. | Mofaroo | Iran | (Rajaei et al., 2011) |
| *T. cinerariifolium* (Trevir.) Sch. Bip. | Pyrethrum, Dalmacya Pire Otu | Turkey | (Baytop, 1999b; Susurluk et al., 2007) |
| *T. polycephalum*. Schultz-Bip. subsp. *polycephalum* | Minaye Porkope and Minaye Sakhrezi | Iran | (Rezazadeh et al., 2014) |
| *T. chiliophyllum* (Fisch. & Mey.) Schultz Bip. | Ceren, Ormadere, Yavşan and Bevujan b | Turkey | (Altundag and Ozturk, 2011; Polatoğlu et al., 2012) |
| | Mokhalaseh, Minaye Gharabaghi | Iran | (Pirbalouti, 2019) |
| *T. balsamita* L. | Shahsparam | Iran | (Javidnia et al., 2008a) |
| | Costmary, Kilicotu, Baga Yapragi and Giyakeçk c | Poland and Turkey | (Altundag and Ozturk, 2011; Bączek et al., 2017) |
| *T. coccineum* (Willd.) Grierson | Pire out d | Turkey | (Baytop, 1999b; Yur et al., 2018) |
| *T. cadmeum* Boiss. Heywood | Ayvadanasi e | Turkey | (Tuzlaci and Erol, 1999; Yur et al., 2018) |

[a] Having a Latin root meaning "fever purge"(Murray, 1995); [b] For var. *chiliophyllum*, [c] For subsp. *balsamitoides* (Sch. Bip.) Grierson; [d] For subsp. *chamaemelifolium* (Sommier & Levier) Grierson; [e] For subsp. *Cadmeum.*

vănescu et al., 2018), insects (Szołyga et al., 2014) and revealed the high antioxidant power of these materials (Juan-Badaturuge et al., 2009; Mureşan et al., 2015; Bączek et al., 2017; Ivănescu et al., 2018). In the Russian folk medicine, *T. vulgare* L. has been recommended as an effective herbal material to relieve painful gastrointestinal and ulcer problems (Polle et al., 2001). In Turkey, tansy is used as a potherb and has gained much attention as an ornamental plant in many gardens. Moreover, the aerial parts of tansy, particularly flowers and leaves are frequently prescribed due to their remarkable tonic, carminative, antiseptic, emmenagogue, sedative, gastric, abortifacient and anti-inflammatory characteristics as well as their high power against gout, simulation of uterine contractions and pleasant fragrance (Gören et al., 2002). Gören et al. (2002) have also stated that the unguent prepared from the tansy leaves can be administered to treat tendons, tumors and muscular pains. In the ancient Egyptian culture, people believed that tansy was a mortal and heavenly plant with a great capability to be used for embalming of pharaonic corpses (Gören et al., 2002).

**Table 3**
Different uses of diverse *Tanacetum* species in the folk medicine of European, American, African and Asian countries all over the world.

| Tanacetum species | Application and usage | Country | Ref |
|---|---|---|---|
| *T. vulgare* L. | For the treatment of intestinal disorders, rheumatism, ulcer, migraine and arthritis | Russia | (Abad et al., 1995; Polle et al., 2001) |
| | Food additive, cosmetics and perfumes industry, to remove intestinal worms, to cure and alleviate kidney pains, and as an abortive agent, to cure respiratory issues | Norway | (Rohloff et al., 2004; Dragland et al., 2005) |
| | Recommended as a powerful anthelmintic, and tonic agent as well as a remedy against hypertension, spasm and diabetes | Morocco | (Lahlou et al., 2007) |
| | Effective antispasmodic and vermifuge herbal drug having a lot of uses in Iranian perfumery industries | Iran | (Javidnia et al., 2008b) |
| *T. parthenium* (L.) Schultz-Bip | For the treatment of migraine and arthritis | Turkey | (Kaplan et al., 2002) |
| | An efficient remedy against worms, cold, fever, headache, cramps and gynecological problem | Canada | (Simmons et al., 2002) |
| | As a sedative agent for severe psoriasis and arthritis, inhibition of formation of blood platelet stack; and a wide range of uses as diaphoretic, analgesic, febrifuge and one of the main ingredients of balsam, also against inflammation, migraine, headache, ashtma and persistent fever | Iran | (Hadjiakhondi et al., 2003; Habibi et al., 2007a; Saharkhiz et al., 2007) |
| | To treat muscular pains and disorders, backache, headache and flu, intestinal malfunctions, to relieve painful toothache, insect repellent and for menstrual problems, to manage labor pains and allergy as well as to stop vomiting and nausea and to remove forms | India | (Jain and Kulkarni, 1999; Petrovic et al., 2003) |
| | Powerful remedies versus teeth and stomach pains as well as muscular fatigue, potent and antipyretic agent and efficient against infertility, mental disease, skin problems, gastritis, giddiness, cold, fever, insect bites and tinnitus as well as to address irregularities in menstrual period, strong against inflammation and having analgesic properties with promising efficacy against migraine prophylaxis, to alleviate "holy fire" | Brazil | (Khan et al., 2003; Tiuman et al., 2005; Chaves et al., 2009; Pareek et al., 2011; Benassi-Zanqueta et al., 2019) |
| | Treating vertigo and psoriasis as well as to adjust women's menstrual in addition to its common uses in traditional folk medicine of other countries | Serbia | (Bulatovic et al., 2006) |
| | To cure migraine and its subsequent headache and as an additive to a variety of functional drinks | USA | (Fonseca et al., 2006) |
| | For the preparation of functional foods and beverages and possessing remarkable anti-inflammation and anti-epilepsy properties | Ireland | (Marete et al., 2009) |
| | With a wide range of uses in treating rheumatism, pains of muscles, cramps, neuralgia, repelling insects and as anthelmintic remedies and as natural appetizer | Brazil | (Onozato et al., 2009; Pavela et al., 2010) |
| *T. polycephalum* Schultz Bip | Having a remarkable potency to address allergy and inflammation and as an insecticidal agent | Iran | (Morteza-Semnani, 2006) |
| *T. balsamita* L. | Botanical water: A sedative agent and tonic remedy for cardiovascular diseases | Iran | (Amin, 1991; Javidnia et al., 2008a) |
| *T. dolichophyllum* (Kitam.) Kitam. | Locally to prepare incense, pungent and fragrant substances in holy places and Hindu shrines of India | India | (Haider et al., 2011) |

In Norway, *T. vulgare* L. has been shown to repel and deter flies, mosquitoes and other insects. On the other hand, the herbal extract of this valuable medicinal species is an aborting agent and can highly address worms, kidney stones and some infections of respiratory system of the human body (Dragland et al., 2005). Furthermore, due to pungent odor of tansy, its leaves can be used as a proper alternative for nutmeg and cinnamon in cookery (Rohloff et al., 2004). In Lithuania, there are some evidences for the use of tansy in some local foods and medicines together with its usage as an acaricidal agent (Mockute and Judzentiene, 2003). In the traditional medicine of Morocco and Moroccan pharmacopeia, tansy leaves have been introduced as a carminative, diuretic, hypoglycemic, antihypertensive, anthelmintic and tonic agent and effective *vs* hysteria, abdominal pains and spasm (Lahlou et al., 2007; Lahlou et al., 2008b). The flowers and leaves of this valuable plant are added to many food products as a garnish and flavoring material. It is also used for the preparation of bitter tea (Facciola, 1990; Lahlou et al., 2008a; Lahlou et al., 2008b). On the other hand, the infusion from its leaves is a powerful emmenagogue and can adjust women's menstrual disorders (Facciola, 1990). It has also been implied that its botanical water is useful to control hypertension and the water extract of tansy may be considered as relatively safe after evaluation of its toxicity in rodents (Lahlou et al., 2008b).

*T. vulgare* is also used in traditional medicine as a vermifuge and it was recently found that the crude extract as well as EO of this plant exhibit *in vitro* schistosomicidal activity (Godinho et al., 2014). Juan-Badaturuge et al. (2009) and Xie et al. (2007) have experimentally confirmed wound healing, antioxidant activity and high potency of tansy against inflammation. It is also noteworthy that this plant contains polysaccharides which exhibit potent macrophage/monocyte-activating activity, enhance the production of reactive oxygen species (ROS), nitric oxide (NO), and tumor necrosis factor α (TNF-α) by J774.A1 murine macrophages, and activate nuclear factor κB (NF-κB) in THP-1 human monocytes (Xie et al., 2007). Antiviral activity of *T. vulgare* was found in the treatment of diseases caused by HSV-1 (Onozato et al., 2009; Álvarez et al., 2011).

The anti-HSV activity was found for petroleum ether extract of *T. vulgare* and the isolated compound spiroketal-enol ether derivative, namely (*E*)-2-(2,4-hexadiynyliden)-1,6-dioxaspiro[4.5]dec-3-ene (Fig. 3) in comparison to ethyl acetate and water extracts of *T. vulgare* (Álvarez et al., 2015). In addition, Alvarez et al. (2015) have written that "the phytomedicines, having multiple mechanisms, which is the case for tansy, may act as an antiviral cocktail whose diverse phytoconstituents target different viral replication stages and together contribute to the overall inhibition, making the development of virus resistance difficult".

Isolated sesquiterpene lactones with the eudesmane skeleton from the dichloromethane extract of the flowers of *T. vulgare* growing in Sicily possessed cytotoxic activity in *in vitro* tests (Rosselli et al., 2012). However, these compounds cannot be used in cancer treatment because they are more active in the healthy

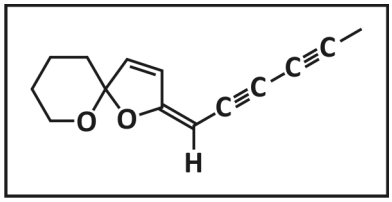


**Fig. 3.** Structure of (*E*)-2-(2,4-hexadiynyliden)-1,6-dioxaspiro[4.5]dec-3-ene.

cells than in tumor cells. On the other hand, it was recently found that tansy methanol extract and EO possessed *in vitro* antiproliferative activity in human tumor cervix carcinoma cells (HeLa) (Devrnja et al., 2017; Ivănescu et al., 2018). Methanol extracts of leaves and flowers revealed the strongest inhibitory effect on growth and proliferation of human cells *in vitro* (HeLa), obtained $IC_{50}$ values were up to 100 µg/mL (Devrnja et al., 2017; Ivănescu et al., 2018). The lower $IC_{50}$ values, the higher activity of extract or substance is presented. Vasileva et al. (2019) have shown *in vitro* antitumor activity of ethyl acetate fraction of the crude extract and the ethyl acetate extract from *Flores Tanaceti* showed the highest activity in MCF-7 (breast cancer), A549 (alveolar non-small cell adenocarcinoma), HeLa (cervical cancer cell line), HepG2 (hepatocellular carcinoma), HT-29 (collon carcinoma), and PC3 (prostate carcinoma) cell lines. *T. vulgare* essential oil (Lithuania) showed the antifungal activity mainly against dermatophyte strains *Cryptococcus neoformans*, and *Candida albicans* (Piras et al., 2014). In a similar report, ethyl acetate extract of the plant showed antifungal activity against *C. albicans* (Kameri et al., 2019).

The EO and methanol extract of the plant from Serbia possessed antimicrobial and antifungal activities which can be used in food preservation (Devrnja et al., 2017). Antimicrobial effect against the tested Gram-positive bacteria and fungi was also confirmed by Ivănescu et al. (2018). It was also found that dried extract of *T. vulgare* flowers exhibited hepatoprotective and choleretic activity in rats (Mishchenko et al., 2019). The most active dosages in hepatoprotective (AST and ALT levels) and antioxidant activity (reduced glutathione level) of the extract were 75 and 100 mg/kg and showed the same anti-cytolytic effect as a standard treatment with silymarin.

Pectin polysaccharide with backbone of linear α-1,4-D-galacturonan-tanacetane has been found in floscules of tansy from Russia (Polle et al., 2002a; Polle et al., 2002b). Three antioxidant phenolic compounds, namely 3,5-*O*-dicaffeoylquinic acid (3,5-diCQA), axillarin and luteolin were isolated from *T. vulgare* L. aerial parts grown in Hadlow, UK (Juan-Badaturuge et al., 2009). A recent study has shown the differences between water and acetone extracts of *T. vulgare* (Lithuania) separated after liquid hydrodistillation of tansy residue (Baranauskiene et al., 2014).

The authors have identified altogether 15 phenolic compounds mainly from the derivatives of luteolin, apigenin (Fig. 4) and chlorogenic acid. Water extract with the highest level of mono- and dicaffeoylquinic acids (Fig. 5) possessed the highest antioxidant activities

in FRAP (Ferric-reducing antioxidant power) and ORAC (Oxygen radical absorbance capacity) assays.

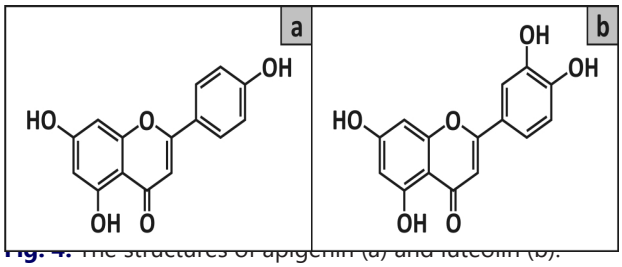


**Fig. 4.** The structures of apigenin (a) and luteolin (b).

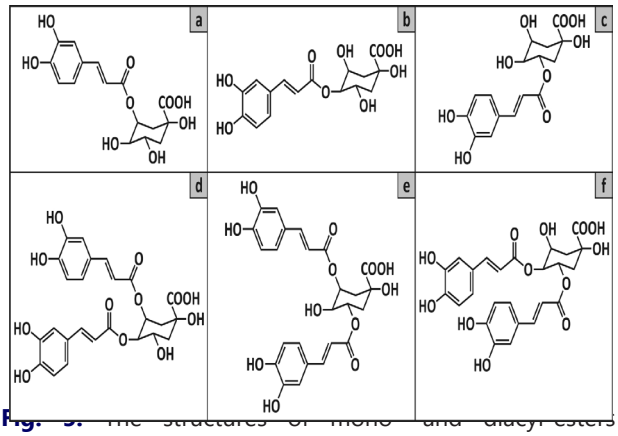


**Fig. 5.** The structures of mono- and diacyl esters (caffeoylquinic acids): a) 3-caffeoylquinnic acid, b) 4-caffeoylquinnic acid, c) 5-caffeoylquinnic acid (chlorogenic acid), d) 3,4-caffeoylquinnic acid, e) 3,5-caffeoylquinnic acid and f) 4,5-caffeoylquinnic acid.

It is worth mentioning that flowers of tansy from Samara Oblast (Russia) contain valuable bioactive compounds such as 5,7-dihydroxy-4′-methoxyflavone 7-*O*-β-D-glucopyranoside (tilianin); 5,7,4′-trihydroxyflavone 7-*O*-β-D-glucopyranoside (cosmosiin); acacetin as well as known apigenin (Kurkina et al., 2011).

Further flavonoids (aglycones and glucosides) were found in *Tanacetum vulgare* var. *boreale* distributed in Russia, China, North Korea and Japan and *Tanacetum vulgare* var. *vulgare* from northern Europe and North America (Uehara et al., 2015). Such aglycones as hispidulin, nepetin, eupatilin, jaceosidin, pectolinarigenin, axillarin as well as scutellarein 7-*O*-glucoside, eriodictyol 7-*O*-glucuronide were also isolated and identified. The leaves of tansy from Poland contained macro- and microelements such as K (2-3.5% dried mass d.m.), P (0.2-0.69 d.m.), Cu, Zn and Mo. The levels of these elements depend on the location and the geographical coordinates of the studied plant (Konieczny and Ślezak, 2019).

### 2.1.2. *T. parthenium* (L.) Schultz-Bip

*T. parthenium* (L.) Schultz-Bip which is also so-called "feverfew" has been used as a strong antipyretic and anti-inflammatory agent for thousands of years (Gören et al., 2002). Many years ago, feverfew was called "Medieval Aspirin". During the 17th century, a famous British botanist (Nicholas Culpepper) proposed feverfew as an efficient miscarriage and for the treatment of colic (Barceloux, 2008a). He also suggested that feverfew is a proper alternative to withdraw opium. Several years later, feverfew was introduced as an inflammatory agent to the scientific community (Barceloux, 2008a). From a mechanistic standpoint, the great potential of feverfew towards inflammation can be attributed to its irreversible inhibition of eicosanoid production and its subsequent inhibition against granules release from platelets along with leukocytes. This is most probably conducted via the possible interaction with protein kinase C.

It has been stated that feverfew may have originated from Balkan Peninsula and now has a widespread distribution in American, European, African and Asian countries (Awang, 1989; Tanko et al., 2003).

According to the "Chemical Market Reporter", CMR, *T. parthenium* (L.) Schultz-Bip (feverfew) is of great commercial value in the trade market of USA and enlisted among the top-selling US products (Minkwitz, 1999; Wu et al., 2006b). The importance of this herbal plant is mainly due to its high capability in the prevention of migraine and its subsequent headache. From a historical point of view, *T. parthenium* (L.) Schultz-Bip has gained much attention owing to its strong ability to treat headache, fever, intestinal problems, *e.g.,* indigestion, stomachache etc. and to adjust women's menstrual and some other promising medical characteristics of this species have been well-documented by European researchers and herbalists during the recent decades, particularly from the late 1970s to date (Wu et al., 2006b). In the local folk medicine of Turkey (Table 3), feverfew has been suggested as an herbal drug against migraine, headache, psoriasis and arthritis. It can reduce fever remarkably and exhibits promising remedial behavior against cold, cough, headache, worms, cramps and gynecological malfunctions (Kaplan et al., 2002). In addition to what previously mentioned in the traditional medicine of Turkey for feverfew, this plant is widely used to alleviate insect bites, menstrual, psoriasis, stomach and tooth pains in some European countries (Petrovic et al., 2003).

In the folk medicine of Brazil and some South American countries, feverfew has got fame to adjust menstrual irregularities and labor problems and for the prophylactic treatment of migraine in commercially available capsules, locally named "Tanaceto" (Izumi et al., 2008). The anti-migraine capability of feverfew is justifiable by the presence of huge quantities of parthenolide in its composition (Wu et al., 2006a; Javidnia et al., 2010). Indeed, parthenolide which is basically a sesquiterpene lactone and belongs to germacranolid class serves as the most prominent bioactive compound characterized in feverfew. The minimum level of parthenolide in Canadian, American and British products is 0.2%, while in French medicine is no less than 0.1% (Jin et al., 2008). Feverfew has also been found effective against a severe disease in Brazil, namely "holy fire" (see Table 3) since the Middle Ages to date (Chaves and Da Costa, 2008). Nevertheless, it is a good option for synthetic chemical drugs to cure headache, gastritis, infertility,

fever, giddiness, dermal diseases, tinnitus and arthritis (Newall, 2002; Benassi-Zanqueta et al., 2019).

Iran is one of the main habitats of feverfew and in many of its Alpine regions and at an average altitude of 2000 to 2500 m.s.l., *e.g.*, mountainous areas of Kohgiluyeh and Boyer-Ahmad province, Savadkooh (Mazandaran province) as well as Arasbaran jungle (East Azerbaijan province), this plant could be abundantly found. In the herbal drugs and trade markets of Iran, feverfew is of commercial importance and huge quantities of this plant are annually exported to some Middle East countries. In the Persian folk medicine, a wide array of applications has been suggested for feverfew. In Iran, feverfew is an astonishing medicinal plant which exerts tonic impact on the brain and is very useful for patients suffering from insomnia. The roots of feverfew are also a powerful aphrodisiac drug when mixed with vinegar and reinforce nervous system of the human body. The decoction and extracts prepared by mild heating of one tablespoon of feverfew are analgesic and can relieve cramps and muscular pains and treat anemia. For dermal diseases, feverfew has many remedial properties. If the flowers of feverfew are immersed in hot water and placed on the skin surface for 20 minutes, they can improve the skin inflammations and wounds, remove acne and control the skin infections. However, the usage of this herbal drug is highly restricted for pregnant and lactating mothers. Moreover, feverfew should not be used with non-steroidal anti-inflammatory drugs (NSAID) at the same time. Feverfew has a high potency to address some serious illnesses and ailments involving earache, indigestion, parasites, anemia, rheumatoid arthritis, vomiting, nausea and asthma (Habibi et al., 2007a; Saharkhiz et al., 2007; Pareek et al., 2011). It has also been known as a strong vermifuge, anti-parasitic and antiseptic in the Persian local folk medicine (Javidnia et al., 2008b; Rezaei et al., 2017).

In some Central American countries like Costa Rica, feverfew decoction gives rise to better digestion and is effective in removing worms (Pareek et al., 2011). This decoction has also emmenagogue and cardiotonic properties. In Venezuela, feverfew has been suggested to cure severe earache (Pareek et al., 2011). In Mexico, feverfew is extremely used to treat culture-bound symptoms (susto: fear, espanto: nervousness, quemados: burns) and convulsions. It also serves as an analgesic remedy and has similar uses like other Central and South American countries (Cárdenas et al., 2017). In the Danish traditional medicine, feverfew has been suggested as a tranquilizer, sleep inducer, anti-convulsion and anti-epilepsy agent capable of being used for the prophylactic treating of migraine (Jäger et al., 2006; Jäger et al., 2009). The traditional usage of this plant has been proved by researchers' studies. Parthenolide-depleted extract of feverfew (PD-feverfew) has a potent anti-inflammatory activity in inhibition of cytokines from activated PBMCs, especially TNFα but not in inhibition of NF-κB activity (Sur et al., 2009). PD-feverfew inhibited the release of $PGE_2$, a lipid mediator acting a major role in inflammation, from both LPS-stimulated macrophages (200 µg/mL) and also from TPA stimulated epidermal equivalents. Ethanol extracts of flowers and leaves showed the activities as a pain reliever in acute, inflammatory, articular and neuropathic pains of rats depends on the dose (30, 100 or 300 mg/kg p.o.) (Di Cesare Mannelli et al., 2015). The flower extract was more effective than leaf extract; it was more active in higher dosage and the effect was similar to diclofenac, ibuprofen or gabapentin (100 mg/kg). In the clinical study of *T. parthenium* tablets enhanced headache frequency and pain intensity in children were affected by tension-type headache (Moscano et al., 2019). In this regard, each typical tablet as a combination of $Mg^{2+}$, $CoQ_{10}$, vitamin $B_2$, feverfew, parthenolides and *Andrographis paniculata* respectively contained 169 mg, 20 mg, 4.8 mg, 150 mg, 1.2 mg and 100 mg of each.

The protective and antimigraine activities were also confirmed in rat astrocytes from the cortex (di Giacomo et al., 2019). However, further investigations should be conducted due to neurotoxic effect of the extract. Moreover, the water extracts of the plant have also shown antidepressant action and reduction of anxiety in mice (Cárdenas et al., 2017). It was dose-dependent effect in which *T. parthenium* at 10, 20, and 40 mg/kg doses significantly reduced immobility time (antidepressant action) in comparison to the control group and at 5, 10, and 20 mg/kg doses decreased the cumulative time that animals spent burying the prod and increased burying behavior latency (reduction of anxiety) and the same effect was after treatment Diazepam at the dosage 0.5 mg/kg. It was also proved that extracts of aerial parts of *T. parthenium* possessed *in vivo* anti-HSV-1 activity and it was nontoxic in oral and topical applications (Benassi-Zanqueta et al., 2019). Recently, a phytochemical-based study showed that parthenolide as well as sudachitin, aceronin and nevadensin isolated from feverfew and confirmed by LC-MS/MS and NMR spectroscopy, can penetrate the blood-brain barrier (Végh et al., 2018). Mahmoodzadeh et al. (2017) have found that the methanolic extract of *T. parthenium* possesses hepatoprotective and antioxidant effects in rats whose livers have been damaged by $CCl_4$. Hwang et al. (2019) have examined 22 Peruvian plants from which *T. parthenium* has a highest potent inhibitory activity against rat lens aldose reductase (RLAR): 61.1 ± 0.5% and DPPH radical scavenging: 88.6 ± 2.1%. These activities and AGEs activities of the *T. parthenium* are important to show the relevance in treatment of diabetic and in the prevention of diabetic complication. Dried aerial parts extracts of *T. parthenium* on *Trypanosoma cruzi* Y strain and may result in potential sources for the development of more effective compounds for the treatment of Chagas' disease (Izumi et al., 2008; Cogo et al., 2012). Furthermore, parthenolide could be responsible for mitigating migraines (Johnson et al., 1985). The crude extracts of *T. parthenuim* as well as parthenolide isolated from the plant species showed *in vitro* schistosomicidal activity (De Almeida et al., 2016). Parthenolide also showed significant activity against the promastigote form of *Leishmania. amazonensis*, with 50% inhibition of cell growth at a concentration of 0.37 µg/mL (Tiuman et al., 2005). Antileishmanial activity of a guaianolide (11,13-dehydrocompressanolide, (Fig. 6) from the aerial parts of the plant was also found. This activity was against promastigote forms of *L.*

*amazonensis*, and the authors showed the possibility for the development of new drugs against leishmaniasis as major infectious disease affecting the poorest regions of the world (da Silva et al., 2010).

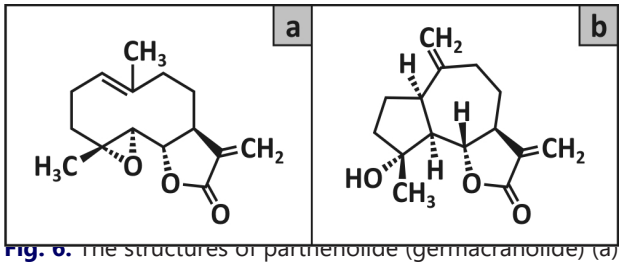


**Fig. 6.** The structures of parthenolide (germacranolide) (a) and 11,13-dehydrocompressanolide (guaianolide) (b).

This biological activity was confirmed in the animal study with the use of sesquiterpene lactone-rich (parthenolide and guaianolide) dichloromethane fraction obtained from the aerial parts of *T. parthenuim* (Rabito et al., 2014b) (Fig. 6). The typical percent of parthenolide in prophylactic treatment for migraine should be at least within the range 0.1-0.2 (w/w%) (Palevitch et al., 1997). The lowest level of this compound was claimed in feverfew extract obtained from leaves (0.2%), while the highest level was found in the corresponding aerial parts (1.2%) (Palevitch et al., 1997).

The differences in the level of parthenolide were found in samples from various origins (Avula et al., 2006). *T. parthenium* from Boulder Colorado, (USA) contained 0.16-0.17% of this compound and two samples from Mexico, namely Puebla and Oaxaca respectively involved 0.25-0.29% and 0.28-0.30% of parthenolide (Avula et al., 2006). On the other hand, the feverfew samples from Ontario (Canada) possessed approximately 0.6% of dry weight of this compound (Fonseca et al., 2006). In another report, the aerial parts of feverfew from Iran contained 1.73 to 1.86 mg/g d.m. (5 different locations) of parthenolide (Shahhoseini et al., 2019). The mean level of this compound in air-dried feverfew leaves from Goodwood, Ontario (Canada), dried in the temperature 60 °C, was 0.225 ± 0.032% , as well (Tanko et al., 2003).While the levels of parthenolide in aerial parts of the plant collected in Palestine were 0.49% and 1.06% in the powder and the hydroalcoholic extracts, respectively (HPLC analysis). The total content of flavonoids (UV/Vis spectroscopy analysis) was found to be 0.54% in the powder and 1.05% in the extract (Chaves and Da Costa, 2008). It was also found that for the cytotoxic properties of the *Tanacetum* species are related with 3 flavonoids including centauredin which is 200 fold more active then santin (not tanetin), and jaceidin (Long et al., 2003). The levels of 566.05 µg/mg of parthenolide and 52.55 µg/mg of guaianolide in the dichloromethane fraction of the hydroalcoholic extract of *T. parthenium* were recently shown (Rabito et al., 2014a). Wu et al. (2006b) have found that feverfew powder extracted by 80% alcohol contained camphor, parthenolide, luteolin and apigenin in 0.30 ± 0.08%, 0.22% ± 0.03%, 0.84% ± 0.10% and 0.68% ± 0.07%, respectively. The antioxidant activity of alcoholic feverfew extract (16.16 mg/mL) measured in DPPH test was 84.4% and $Fe^{2+}$-chelating capacity was 53.1%. Total phenolic content of the extract showed 21.21 ± 2.11 µg gallic acid equivalent per mg of dry material. The same authors (Wu et al., 2007) also isolated 3,5-, 4,5- and 3,4-di-*O*-caffeoylquinic acids from this plant and feverfew golden powder possessed antioxidant activity when using DPPH (1,1-diphenyl-2-picrylhydrazyl) and $Fe^{2+}$-chelating activity assays. In addition, a number of flavones such as apigenin, luteolin and chrysoeriol, as well as their glucuronides and glycosides such as apigenin 7-glucuronide, luteolin 7-glucuronide, luteolin 7-glucoside and chrysoeriol 7-glucuronide have been identified (Williams et al., 1999). The total flavonoid and parthenolide contents in the spray-dried extract of Palestine plant were 1.31% and 0.76%, respectively (Chaves et al., 2009).

Feverfew grown in Roscommon (Ireland) extracted in temperature of 80 °C was found to provide extracts rich in parthenolide content (about 1.4%), phenolic content (25 mg/g GAE dry mass) and a desirable color, suitable as an ingredient of functional beverage (Marete et al., 2009). Rateb et al. (2007) showed that the addition of monosaccharides (glucose or fructose) and low of the plant growth regulation in half strength medium could increase the level of parthenolide in *in vitro* culture. The optimum parameters for the supercritical fluid extraction ($CO_2$) reached the highest content of parthenolide in the extracts were found: pressure 22 MPa, the temperature of extraction -64 °C and the addition of 7% ethanol (Végh et al., 2014). The flower heads contain the highest content of parthenolide (0.604 wt.%) in comparison to leaves before and after flowering stage. It is worth mentioning that the extracts from flower of feverfew contained melatonin, in hot water extract was 1.12 µg/g (d.w.-dry weight) and 50% methanol-water -2.09 µg/g d.w. (Ansari et al., 2010).

### 2.1.3. *T. balsamita* L.

*T. balsamita* L. called as "Shahsparam" and "costmary" is one of the main ingredients of Iranian aromatic and botanical water (Table 3) with remarkable sedative, tonic and carminative properties (Javidnia et al., 2008a). In Turkey, there is a great attention to the frequent use of *T. balsamita* L. in the folk medicine to control diabetes, inflammation, abscess, wounds and the skin problems along with to remove gallstone (Zengin et al., 2019). The essential oil obtained from *T. balsamita* subsp. *balsamita* (Iran) showed significant antibacterial and low cytotoxic activities (Yousefzadi et al., 2009). The antibacterial activity of costmary EO from Turkey was also confirmed by Bączek et al. (2017). Phenolic compounds mainly dicaffeoyltartaric acid (cichoric acid), apigenin-7-*O*-glucoside (cosmosiin) and 3-caffeoylquinic acid (chlorogenic acid) were determined in the Turkish costmary cultivated in Poland (Bączek et al., 2017).

### 2.1.4. *T. fisherae* Aitch. & Hemsl.

Although *T. fisherae* Aitch. & Hemsl. is a rare species of *Tanacetum* in the world and grows only in some Alpine regions of Kerman province, Iran, it is employed towards gastrointestinal problems and as a spicy additive to

many local foods of Kerman, Iran (Rajaei et al., 2011).

### 2.1.5. *T. chiliophyllum* (Fisch. & Mey.) Schultz Bip.

Local Turkish people in Eastern Anatolia extensively use the decoction from the flowers of *T. chiliophyllum* (Fisch. & Mey.) Schultz Bip. as an antipyretic drug and to address pulmonic malfunctions and kidney stones (Polatoğlu et al., 2012). It has been reported that *T. chiliophyllum* oil shows significant broad spectra antifungal activity and strong phytotoxic effects against *Amaranthus retroflexus*, *Chenopodium album* and *Rumex crispus*. The oil could be a good alternative to pesticides and herbicides (Salamci et al., 2007). The insecticidal activity of extracts from the aerial parts and roots of *T. chiliophyllum* (Fisch. & Mey.) *var. monocephalum* Grierson from Turkey was confirmed by Polatoğlu et al. (2011b). Moreover, a new sesquiterpen lactone, namely 1-*epi*-chiliophyllin as a derivative of the compound chiliophyllin from this plant along with neolupenyl acetate (lup-12-ene-3b-acetate); 4′,5,7-trihydroxy-30,8-dimethoxyflavone, and 4′,5,7-trihydroxy-8-methoxyflavone were identified in the ethyl acetate extract of aerial parts of *T. chiliophyllum* (Fisch. & Mey.) *var. monocephalum* Grierson. As shown in this study, the highest antioxidant activity in DPPH assay was found in the ethyl acetate extract (10 mg/mL) of the plant roots.

The cytotoxic effect on the tested cell lines of the isolated compounds from *T. chiliophyllum* was ranged between 22.34-49.77 µg/mL $IC_{50}$ values in comparison to pure parthenolide 0.52-1.65 µg/mL $IC_{50}$ values (Polatoğlu et al., 2017). 5-Hydroxy-3′,4′,7-trimethoxyflavone and 5-hydroxy-3′,4′,6,7-tetramethoxyflavone possessed the highest cytotoxic activity against MCF-7 and HEK 293 cell lines. Additionally, compounds such as eupatilin, cirsilineol, 5-hydroxy-3′,4′,7-trimethoxyflavone and ulubelenolide exhibited significant antimicrobial effect especially on *C. albicans*.

### 2.1.6. *T. polycephalum* Schultz Bip

*T. polycephalum* Schultz Bip has found some therapeutic applications in the Iranian folk medicine to be administered against a broad spectrum of diseases like respiratory tract disorders, cutaneous infections and rheumatoid arthritis. This plant has been shown as an anesthetic, antiseptic, anticancer, antiarrhythmic and antiallergic remedy, as well (Rezazadeh et al., 2014). The EO of Iranian samples showed significant antimicrobial activity against *Staphylococcus aureous* and *Bacillus subtilis* (Rezazadeh et al., 2014), antioxidant and antifungal activities (Eblaghi et al., 2016).

Karimian et al. (2015) have shown that the hexane extracts from the leaves of *T. polycephalum* Schultz Bip, with the main bioactive compound of 8β-hydroxy-4β,15-dihydrozaluzanin, inhibited the proliferation of breast cancer cells, resulting in the cell cycle arrest and apoptosis (Karimian et al., 2014). Regarding the main outputs of this study, the chemopreventive effect of the extracts was also confirmed in rats (Karimian et al., 2015). The activity of extract depended on the dose and the higher dose (500 mg/kg) of hexane extract showed the almost the same reduction of breast tumor 78.6% compared with the group of rats treated with tamoxifen -81.5%. The lower dose (250 mg/kg) show only 16.6% reduction of the tumor after 6 weeks treatment.

### 2.1.7. *T. sinaicum*

In some Middle East countries like Egypt, *T. sinaicum* (*T. santolinoides*) has been traditionally prescribed to cure bronchitis, migraine, fever, cold and some ailments relating to digestion (Hegazy et al., 2015). The anti-inflammatory activity of sesquiterpenes tanacetolide were confirmed by inhibition of NO production (Hegazy et al., 2015). The methanolic extract from the aerial parts of this plant conatined sesquiterpene - tanacetonic acid and three methoxylated flavonoids, namely 5,7-dihydroxy-6,3′,4′-trimethoxyflavone, 7,4′-dihydroxy-3,5,6,3′-tetramethoxyflavone, and 5,4′-dihydroxy-6,7,3′-trimethoxyflavone. The tanacetonic acid showed a significant cytotoxic activity in the brine shrimp bioassay, whereas three flavonoids demonstrated anti-inflammatory effects in the rat paw oedema test (Ibrahim et al., 2007).

In addition, a novel and very rare germacranolide-type sesquiterpene lactone, 1α-hydroxy-3-oxo-7α,11βH-germacra-4*Z*,9*Z*-dien-12,6α-olide (Fig. 7), was isolated from the $CH_2Cl_2$-MeOH extract of the aerial parts of *T. santolinoides* (Mahmoud et al., 2007).

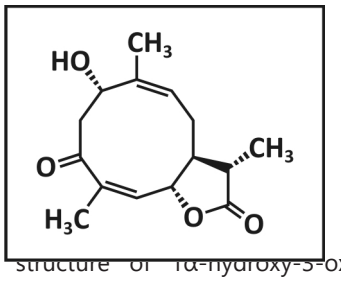


**Fig. 7.** The structure of 1α-hydroxy-3-oxo-7α,11βH-germacra-4Z,9Z-dien-12,6α-olide.

Marzouk et al. (2016) have isolated apigenin, acacetin, luteolin, apigenin 7-*O*-β-glucuronide, luteolin 7-*O*-β-glucopyranoside, 4-hydroxy-3-methoxybenzoic acid, 3,4-dimethoxybenzoic acid and 4-hydroxy acetophenone and identified them in *T. sinaicum* for the first time.

### 2.1.8. *T. gracile*

*T. gracile* as an endemic plant in India, Pakistan and Afghanistan has been utilized in the traditional medicine of these countries for a long period of time in decoction and powder forms. It has been reported that the decoction prepared from the leaves and flowers of *T. gracile* has a great potency against children forms, while the leaves powder has therapeutic properties vs. sore throat and obesity (Sharma et al., 2016). In addition, the biological activity of this plant was confirmed and the EO from flowering shoots exhibited potential cytotoxic and apoptotic activity in human leukemia HL-60 cells (Verma et al., 2008).

Bhat et al. (2016) have isolated a novel sesquiterpene lactone, namely gracilone in the methanol extract

and confirmed its structure by 1D, 2D NMR and MS spectroscopic analysis. Gracilone possessed moderate antibacterial and antioxidant activities. The main flavonoid isolated from the plant, apigenin showed the highest antibacterial potentiality against Gram positive and Gram negative tested strains as well as antioxidant and cytotoxic activities in human cancer cell lines (Bhat et al., 2016). In addition, two flavonoid derivatives, namely 5-hydroxy-3,6,7,3′,4′-pentamethoxyflavone and 5,4′-dihydroxy-3,6,7,3′,4′-tetramethoxyflavone showed significant cytotoxic activity against human breast cancer cells (MCF-7 and T47D) (Sinha et al., 2015). Sharma et al. (2016) have successfully determined remarkable amounts of compounds such as kaempferol 0.77%, ketoplenolide 0.006-1.510%, tetramethoxyflavone 0.079-0.733% and artemetin 0.010-1.787% in ether extracts of Indian plant using HPLC-ESI-QTOF-MS method.

#### 2.1.9. *T. densum* (Lab.) Schultz Bip.

The infusion made from the aerial parts of another *Tanacetum* endemic plant in Turkey, namely *T. densum* (Lab.) Schultz Bip. has been found to treat spelling and wound-healing (Özbilgin et al., 2018). The chloroform extract of *T. densum* showed the highest anti-inflammatory activity (31.6%) in comparison to *T. vulgare* (13.5%) or and *T. heterotomum* (3.6%), and this promising extract decreased the wound area to almost 97.3% after 10 days of treatment. The *in vivo* wound-healing activity of this plant may be attributed to the presence of parthenoide with its active chemical structure (Özbilgin et al., 2018). The methanol extracts of this plant from Sivas-Turkey, namely *T. densum* subsp. *sivasicum*, *T. densum* subsp. *eginense* and *T. densu*m subsp. *amani* possess antioxidant activity in DPPH test, react with Folin-Ciocalteu and inhibit the linoleic acid oxidation. In this sense and among the three tested MeOH extracts, *T. densum* subsp. *sivasicum* activities were the highest in all assays (Tepe and Sokmen, 2007).

#### 2.1.10. *T. cinerarii-folium* (Trevir.) Sch.Bip.

*T. cinerarii-folium* (Trevir.) Sch.Bip. trivially known as "Pyrethrum" has been widely employed by Chilean people as a natural insecticide (Bergmann et al., 2018) and also in other European countries; it is native to Croatia and Albania (Marongiu et al., 2009; Grdiša et al., 2013). Dalmatian endemic plant extracts contained pyrethrins, cinerins and jasmolins compounds (Grdiša et al., 2013). The level of pyrethrin content from 1.37% to 1.69% was found in dried flowers (Li et al., 2014).

#### 2.1.11. *T. poteriifolium* Grierson

The infusion from the aerial parts of *T. poteriifolium* Grierson has considerable emmenagogue properties and can highly relieve inflammation as well as stomach and digestive disorders in the Turkish folk medicine (Dalar et al., 2018). The water extract of *T. poteriifolium*-the richest in caffeoylquinic acids and other phenolic compounds-possessed the highest radical scavenging and reducing properties in *in vitro* assays. On the other hand, the ethyl acetate extract as the main source of flavone aglycones with methylquercetin (tetrahydroxy-3-methoxyflavone), its derivative, tetrahydroxy-dimethoxyflavone and trihydroxy-dimethoxyflavone showed the strongest cholinesterase and α-glucosidase inhibitor in contrary to the methanol extract which showed tyrosinase inhibitor activities.

#### 2.1.12. *T. larvatum* (Gris.) Kanitz.

There have been some reports on anti-inflammatory and anti-ulcer properties of *T. larvatum* (Gris.) Kanitz. (Petrovic et al., 2003). *T. larvatum* leaves contain sesquiterpene lactone parthenolide in a concentration of 1.1% which inhibit NF-κB (Vajs et al., 2000).
The aerial parts of *T. larvatum* extract has shown the anti-inflammatory activities (49.5% in dose 200 mg/kg) in comparison to indomethacin (73.4% in dose 8 mg/kg) and the protection against indomethacin-induced ulcerogenesis in rats (Petrovic et al., 2003). Aljancic et al. (2010) showed the differences between the level of parthenolide, not only in the location but also between the years of harvest.

#### 2.1.13. *T. santolinoides* (DC.) Feinbr & Fertig

Local people of Egypt believe in high ability of *T. santolinoides* (DC.) Feinbr & Fertig to treat cholera. They have also stated in the relevant agricultural-based resources that the flowers of this species are very poisonous for goats as feed (Youssef et al., 2007). This plant encompasses compounds such as tanacetolide and other sesquiterpene lactones which showed good cytotoxic activity (Youssef et al., 2007).

#### 2.1.14. *T. sonboli*

The tea packages made from an endemic Iranian species of *Tanacetum*, namely *T. sonboli* has been locally found to improve intestinal (diarrhea), emphysema and digestion problems (Esmaeili et al., 2010).

#### 2.1.15. *T. corymbosum* (Willd.) Shultz-Bip.

In some Mediterranean countries, an infusion from the inflorescence parts of *T. corymbosum* (Willd.) Shultz-Bip. has found prominence attention for the treatment of parasitic infections caused by human intestinal worms (Zinicovscaia et al., 2019).

#### 2.1.16. *T. longifolium*

Mahmood et al. (2003) have found such compounds as *p*-coumaric acid esters: eicosanyl-*trans*-*p*-coumarate, and 2 novel compounds including 21′-hdroxyheneicosanyl-*p*-coumarate and 27′-hydroxy heptacosanyl-*cis*-*p*-coumarate in *T. longifolium* roots.

#### 2.1.17. *T. huronense*

*T. huronense* named also "Lake Huron tansy" has been found to be native to the upper Midwest region of USA and Canada. Ethyl acetate extract of aerial parts of the

plant was examined and six active sesquiterpenoid lactones, namely tatridin A, 1-*epi*-tatridin B, tatridin B, tanacin together with its two structural analogues of tanacin lactone were subsequently identified, among which tanacin showed the highest inhibition activity of glioblastoma cell proliferation in *in vitro* human tumor cells (Dissanayake et al., 2016). The whole (air dried) plant material of *T. fruticulosum* Ledeb. contained new sesquiterpene lactone with guaianolide structure, named carlaolide (Hadjiakhondi et al., 2003) and the obtained results were confirmed using NMR spectroscopy.

#### 2.1.18. *T. microphyllum*

Another *Tanacetum* species, *T. microphyllum* from Spain was analyzed and four flavonoids (santin, ermanin, centaureidin and 5,3′-dihydroxy-4′-methoxy-7-methoxycarbonylflavonol) and one sesquiterpene lactone (hydroxyachillin) isolated from this plant which were assessed as potential inhibitors of some macrophage functions involved in the inflammatory process. Among these compounds, only centaureidin and hydroxyachillin significantly inhibited the accumulation of TNF-alpha in the tumor necrosis factor-alpha (TNF-alpha) assay (Abad et al., 2004).

#### 2.1.19. *T. aucheranum*

*T. aucheranum* oil from Turkey showed the antifungal activity and phytotoxic effects against *A. retroflexus, C. album* and *R. crispus*. Due to these activities, the oil could be an alternative pesticide and herbicide (Salamci et al., 2007).

#### 2.1.20. *T. pinnatum*

The extract of *T. pinnatum* showed the antioxidant activity in the DPPH assay, while its EO displayed the highest antioxidant activity in the β-carotene-linoleic acid assay. EO of this plant also possessed antibacterial activity against *Staphylococcus aureus* (Esmaeili and Amiri, 2011).

#### 2.1.21. *T. cadmeum* ssp. *cadmeum*

In addition, *T. cadmeum* ssp. *cadmeum* contained artesin, taurin, artemin, tavulin, tanachin, tamirin, scopoletin, tanetin (6-hydroxykaempferol 3,7,4′-trimethylether), 6-hydroxykaempferol 3,6-dimethylether (Susurluk et al., 2007). It was also found that *T. cadmeum* aerial parts extract can be used as feeding deterrents in integrated pest management.

### 2.2. The antioxidant and other biological activities among the genus *Tanacetum*

The antioxidant activities of the plant are connected with flavonoids and derivatives, phenolic acids and other phenolic compounds determined in *Tancacetum* species. The ethanolic extracts of six species of *Tanacetum*, viz. *T. budjnurdense, T. hololeucum, T. chiliophyllum, T. sonboli, T. tabrisianum, T. kotschyi* from Iran were measured using *in vitro* antioxidant systems like DPPH and β-carotene-linoleic acid inhibition assays and abilities to protect human leukemia K562 cells against oxidative insult by modulating GSH concentration, ROS generation, TBARS production and antioxidant enzyme activity (Esmaeili et al., 2010). Accordingly, it was found that extracts of *T. hololeucum* and *T. kotschyi* with the highest level of total phenolic compounds and total flavonoids showed the highest antioxidant activities in *in vitro* assays.
The antioxidant activity of *T. sonbolii* (from Iran) extracts was measured by using two *in vitro* assays involving DPPH radical scavenging and β-carotene-linoleic acid (Firozy et al., 2012). In this relation, six different solvents, viz. hexane, chloroform, ethyl acetate, methanol, butanol and water, were compared and the total phenolic and flavonoid contents of these extracts were also determined. Taking into account the obtained results, the water extract showed the highest activity in DPPH assay, while ethyl acetate and methanol extracts contained the highest levels of phenolic compounds using the standard spectrophotometric-based methods. Moreover, Arituluk et al. (2016) have analyzed five *Tanacetum* taxa (*T. armenum* (DC.) Schultz Bip., namely *T. cadmeum* (Boiss.) Heywood ssp. *cadmeum, T. cilicicum* (Boiss.) Grierson, *T. praeteritum* (Horw.) Heywood ssp. *Massicyticum* Heywood*, and T. praeteritum* (Horw.) Heywood ssp. *praeteritum*) from Antalya, Turkey. They have used four *in vitro* methods: DPPH; 2,2′-azinobis-(3-ethylbenzothiazolin-6-sulphonic acid) (ABTS) radical cation scavenging capacity, cupric ion reducing antioxidant capacity (CUPRAC) and ferric-reducing antioxidant power (FRAP) assays measured in the methanol extracts of the plants. As being reported, *T. praeteritum* ssp. *massicyticum*, showed the highest scavenging activity in DPPH, ABTS and CUPRAC assays and also contained the highest total phenolic and flavonoid compounds. It was recently found that *Tanacetum haussknechtii* Bornm. Grierson collected in Turkey, very rarely analyzed, possessed antioxidant as well as acetylcholinesterase activity (Yur et al., 2018). The methanolic extracts showed the highest antioxidant activity in DPPH test.

### 2.3. Chemical profiles of EOs of different species of the genus *Tanacetum*

It has been well-documented that *Tanacetum* species are rich sources of EOs, bitter compounds along with a wide variety of sesquiterpene lactones (Baytop, 1999a; Salamci et al., 2007). The dominant natural compounds characterized in a number of *Tanacetum* species have been summarized in Table 4 along with the respective prevailing class, isolation method(s), total percent of identified profile, oil yield and the corresponding sampling areas in which these species grow widely. Characterization of the oil compositions is often performed considering the following criteria:
i. Consistency of the calculated retention index of each constituent with that of tabulated in literature ii. Superimposition of the mass spectral patterns of each characterized constituent
iii. Reports of advanced library of GC-MS instruments (GC-MS or GC-MS/MS).

EOs always contain diverse class of natural compounds, *e.g.,* monoterpene hydrocarbons (MHs) oxygenated monoterpenes (OMs), sesquiterpene hydrocarbons (SHs), oxygenated sesquiterpenes (OSs) and non-terpene hydrocarbons (NHs). Furthermore, the EOs are frequently isolated from plant organs using classical hydrodistillation (HD) or advanced approaches like microwave-assisted hydrodistillation (MAHD) and subsequently analyzed using gas chromatography (GC) or gas chromatography combined with mass spectrometry (GC-MS).
As seen in Table 4, in the majority of the reported profiles of EOs up to present, OMs have the highest frequencies compared to other natural compounds constituting groups. According to Table 4, there is a remarkable intraspecific variation in EO composition of a large number of *Tanacetum* species. The EOs of *Tanacetum* plants are discussed below from the relevant species point of view.

### 2.3.1. *T. vulgare* L.

As one of the most important species of, many authors have reported the composition of EOs of *T. vulgare* L. in a variety of habitats. According to Table 4, OMs like camphor and chrysanthenyl acetate (*cis*- and *trans*-isomers), thujone (α- and β), 1,8-cineole and borneol had the highest abundance and were common in most of the characterized profiles of *T. vulgare* L. EOs. In a related study by Goudarzi et al. (2015) on five stages involving rosette stage (RS), stem initiation stage (SIS), floral budding stage (FBS), full flowering stage (FFS) and beginning of the fruit stage (BFS), OMs were found to be the major fractions of the isolated and identified EOs among which *trans*-thujone, camphor and *trans*-chrysanthenyl acetate were common and had the highest quantities is in all of the EO profiles.
It is also noteworthy that the total amounts of the other classes of natural compounds were considerably lower than OMs with the exception of an old report by Dembitskii et al. (1985b) in which MHs were the most abundant constituents of the characterized oil. Furthermore, the oil yield percent of the isolated oils varied over the range 0.05-1.76%.

### 2.3.2. *T. parthenium* (L.) Schultz-Bip

Characterization of the EO profiles of the other important *Tanacetum* species, namely *T. parthenium* (L.) Schultz-Bip has been reported by several authors in the literature, as well (see Table 4). Accordingly and similar to the EOs of *T. vulgare* L. species, in all of the characterized profiles of *T. parthenium* (L.) Schultz-Bip under various climatic conditions, OMs were the major fractions and dominated the profiles with the aforementioned natural compounds in addition to bornyl acetate. However, the mean yields of the separated EO (0.15-6.94%) were higher compared to those of *T. vulgare* L. and this denotes that *T. parthenium* (L.) Schultz-Bip species possess higher capability to produce EOs.

### 2.3.3. *T. polycephalum* Schultz Bip.

As anticipated, EOs of *T. polycephalum* Schultz Bip. were dominated by OMs like EOs of *T. vulgare* L. and *T. parthenium* (L.) Schultz-Bip. Najafi et al. (2007) have assessed the EO profiles of *T. polycephalum* Schultz Bip. subsp. *argyrophyllum* (K. Koch.) at two stages, namely before flowering stage (BFlS) and full flowering stage (FFS). In this context, apart from camphor and bornyl acetate, another oxygenated monoterpene, namely pinocarvone was among the most abundant compounds. Moreover, some monoterpene hydrocarbons, *e.g.,* α-pinene and *p*-cymene with lower quantities constituted the oil profiles. It should be mentioned that chrysanthenol isomers (*cis*- and *trans*-) have remarkable percents of some *T. polycephalum* Schultz Bip. EOs. Mirahmadi et al (2011) have reported the chemical profile of an EO from *T. polycephalum* Schultz Bip. with OMs as the main constituent components, but with some other relating natural compounds as artemisia alcohol and yomogi alcohol in addition to camphor and 1,8-cineole along with a monoterpene hydrocarbon like camphene.

### 2.3.4. *T. balsamita* L.

A perusal of Table 4 also demonstrates that the major constituent component of EOs of *T. balsamita* L. growing wild in some localities of Iran and Turkey contained remarkable quantities of carvone, α-thujone (α and β), pinocarvone, camphor, bornyl acetate etc. all belonging to OMs group of natural compounds.

### 2.3.5. *T. chiliophyllum* (Fisch. & Mey.) Schultz Bip.

In the reported profiles of EOs of *T. chiliophyllum* (Fisch. & Mey.) Schultz Bip., in some parts of Iran and particularly Turkey besides the common OMs like camphor, 1,8-cineole and borneol, some natural compounds like carveol, linalool, terpinene-4-ol and carvacrol contributed to the relevant profiles that all are of OMs type. There is also one report dealing with the analysis of the water-distilled EO of *T. chiliophyllum* (Fisch. & Mey.) Schultz Bip. in Turkey in which the flower in the stem oils were rich in camphor and 1,8-cineole, whereas the roots EO had high quantities of hexadecanoic acid and was subsequently dominated by non-terpene hydrocarbons (NH) (Polatoglu et al., 2012a).

### 2.3.6. *T. annuum* L.

Two EO samples of *T. annuum* L. have been analyzed and found to possess considerable amounts of sabinene accounting for high dominance of MHs (Greche et al., 2000; Hmiri et al., 2011).

### 2.3.7. *T. longifolium* Wall.

In the work of Kaul (1993) focusing on the composition of EO from the aerial parts and roots of *T. longifolium* Wall growing in India, OMs and MHs were the major classes with *trans*-sabinyl acetate and *trans*-sabinol as well as sabinene and *p*-cymene, respectively.

### 2.3.8. *T. argenteum* (Lam.) Willd.

There are some reports on EOs of *T. argenteum* (Lam.)

**Table 4**
Brief chemical profiles of a wide spectrum of characterized *Tanacetum* species (1985-to date).

| *Tanacetum* species | Main components or chemotype(s) | YO [a] | PCNC [b] | Separation/Characterization methods or criteria | TCF(%) c | | | Ref |
|---|---|---|---|---|---|---|---|---|
| | | | | | ≤80 | 80-90 | ≥90 | |
| *T. vulgare* L. | Artemisia alcohol, γ-campholenol, davanone, lyratol, lyratyl acetate and 4-thujen-2α-yl acetate | NR d | OM e | HD/GC/MS | | | × | (Héthelyi et al., 1981) |
| | α-Pinene, achillene, camphene, β-pinene, sabinene, myrcene, limonene, β-phellandrene, 1,8-cineole, γ-terpinene, *p*-cymene and terpinolene | 0.1 | MH f | HD/GLC | × | | | (Dembitskii et al., 1985b) |
| | Camphor and *trans*-chrysanthenyl acetate | 0.3-0.68 [g] | OM | HD/GC, GC/MS | | | × | (De Pooter et al., 1989) |
| | | 1.14 h | | | | | × | |
| | Artemisia ketone, chrysanthenol/chrysanthenyl acetate, lyratol/lyratyl acetate and β-thujone chemotypes | 0.48- 0.94 [i] | OM | HD/GC-FID, GC/MS | | × | × | (Hendriks et al., 1990) |
| | | 0.74-1.76 [j] | | | | | | |
| | *trans*-Chrysanthenyl acetate and trans-chrysanthenol | 0.25-0.32 | OM | HD/GC, GC/MS, 1H- and 13C-NMR | | | × | (Neszmélyi et al., 1992) |
| | Camphor-1,8-cineole-borneol mixed chemotype | 0.15-0.2 | OM | HD/GC and GC/MS | | × | | (Collin et al., 1993) |
| | Thujone, camphor, chrysanthenyl acetate, borneol, and 1,8-cineole | - | OM | SFE k/GC and GC/MS | × | | | (Smith and Burford, 1994) |
| | Camphor, α-thujone, 1,8-cineole and artemisia ketone chemotypes | 0.4-1.1 | OM | HD/GC-FID and GC/MS | | × | × | (Mockute and Judzentiene, 2004) |
| | Steinvikholmen genotype: Thujone-camphor | 0.7-1.22 | OM | HD/GC/MS | × | | | (Dragland et al., 2005) |
| | Alvdal genotype: Thujone-camphor-borneol | 0.2-0.5 | | | | | | |
| | Brumunddal genotype: Thujone-camphor-chrysanthenyl | 0.3-1.43 | | | | | | |
| | 1,8-Cineole, *trans*-thujone, camphor and myrtenol l | 0.4-1.1 | OM | HD/GC and GC/MS | | × | × | (Judzentiene and Mockute, 2005) |
| | Polluted Pancevo zone: trans-Chrysanthenyl acetate, β-thujone and *trans*-carveol acetate | NR | OM | HD/GC and GC/MS | | × | | (Stevović et al., 2011) |
| | Unpolluted Lisovici zone: *trans*-Chrysanthenyl acetate, trans-carveol acetate and linalool oxide acetate | | | | × | | | |
| | α-Thujone, β-thujone and 1,8-cineole [m] | 0.19-0.31 | OM | HD/GC/MS | | | × | (Formisano et al., 2009) |
| | β-Thujone | NR | OM | HD/GC/MS | | | × | (Knaak et al., 2013) |
| | β-Thujone | 0.05 | OM | HD/GC/MS | | | × | (Godinho et al., 2014) |
| | 1,8-Cineole, *trans*-thujone, *cis*-chrysanthenol, borneol and myrtenol | 0.3 | OM | HD/GC-FID and GC/MS | | × | × | (Piras et al., 2014) |
| | | 0.9 | | SFE/GC-FID and GC/MS | | | | |
| | Harju district: trans-Chrysanthenone, 1,8-cineole, β-pinene, α-pinene and 6-camphenone | 0.4 | OM | HD/GC/MS | | | × | (Raal et al., 2014) |
| | Tartu district: β-Thujone and *trans*-chrysanthenyl acetate | 0.5 | | | | | | |
| | β-Thujone, camphor, and *trans*-chrysanthenyl acetate | 0.2 | OM | HD/GC and GC/MS | | | × | (Szołyga et al., 2014) |
| | RS [n]: *trans*-Thujone, camphor and trans-chrysanthenyl acetate | 0.52 | OM | HD/GC and GC/MS | | | × | (Goudarzi et al., 2015) |
| | SIS [o]: *trans*-Chrysanthenyl acetate camphor and *trans*-thujone | 0.55 | | | | | × | |
| | FBS [p]: Camphor, trans-chrysanthenyl acetate and *trans*-thujone | 0.53 | | | | | × | |
| | FFS [q]: *trans*-Chrysanthenyl acetate, camphor and *trans*-thujone | 0.91 | | | | | × | |
| | BFS [r]: *trans*-Thujone, *trans*-chrysanthenyl acetate and camphor | 0.73 | | | | | × | |
| | Camphor, trans-thujone, trans-chrysanthenyl acetate camphene, sabinene, and germacrene D | 0.65-1.0 | OM | HD/GC and GC/MS | | | × | (Goudarzi et al., 2016) |
| | *trans*-Chrysanthenyl acetate, β-thujone, (*E*)-dihydrocarvone and artemisia ketone | 1.2 | OM | HD/GC-FID and GC/MS | | | × | (Bączek et al., 2017) |
| | *trans*-Chrysanthenyl acetate, *trans*-chrysanthenol, *trans*-thujone and *cis*-thujone | 0.32 | OM | HD/GC-FID and GC/MS | | | × | (Devrnja et al., 2017) |
| | β-Thujone | 0.67 | OM | HD/GC-FID and GC/MS | | | × | (Radulović et al., 2017) |

**Table 4** Continued

| *Tanacetum* species | Main components or chemotype(s) | YO [a] | PCNC [b] | Separation/Characterization methods or criteria | TCF(%) c | | | Ref |
|---|---|---|---|---|---|---|---|---|
| | | | | | ≤80 | 80-90 | ≥90 | |
| *T. vulgare* L. | α-Thujone and 1,8-cineole | 0.65 | OM | HD/GC/MS | | | × | (Czerniewicz et al., 2018) |
| | Camphor, eucalyptol and camphene | NR | OM | HD/GC/MS | | | × | (Dolarslan and Gurkok, 2018) |
| *T. parthenium* (L.) Schultz-Bip | Camphor and *trans*-chrysanthenyl acetate | 0.15-0.17 s<br>0.75 t | OM | HD/GC, GC/MS | | | × | (De Pooter et al., 1989) |
| | Camphor, chrysanthenyl acetate, dihydroparthenolide and parthenolide | - | OM | SFE/GC and GC/MS | | | × | (Smith and Burford, 1994) |
| | Camphor and chrysanthenyl acetate | 0.3-0.83 | OM | HD/GC and GC/MS | | | × | (Hendriks et al., 1996) |
| | Camphor, camphene and p-cymene | 0.43 | OM | HD/GC and GC/MS | | | × | (Akpulat et al., 2005) |
| | Camphor, chrysanthenyl acetate and camphene | 0.31-6.94 | OM | HD/GC and GC/MS | × | × | × | (Izadi et al., 2010) |
| | Davutpaşa-İstanbul location: Camphor, trans-chrysanthenyl acetate and camphene | 0.7 | OM | HD/GC and GC/MS | | | × | (Polatoğlu et al., 2010a) |
| | Şavşat-Ardahan location: Camphor and camphene | 0.45 | | | | | × | |
| | Camphor, bornyl acetate, camphene, bornyl isovalerate, borneol, juniper camphor and β-eudesmol | 0.75-1.02 | OM | HD/GC/MS | × | | × | (Mohsenzadeh et al., 2011) |
| | Camphor and camphene | 0.57 | OM | HD/GC and GC/MS | | | × | (Stanković et al., 2016) |
| | Camphor and chrysanthenyl acetate | NR | OM | HD/GC-FID and GC/MS | | | × | (Farzadfar et al., 2017) |
| | Camphor, trans-β-farnesene, camphene, β-caryophyllene chrysanthenone, bornyl acetate, 4-hydroxy-benzenepropanoic acid and borneol | 0.8 | OM | HD/GC and GC/MS | | | × | (Shafaghat et al., 2017) |
| | Camphor, α-pinene, chrysanthenyl acetate and limonene | 0.6 | OM | HD/GC/MS | | | × | (Alizadeh Behbahani and Imani Fooladi, 2018) |
| | Camphor, guaiol, caryophyllene oxide, bornyl acetate, (E)-verbenol, camphene and α-cadinol | NR | OM | HD/GC and GC/MS | | × | | (Coban et al., 2019) |
| | Camphor, neryl acetate, p-cymene, bornyl acetate, camphene and borneol | 0.84 [u] | OM | HD/GC/MS | | | × | (Shahhoseini et al., 2019) |
| T. *parthenium* (L.) cv. Zardband | camphor, chrysanthenyl acetate, camphene, p-cymene and α-pinene | 0.41-0.52 | OM | HD/GC and GC/MS | × | × | × | (Saharkhiz et al., 2007) |
| T. *polycephalum* Schultz Bip. | Camphor, camphene, 1,8-cineole, bornyl acetate and borneol v | 0.41-0.45 | OM | HD/GC and GC/MS | | × | × | (Nori-Shargh et al., 1999) |
| | Camphor, 1,8-cineole, carveol and trans-isopulegone | 0.78 | OM | HD/GC and GC/MS | | × | | (Rustaiyan et al., 1999) |
| | α-Thujone, camphor, borneol, 1,8-cineole and β-thujone | 1.1 | OM | HD/GC and GC/MS | | | × | (Morteza-Semnani, 2006) |
| | Borneol, β-pinene, α-pinene, camphene, α-terpineol and 1,8-cineole | NR | OM | HD/GC and GC/MS | | | × | (Amiri, 2007) |
| | BFIS [w]: Camphor, pinocar-vone, α-pinene, p-cymene and bornyl acetate 0.22 | 0.22 | OM | HD/GC and GC/MS | | | × | (Najafi et al., 2007) |
| | FFS [x]: Pinocarvone, 1,8-cineole camphor, α-pinene, *p*-cymene and bornyl acetate | 0.48 | | | | | × | |
| | *trans*-Chrysanthenyl acetate, 1,8-cineole, *trans*-chrysanthenol, *cis*-chrysanthenyl acetate and *cis*-chrysanthenol [y] | 0.4 | OM | HD/GC and GC/MS | | × | | (Javidnia et al., 2008a) |
| | Camphor, trans-chrysanthenyl acetate and camphene [z] | 0.23-0.36 | OM | HD/GC and GC/MS | | | × | (Dajić Stevanović et al., 2009) |
| | Isobornyl-2-methyl butanoate, linalool butanoate, *cis*- chrysanthenyl acetate, geranyl acetone and trans-myrtenol acetate aa | 1.6 | OM | HD/GC/MS | | | × | (Nezhadali et al., 2010) |
| | Artemisia alcohol, camphor, yomogi alcohol, camphene and 1,8-cineole [ab] | 0.95 | OM | HD/GC and GC/MS | | | × | (Mirahmadi et al., 2011) |

**Table 4** Continued

| *Tanacetum* species | Main components or chemotype(s) | YO [a] | PCNC [b] | Separation/Characterization methods or criteria | TCF(%) c | | | Ref |
|---|---|---|---|---|---|---|---|---|
| | | | | | ≤80 | 80-90 | ≥90 | |
| T. *polycephalum* Schultz Bip. | Region 1 close to mine: Camphor, cinnamic aldehyde, 1,8-cineole and borneol | NR | OM | HD/GC/MS | | | × | (Givianrad and Hashemi, 2014) |
| | Region 2 near the mine (5 km): Camphor, borneol and 1,8-cineole | | | | | | × | |
| | Region 3 located at high distance from mine: Camphor, borneol, 1,8-cineole and bornyl acetate | | | | | | × | |
| | Camphor, cis-carveol and 1,8-cineole | 0.8 | OM | HD/GC/MS | × | | | (Pirbalouti et al., 2014) |
| | Behshahr habitat: Camphene, 1,8-cineole, chrysanthenone, camphor and borneol [ac] | 0.76 | OM | HD/GC-FID and GC/MS | | | × | (Rezazadeh et al., 2014) |
| | Baladeh habitat: 1,8-Cineole, chrysanthenone, camphor and borneol [ac] | 1.1 | | | | × | | |
| | Savadkooh habitat: α-Pinene, 1,8-cineole, camphor, pinocarvone, iso-menthol, borneol and β-eudesmol [ac] | 1.3 | | | | × | | |
| | Borneol,1,8-cineole, camphor, bornyl acetate, camphene, p-cymene, carvacrol and thymol | 2.93 | OM | HD/GC/MS | | | × | (Eblaghi et al., 2016) |
| | | 2.85 | | MAHD [ad]/GC/MS | | | × | |
| | 1,8-Cineole, cis-thujone, trans-thujone, camphor, borneol and bornyl acetate | NR | OM | HD/GC-FID and GC/MS | | | × | (Mojarrad et al., 2018) |
| | 1,8-Cineole, borneol, bornyl acetate and camphor | 0.44-0.47 | OM | HD/GC-FID and GC/MS | | × | | (Pirbalouti, 2019) |
| *T. balsamita* L. | Carvone and α-thujone | 0.38 | OM | HD/GC/MS | | | × | (Başer et al., 2001) |
| | Carvone [ae] | 0.25 | OM | HD/GC and GC/MS | | | × | (Monfared et al., 2002) |
| | Leaf: Bornyl acetate, pinocarvone, camphor and terpinolene ae | 0.25 | OM | HD/GC and GC/MS | | | × | (Jaimand and Rezaee, 2005) |
| | Flower: Bornyl acetate, pinocarvone, camphor and terpinolene [ae] | 0.15 | | | | | × | |
| | Stem: Bornyl actate, pinocarvone, camphor and terpinolene [ae] | 0.05 | | | | | × | |
| | *trans*-Chrysanthenol, chrysanthenyl acetate, linalool oxide, camphor and 1,8-cineole [af] | 0.25 | OM | HD/GC and GC/MS | | | × | (Bagci et al., 2008) |
| | Carvone, β-thujone, 1,8-cineole and α-thujone [af] | 0.48 | | HD/GC and GC/MS | | | × | (Yousefzadi et al., 2009) |
| | β-Thujone and α-thujone | 0.7 | OM | HD/GC-FID and GC/MS | | | × | (Bączek et al., 2017) |
| T. chiliophyllum (Fisch. & Mey.) Schultz Bip. | Camphor and *cis*- chrysanthenyl acetate and α-thujone [ag] | 0.4 | OM | HD/GC/MS | | × | | (Başer et al., 2001) |
| | Camphor, 1,8-cineole and borneol [ag] | 0.22 | OM | HD/GC/MS | | | × | (Salamci et al., 2007) |
| | Camphor, 1,8-cineole, camphene, isobornyl propionate, carveol and borneol [ag] | 0.35 | OM | HD/GC and GC/MS | | | × | (Bagci et al., 2008) |
| | Van-Muradiye location: Flower and stem oils: Camphor, 1,8-cineole and chamazulene ah | 0.1-0.2 | OM | HD/GC and GC/MS | | × | | (Polatoğlu et al., 2012) |
| | Van-Muradiye location: Flower and stem oils: 1,8-Cineole, terpinene-4-o1, (*E*)-sesquilavandullol, p-cymene and hexadecanoic acid ai | 0.06 | OM and OS [aj] | | × | | | |
| | Van-Güzeldere location: 1,8-Cineole, terpinene-4-ol and α-pinene | 0.1-0.16 | OM and NH [ak] | | × | | | |
| | Flower and stem oils: Camphor and 1,8-cineole | 0.05-0.06 | OM | HD/GC and GC/MS | × | | | (Polatoglu et al., 2012a) |
| | Root oil: Hexadecanoic acid, alismol and geranyl isovalerate [al] | <0.01 | NH | | × | | | |
| | Linalool, camphor, *trans*-chrysanthenyl acetate, carvacrol, *cis*-chrysanthenol, and thymol | 0.25-0.55 | OM | HD/GC-FID and GC/MS | | | × | (Pirbalouti, 2019) |

**Table 4** Continued

| *Tanacetum* species | Main components or chemotype(s) | YO [a] | PCNC [b] | Separation/Characterization methods or criteria | TCF(%) c | | | Ref |
|---|---|---|---|---|---|---|---|---|
| | | | | | ≤80 | 80-90 | ≥90 | |
| *T. nubigenum* Wallich ex DC. | Pindari glacier (Bageshwar): (-)-*cis*-Chrysanthenol and sabinene | 0.29 | OM | HD/GC and GC/MS | | × | | (Beauchamp et al., 2001) |
| | Milam glacier moraine region: Bornyl acetate, borneol, (*E*)-β-farnesene and 1,8-cineole | 0.3 | OM | HD/GC, GC/MS and 1D- and 2D-NMR | | | × | (Chanotiya and Mathela, 2007) |
| | Pindari glacier region: (3*R*, 6*R*)-linalool oxide acetate, β-eudesmol and selin-11-en- 4α-ol | 0.25 | | | | | | |
| | 1,8-Cineole, sabinene, eudesmol and camphor | 0.64 | OM | HD/GC and GC/MS | | | × | (Lohani et al., 2012) |
| *T. annuum* L. | Sabinene and camphor | NR | MH | HD/GC and GC/MS | | | × | (Greche et al., 2000) |
| | Sabinene | NA | MH | HD/GC/MS | NA | | | (Hmiri et al., 2011) |
| *T. boreale* | 3-Hydroxy-2,2,6-trimethyl-6-vinyltetrahydropyran | 0.1 | OM | HD/GC/MS | NR | | | (Dembitskii et al., 1985a) |
| *T. longifolium* Wall | *trans*-Sabinyl acetate and trans-sabinol am | 0.3 | OM | HD/GC/MS | × | | | (Kaul et al., 1993) |
| | Terpinen-4-ol, sabinene and *p*-cymene an | 0.1 | MH | | × | | | |
| *T. fruticulosum* Ledeb. | 1,8-Cineole, camphor, lavandulol, lavandulyl acetate | 0.1 | OM | GC, GC/MS and NMR | | | × | (Weyerstahl et al., 1999) |
| *T. armenum* (DC.) Schultz Bip. | 1,8-Cineole and camphor | 0.62 ao | OM | HD/GC/MS | | × | | (Başer et al., 2001) |
| | | 0.67 ap | | | | | | |
| | p-Cymene, thymol, α-terpineol and 4-thujen-2α-yl acetate | NR | OM | HD/GC/MS | | | × | (Karabörkü et al., 2011) |
| *T. haradjani* (Rech. fil.) Grierson | Camphor and 1,8-cineole | 0.55 | OM | HD/GC/MS | | × | | (Başer et al., 2001) |
| *T. argyrophyllum* (C. Koch) Tvzel. | α-Thujone [aq] | 0.96-1.03 | OM | HD/GC/MS | | × | | (Gören et al., 2001) |
| | cis-Thujone, trans-thujone and 1,8-cineole [aq] | 0.78 | OM | HD/GC and GC/MS | | | × | (Akpulat et al., 2005) |
| | The flower oil: Camphor, borneol, 1,8-cineole and bornyl acetate [aq] | 0.95 | OM | HD/GC and GC/MS | | × | | (Polatoğlu et al., 2010c) |
| | The stem oil: Camphor, 1,8-cineole and borneol [aq] | 0.6 | | | | | × | |
| *T. argenteum* (Lam.) Willd. | α-Thujone and caryophyllene oxide [ar] | 0.04 | OS | HD/GC/MS | × | | | (Gören et al., 2001) |
| | α-Pinene, (E)-sesquilavandulol and camphor [as] | 0.36 | MH and OM | HD/MDGC-MS at | | | × | (Tabanca et al., 2007) |
| | α-Pinene, santolinatriene, 1,8-cineole, chrysanthenone, cadina-1,4-dien and β-pinene [au] | 0.7 | MH | HD/GC and GC/MS | | × | | (Bagci and Kocak, 2010) |
| | α-Pinene, β-pinene and 1,8-cineole [au] | 0.27 | MH | HD/GC and GC/MS | | | × | (Polatoğlu et al., 2010b) |
| | α-Pinene and β-pinene [au] | 0.32 | MH | HD/GC/MS | | | × | (Ali et al., 2014) |
| | α-Pinene, 1,8-cineole and camphor [av] | 0.35 | MH | HD/GC/MS | | | × | |
| *T. praeteritum* (Horwood) Heywood | Borneol, 1,8-cineole and bornyl acetate [aw] | 1.09 | OM | HD/GC/MS | | | × | (Gören et al., 2001) |
| | α-Thujone and β-thujone [ax] | 0.92 | OM | HD/GC/MS | | × | | (Gören et al., 2001) |
| | Sample A: Camphor, 1,8-cineole and terpinen-4-ol [ay] | 0.18 | OM | HD/GC-FID and GC/MS | | | × | (Özek, 2018) |
| | Sample B: α-Thujone and β-thujone ay | 0.24 | | | | | × | |
| *T. santolinoides* | Thymol, *trans*-thujone, *trans*-chrysanthenyl acetate, cis-chrysanthenyl acetate, umbellulone and 1,8-cineole | 1.41 | OM | HD/GLC and GLC-MS | | | × | (El-Shazly et al., 2002) |
| *T. khorassanicum* (Krasch.) Parsa. | (*E*)-Myroxide, camphor, isopulegone and 1,8-cineole | 0.9 | OM | HD/GC and GC/MS | | × | | (Majed-Jabari et al., 2002) |
| *T. lingulatum* Boiss. Bornm. | 1,8-Cineole and camphor | 0.32 | OM | HD/GC, GC/MS and 1H-NMR | | | × | (Afsharypuor and Jahromy, 2003) |
| | Flowers: α-Pinene, 1,8-cineole, sabinene, 2-pyrrolidinone, camphor, bicyclo [3.1.0] hexane and camphene | NR | MH | HD/GC/MS | | | × | (Olamazadeh et al., 2014) |
| | Leaves: 1,8-Cineole, α-pinene, sabinene, camphor and 2-pyrrolidinone | | OM | | | | × | |

**Table 4** Continued

| *Tanacetum* species | Main components or chemotype(s) | YO [a] | PCNC [b] | Separation/Characterization methods or criteria | TCF(%) c | | | Ref |
|---|---|---|---|---|---|---|---|---|
| | | | | | ≤80 | 80-90 | ≥90 | |
| *T. larvatum* (Oris.) Kanitz. | Sample I : *trans*-Sabinyl acetate | 0.3 | OM | HD/GC and GC/MS | | | × | (Bulatovic et al., 2006) |
| | Sample II: *trans*-Sabinyl acetate | 0.2 | | | | | × | |
| | Planinica habitat: *trans*-Sabinyl acetate | 0.1 | OM | HD/GC and GC/MS | | × | | (Tadić et al., 2010) |
| | Visitor habitat: *trans*-Sabinyl acetate | 0.1 | OM | | | | × | |
| | Sinjajevina habitat: β-Pinene and santolinatriene | 0.1 | MH | | | × | | |
| *T. sorbifolium* (Boiss.) Grierson | Camphor, pinocarvone, chrysanthenone, bornyl acetate and camphene | 0.5 | OM | HD/GC/MS | | | × | (Özer et al., 2006) |
| *T. macrophyllum* (Waldst. et Kit.) Schultz. Bip | β-Eudesmol and *cis*-chrysanthenol | 0.43 | OM | HD/GC and GC/MS | | × | | (Demirci and Baser, 2007) |
| | β-Eudesmol | 0.58 | OS | HD/GC and GC/MS | | | × | (Javidnia et al., 2010) |
| *T. elburensis* Mozaff. | Menthyl isovalerate and 1,8-cineole | 1 | OM | HD/GC and GC/MS | | | × | (Habibi et al., 2007b) |
| *T. persicum* (Boiss.) Mozaff. | Borneol, menthyl acetate, isobornyl2-methyl butyrate and artedouglasia oxide D | 0.95 | OM | HD/GC and GC/MS | | | × | (Habibi et al., 2007b) |
| | Borneol, bornyl acetate and linalool | NR | OM | HD/GC and GC/MS | | × | | (Mahdian et al., 2017) |
| | borneol and bornyl acetate | 0.35 | OM | HD/GC-FID and GC/MS | | | × | (Pirbalouti, 2019) |
| *T. cadmeum* (Boiss.) Heywood | 1,8-Cineole, *p*-cymene, terpinen-4-ol, borneol and γ-terpinene [az] | 0.5 | OM | HD/GC and GC/MS | | | × | (Özek et al., 2007) |
| | α-Thujone, cis-linalool oxide and trans-chrysanthenyl acetate [ba, bb] | 0.95 | OM | HD/GC and GC/MS | | × | | (Polatoğlu et al., 2009b) |
| | β-Eudesmol and 1,8-cineole [ba, bc] | 0.5 | OM | | × | | | |
| | Hexadecanoic acid spathulenol and β-muurolol [ba, bd] | 0.05 | OS | | × | | | |
| | Camphor, borneol and α-thujone [ba, be] | 0.25 | OM | | | × | | |
| | 1,8-Cineole [ba, bf] | 0.75 | OM | | | × | | |
| | Nonacosane, spathulenol and hexadecanoic acid [ba, bg] | tr [bh] | NH | | × | | | |
| *T. aucheranum* | 1,8-Cineole, camphor, terpinen-4-ol, α-terpineol, borneol, (E)-thujone, epi-α-cadinol and artemisia ketone | 0.15 | OM | HD/GC/MS | | × | | (Salamci et al., 2007) |
| *T. bachtiaricum* | 1,8-Cineole, α-pinene and borneol | 0.6 | OM | HD/GC/MS | | | × | (Javidnia et al., 2008b) |
| *T. alyssifolium* | Borneol, α-thujone, camphor, β-eudesmol, 1,8-cineole and thymol | NR | OM | HD/GC/MS | | | × | (Kandemir et al., 2008) |
| *T. gracile* | Lavandulol, lavandulol acetate, α-pinene, 1,8-cineole, *cis*-β-ocimene, borneol, limonene and chamazulene | 0.4 | OM | HD/$^{1}$H-NMR, $^{13}$C-NMR and GC-MS | × | | | (Verma et al., 2008) |
| | α-Bisabolol, chamazulene, α-phellandrene, germacrene-D and eudesmol | 0.1 | OS | HD/GC and GC/MS | | | × | (Lohani et al., 2012) |
| *T. densum* (Lab.) Schultz Bip. | Bisabolone oxide, carvacrol, isoborneol, borneol, β-panasinsene, eucalyptol and camphor bi | 0.1-0.15 | OM and OS | HD/GC/MS | | × | × | (Kizil, 2009) |
| | Borneol, endoborneol, 1,8-cineole and α-pinene bj | 0.3 | OM | HD/GC and GC/MS | | | × | (Bagci, 2009) |
| | α-Pinene, (+)-*epi*-bicyclosesquiphellandrene, α-cadinol, 1-heptadecanol and eicosane bk | 0.15 | SH [bl] | HD/GC and GC/MS | | × | | (Bagci, 2009) |
| | Flowers: 1,8-Cineole, camphor and borneol [bm] | 0.25 | OM | HD/GC and GC/MS | × | | | (Polatoğlu et al., 2009a) |
| | Stems: 1,8-Cineole, camphor and borneol [bm] | 0.1 | | | | × | | |
| | β-Pinene, 1,8-cineole, α-pinene and p-cymene [bn] | 0.45 | MH | HD/GC and GC/MS | | | × | (Polatoğlu et al., 2010b) |
| | Flower: Camphor, 1,8-cineole, camphene, bornyl acetate, α-pinene and neodihydrocarveol [bo] | 0.35 | OM | HD/GC and GC/MS | | × | | (Polatoğlu et al., 2012) |
| | Leaf oils: Camphor, camphene, bornyl acetate, α-pinene and borneol [bo] | 0.45 | | | × | | | |
| | Stem oils: Camphor, bornyl acetate and borneol bo | 0.25 | | | × | | | |
| | 1,8-Cineole, camphor, borneol, piperitenone, bornyl acetate and α-campholenal [bp] | NR | OM | HD/GC-FID and GC/MS | | | × | (Diraz et al., 2018) |
| *T. pinnatum* Boiss | Camphor, α-pinene and camphene | 0.5 | OM | HD/GC and GC/MS | | | × | (Esmaeili et al., 2009) |
| *T. turcomanicum* | trans-Chrystanthenyl acetate, trans-thujone, chrysanthemone, and camphor | 0.4 | OM | HD/GC/MS | | | × | (Habibi et al., 2009) |

**Table 4** Continued

| *Tanacetum* species | Main components or chemotype(s) | YO [a] | PCNC [b] | Separation/Characterization methods or criteria | TCF(%) [c] | | | Ref |
|---|---|---|---|---|---|---|---|---|
| | | | | | ≤80 | 80-90 | ≥90 | |
| *T. canescens* | 1,8-Cineole, α-pinene, borneol, β-eudesmol and α-terpinol | 0.3 | OM | HD/GC/MS | | | × | (Habibi et al., 2009) |
| *T. nitens* (Boiss.&Noe) Grierson | 1,8-Cineole, α-pinene, spathulenol and *trans*-pinocarveol | 0.4 | OM | HD/GC and GC/MS | | × | | (Bagci and Kocak, 2010) |
| *T. kotschyi* | Flowers: Artemisia ketone, longiverbenone (vulgarone B) and artemisia alcohol | 0.25 | OM | HD/GC and GC/MS | | | × | (Polatoglu et al., 2011) |
| | Stems: Artemisia ketone, longiverbenone (vulgarone B), intermedeol and artemisia alcohol | 0.15 | | | | | × | |
| | α-Bisabolol, camphor, carvacrol and 1,8-cineole | 0.3 | OM | HD/GC-FID and GC/MS | | | × | (Pirbalouti, 2019) |
| *T. zahlbruckneri* (Náb.) | Flower oil: Germacrene D and spathulenol | tr | SH and OS | HD/GC and GC/MS | × | | | (Polatoğlu et al., 2011a) |
| *T. tabrisianum* (Boiss.) Sosn. and TakhT. | Flower oil: 1,8-Cineole, hexadecanoic acid, decanoic acid, and trans-linalool oxide acetate | 0.16 | OM | HD/GC and GC/MS | | | × | (Polatoğlu et al., 2011a) |
| | Stem oil: 1,8-Cineole, hexadecanoic acid and trans-linalool oxide acetate | 0.1 | | | | | × | |
| *T. fisherae* Aitch. & Hemsl. | 1,8-Cineole, *cis-p*-menth-2-en-1-ol and *trans-p*-menth-2-en-1-ol | 1.1 | OM | HD/GC and GC/MS | | | × | (Rajaei et al., 2011) |
| *T. sonbolii* Mozaff. | β-Cadinol, globulol and 1,8-cineole | 0.17 | OS | HD/GC and GC/MS | | | × | (Firozy et al., 2012) |
| | α-Cadinol and globulol | 0.15 | OS | HD/GC/MS | | × | | (Talebpour et al., 2013) |
| | α-Pinene and β-pinene | - | MH | HS-SE [bq]/GC/MS | | | × | |
| *T. mucroniferum* Hub. -Mor. & Grierson | 1,8-Cineole and camphor | 0.1 | OM | HD/GC and GC/MS | × | | | (Polatoglu et al., 2012b) |
| *T. punctatum* (Desr.) Grierson | trans-β-Farnesene, caryophyllene oxide, β-caryophyllene and bicyclo [3, 1, 1] heptan-2-one | 0.1 | SH | HD/GC and GC/MS | | | × | (Shafaghat, 2012) |
| | Camphor, trans-β-farnesene, camphene, β-caryophyllene and chrysanthenone | 0.2 | OM | HD/GC and GC/MS | | | × | (Shafaghat et al., 2017) |
| *T. dumosum* Boiss. | Fragranol, 1,8-cineole, fragranyl acetate, and trans-carvyl acetate | 0.29 | OM | HD/GC-FID and GC/MS | | | × | (Jassbi et al., 2013) |
| | Leaves: Borneol, bornyl acetate, 1,8-cineole, α-terpineol, cis-chrysanthenyl acetate and camphene | 0.36 | OM | HD/GC and GC/MS | | | × | (Ghanbarian et al., 2015) |
| | Flowers: Isobornyl-2-methyl butanoate, trans-linalyl oxide acetate, 1,8-cineole, thymol, linalool, camphor, isobornyl propanoate and α-terpineol | 0.33 | OM | | | | × | |
| *T. abrotanifolium* Druce. | Flower oils: Camphor, (*E*)-sesquilavandulol, 1,8-cineole and tetradecanoic acid 6.6% | 0.23 | OM | HD/GC and GC/MS | | | | (Polatoğlu et al., 2015) |
| | Stem oils: Hexadecanoic acid, (*E*)-sesquilavandulol, tetradecanoic acid and phytol | 0.05 | NH | | | | × | |
| *T. hololeucum* | Artemisia alcohol, yomogi alcohol, artemisyl acetate, γ-eudesmol and camphor | NR | OM | HD/GC-FID and GC/MS | | | × | (Shamkhani et al., 2016) |
| *T. cilicicum* | Linalool, sesquisabinene hydrate, eucalyptol, nerolidol, α-muurolol, borneol, camphor, limonene, α-terpineol, spathulanol, α-pinene, juniper camphor, (-)-caryophyllene oxide, 8-hydroxy linalool and Δ-cadinene | 0.4 | OS | HD/GC/MS | | | × | (Ulukanli et al., 2017) |
| *T. walteri* | Thymol, 1,8-cineole, umbellulone, α-bisabolol, camphor, myrtenol and myrtenal | 0.25 | OM | HD/GC-FID and GC/MS | | | × | (Ghaderi and Sonboli, 2018) |

[a] YO: Yield of oil; [b] PCNC: Prevailing class of natural compounds; [c] TCF(%): Total characterized profile; [d] NR: Not reported; [e] OM: Oxygenated monoterpenes; [f] MH: Monoterpene hydrocarbons; [g] Based on the fresh weight; [h] Based on the dry weight; [i] Based on air-dried leaves; [j] Based on flower heads; [k] Supercritical fluid extraction; [l] var. *vulgare*; [m] subsp. *siculum* (Guss.) Raimondo et Spadaro: Of thujone chemotype; [n] RS: Rosette stage; [o] SIS: Stem initiation stage; [p] FBS: Floral budding stage; [q] FFS: Full flowering stage; [r] BFS: Beginning of the fruit stage; [s] Based on the fresh weight; [t] Based on the dry weight; [u] The average amount; [v] ssp. *heterophyllum*; [w] BFlS: Before flowering stage (subsp. *argyrophyllum* (K. Koch.) Podlech); [x] FFS: Full flowering stage (Subsp. *argyrophyllum* (K. Koch.) Podlech); [y] subsp. *farsicum* Podl; [z] In four of its cultivated populations; [aa] subsp. *duderanum*; [ab] subsp. *duderanum* (Boiss) Podl.; [ac] subsp. *polycephalum*; [ad] MAHD: Microwave-assisted hydrodistillation; [ae] ssp. *balsamitoides* (Schultz bip.) Grierson; [af] subsp. *Balsamita*; [ag] For var. *chiliophyllum*; [ah] For the first sample (var. *chiliophyllum*); [ai] For the second sample (var. *chiliophyllum*); [aj] OS: Oxygenated sesquiterpenes; [ak] NH: Non-terpene hydrocarbons; [al] For var. *monocephalum* Grierson; [am] For the oil separated from the aerial parts of the plant; [an] For the oil separated from the roots of the plant; [ao] Leaves; [ap] Aerial parts; [aq] var. *argyrophyllum*; [ar] subsp. *canum* (C. Koch) Grierson var. *canum*; [as] *subsp. flabellifolium (*Boiss. & Heldr.) Grierson; [at] MDGC-MS: Multidimensional gas chromatography/mass spectrometric analysis; [au] subsp. *argenteum*; [av] subsp. *canum* (C. Koch) Grierson; [aw] subsp. *praeteritum*; [ax] subsp. *massicyti*cum Heywood; [ay] subsp. *praeteritum*; [az] subsp. *orientale* Grierson; [ba] ssp. *orientale* Grierson; [bb] Adana location: For flower and stem oils; [bc] Adana location: For stem oil; [bd] Adana location: For root oil; [be] Sivas location: For flower and stem oils; [bf] Sivas location: For stem oil; [bg] Sivas location: For root oil; [bh] tr: trace; [bi] subsp. *amani* Heywood; [bj] subsp. *amani*; [bk] subsp. *laxum*; [bl] SH: Sesquiterpene hydrocarbons; [bm] ssp. *sivasicum* Hub.-Mor. and Grierson; [bn] ssp. *amani*; [bo] ssp. *eginense* Heywood; [bp] subsp. *amani*, [bq] HS-SE: Head space sorptive extraction.

Willd. all relating to Turkey. In one report by Gören (2001), OSs were dominant with caryophyllene oxide as one of the main constituents. In another work performed using multidimensional gas chromatography/mass spectrometric analysis (MDGC-MS) by Tabanca et al. (2007), both MHs and OMs were major fractions with α-pinene and camphor as representative compounds. However, in four separate profiles of *T. argenteum* (Lam.) Willd., total amounts of MHs like α-pinene and β-pinene were higher than the other groups of natural compounds (Bagci and Kocak, 2010; Polatoğlu et al., 2010b; Ali et al., 2014). It was also found that the oil of this plant possess (weak to moderate growth inhibition) antimicrobial activity against the pathogenic bacteria: *Escherichia coli, Staphylococcus aureus, Proteus vulgaris,* and *Salmonella typhimurium* Tabanca et al. (2007).

#### 2.3.9. *T. lingulatum* Boiss. Bornm.

Olamazadeh and coworkers (2014) have evaluated the EOs from the flowers and leaves of *T. lingulatum* Boiss. Bornm. and reported MHs and OMs as the most frequently occurring compounds in these two profiles, respectively.

#### 2.3.10. *T. macrophyllum* (Waldst. et Kit.) Schultz. Bip

In two parallel works on EO of *T. macrophyllum* (Waldst. et Kit.) Schultz. Bip in Turkey (Demirci and Baser, 2007) and Iran (Javidnia et al., 2010), remarkable contents of β-eudesmol were found. However, the Turkish sample had high amounts of *cis*-chrysanthenol and was totally dominated by OMs, while in the Iranian sample of *T. macrophyllum* (Waldst. et Kit.) Schultz. Bip EO, OSs had the first rank from the frequency point of view.

#### 2.3.11. *T. cadmeum* (Boiss.) Heywood

Although in most of the EO profiles of *T. cadmeum* (Boiss.) Heywood in Turkey, the highest frequency was due to OMs, in one oil sample, OSs with spathulenol and β-muurolol were the main class of natural compounds (Ali et al., 2014). Özek et al. (2007) have found that the main compounds of the oil were 1,8-cineole (18.9%), *p*-cymene (15.7%), terpinen-4-ol (14.8%), borneol (9.8%) and γ-terpinene (3.5%). This plant also possesses antimicrobial activity towards to *Staphylococcus epidermidis* (Özek et al., 2007).

#### 2.3.12. *T. gracile*

In the EO of *T. gracile* from India, OSs like α-bisabolol and eudesmol were the major constituent component (Lohani et al., 2012).

#### 2.3.13. *T. densum* (Lab.) Schultz Bip

Characterization of EOs of *T. densum* (Lab.) Schultz Bip has led to various patterns of prevailing natural compounds involving OMs (Bagci, 2009; Polatoğlu et al., 2009a; Polatoğlu et al., 2012), MH (Polatoğlu et al., 2010b) and SHs (Bagci, 2009) and in one report OMs and OSs were both among the main constituents (Polatoğlu et al., 2012) (see Table 4).

#### 2.3.14. *T. zahlbruckneri* (Náb.)

In the work of Polatoğlu et al. (2011a) on the EO from the flowers of *T. zahlbruckneri* (Náb.), the oil yield of the obtained oil was negligible and its subsequent analysis revealed the high prevalence of SH (germacrene D) and OS (spathulenol).

#### 2.3.15. *T. sonbolii* Mozaff.

In two Iranian EO samples of *T. sonbolii* Mozaff., some OSs like cadinol (α- and β-) along with globulol were characterized to have the highest contents (Firozy et al., 2012; Talebpour et al., 2013).

#### 2.3.16. *T. punctatum* (Desr.) Grierson

In the report of Shafaghat (2012) on EO of *T. punctatum* (Desr.) Grierson, *trans*-β-farnesene and β-caryophyllene were the principal constituents and accounted for the highest frequency of SHs in related profile.

#### 2.3.17. *T. abrotanifolium* Druce.

Polatoğlu et al. (2015) have assessed the EO compositions of flowers and stems of *T. abrotanifolium* Druce. and found OMs (camphor, (*E*)-sesquilavandulol, 1,8-cineole) and NHs (hexadecanoic acid and tetradecanoic acid) as the main groups of constituting compounds of these two profiles.

#### 2.3.18. Other similar EO profiles and other chemical compounds of *Tanacetum* species

To date, similar patterns of chemical profiles have also been reported for *T. nubigenum* Wallich ex DC. (Chanotiya and Mathela, 2007), *T. fruticulosum* Ledeb. (Weyerstahl et al., 1999), *T. armenum* (DC.) Schultz Bip. (Başer et al., 2001; Karabörkü et al., 2011), *T. haradjani* (Rech. fil.) Grierson (Başer et al., 2001), *T. argyrophyllum* (C. Koch) Tvzel. (Gören et al., 2001; Akpulat et al., 2005; Polatoğlu et al., 2010c), *T. praeteritum* (Horwood) Heywood (Gören et al., 2001; Özek, 2018), *T. santolinoides* (El-Shazly et al., 2002), *T. lingulatum* Boiss. Bornm. (Afsharypuor and Jahromy, 2003), *T. sorbifolium* (Boiss.) Grierson (Özer et al., 2006), *T. elburensis* Mozaff. (Habibi et al., 2007b), *T. persicum* (Boiss.) Mozaff. (Habibi et al., 2007b; Mahdian et al., 2017; Pirbalouti, 2019), *T. aucheranum* (Salamci et al., 2007), *T. bachtiaricum* (Javidnia et al., 2008b), *T. alyssifolium* (Kandemir et al., 2008), *T. pinnatum* Boiss (Esmaeili et al., 2009), *T. turcomanicum* (Habibi et al., 2009), *T. canescens* (Habibi et al., 2009), *T. tabrisianum* (Boiss.) Sosn. and TakhT. (Polatoğlu et al., 2011a), *T. fisherae* Aitch. & Hemsl. (Rajaei et al., 2011), *T. mucroniferum* Hub. -Mor. & Grierson (Polatoglu et al., 2012b), *T. dumosum* Boiss. (Jassbi et al., 2013; Ghanbarian et al., 2015), *T. hololeucum* (Shamkhani et al., 2016) and *T. walteri* (Ghaderi and Sonboli, 2018) with high occurrence of OMs as mentioned earlier.

## 3. Concluding remarks and future perspectives

There is an unavoidable need for human beings to use different medicinal and herbal plans for a wide variety of purposes, *e.g.,* to treat different diseases, in industrial applications, cosmetics and perfumery disciplines among others. Rich data are available in literature which cover diverse aspects of two widely used species, namely *T. vulgarae* and *T. parthenium*. However, for future investigations, the other herbal species of the genus may be considered to explore their potential ability in a wide variety of medicinal and pharmaceutical disciplines.

**References**


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