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*Review*

# Mining the essential oils of the Anthemideae

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**Numerous members of the Anthemideae are important cut-flower and ornamental crops, as well as medicinal and aromatic plants, many of which produce essential oils used in folk and modern medicine, the cosmetic and pharmaceutical industries. These oils and compounds contained within them are used in the pharmaceutical, flavour and fragrance industries. Moreover, as people search for alternative and herbal forms of medicine and relaxation (such as aromatherapy), and provided that there are no suitable synthetic substitutes for many of the compounds or difficulty in profiling and mimicking complex compound mixtures in the volatile oils, the original plant extracts will continue to be used long into the future. This review highlights the importance of secondary metabolites and essential oils from principal members of this tribe, their global social, medicinal and economic relevance and potential.**

**Key words:** Apoptosis, artemisinin, chamomile, essential oil, feverfew, pyrethrin, tansy.

## THE ANTHEMIDAE

Chrysanthemum (Compositae or Asteraceae family, subfamily Asteroideae, order Asterales, subclass Asteridae, tribe Anthemideae), sometimes collectively termed the *Achillea*-complex or the *Chrysanthemum*-complex (tribes Astereae-Anthemideae) consists of 12 subtribes, 108 genera and at least another 1741 species (Khallouki et al., 2000). Anthemideae is one of the most well investigated tribes of the Asteraceae, which together with members of Astereae, Cynareae and Heliantheae tribes share compounds such as acetylenes and related compounds such as alkamines, sulphur compounds, isocoumarins and lactones. Essential oils, secondary metabolites and medicinally important compounds with or without bioactivity, have been isolated from *Achillea*, *Anthemis*, *Artemisia*, *Balsamita*, *Chrysanthemum*, *Matricaria*, *Santolina* and *Tanacetum*.

Numerous chrysanthemum plants, apart from their ornamental value, are highly aromatic due to the many volatile components of their essential oils (Table 1), many of which are used in the flavour and fragrance industries, others in alcoholic beverages such as nojigiku alcohol from *Chrysanthemum japonense*. In some countries, such as Japan, both edible (garland, ryouri, shun or shokuyo giku, or chopsuey green, *C. coronarium*) and garnish (tsuma giku, *C. morifolium*) chrysanthemums are popular. The petals of *D. grandiflora* 'Enmeiraku' (or Mottenohoka) containing antioxidant properties and are a popular food in Yamagata, Japan.

## SECONDARY METABOLITES AND ESSENTIAL OILS IN MEDICINE AND INDUSTRY

Secondary metabolism in a plant not only plays a role for its survival by producing attractants for pollinators, and a chemical defence against predators and diseases. Often high light or UV leads to the production of anthocyanins, flavones, sinapyl esters, isoflavonoids and psoralens; wounding to coumestrol, coumarin, psoralen, chlorogenic acid, ferulate ester, wall bound phenolic acid, lignin and suberin production; pathogen attack to pterocarpan, isoflavan, prenylated isoflavonoid, stilbene, coumarin, furanocoumarin, 3-deoxyanthocyanidin, flavonol and aurone production; low temperature to anthocyanin production; low nitrogen, phosphate or iron in the soil results in flavonoid/ isoflavonoid, anthocyanin and phenolic acid production, respectively (Heath, 2002; Pichersky and Gershenzon, 2002).

Many secondary metabolites are also an important trait for our food (taste, colour, scent), while others yet such as alkaloids, anthocyanins, flavonoids, quinines, lignans,

**Table 1.** Volatile essential oils in Anthemidae species.

| | Main compounds (values as relative % of essential oil, rounded-up) | Rare compounds (%) | TNC | % Yield | Notes | Reference |
|---|---|---|---|---|---|---|
| *T. vulgare* | Sabinene 79, p-cymene 7, isothujone 2 | Carvone tr. | >25 | 0.1 | Pyrethrins | Banthorpe and Wirz-Justice 1972 |
| *C. coronarium* | Camphor, α-pinene, trans-2-(hexa-2,4-diyn-1-yliden)-1,6-dioxaspiro[4,4]non-3-ene | n.s. | 13 | 0.01 | - | Kameoka et al. 1975 |
| *T. vulgare* | Thujone 29-94, 1,8-cineole 15-42, camphene 20-31, α- and β-pinene 15-24 | Chrysanthenyl acetate 53 | 23 | 0.02-0.66 | Hungarian | Tétényi et al. 1975 |
| *Art. capillaris (7)* | Stalk+leaf:capillen 0-80, ε-cadinene 0-46,α-thujone 0-40, α-humulene 0-16, borneol 0-15 | Azulene 0.3 | 70 | n.s. | Japan | Miyazawa and Kameoka 1977 |
| *M. chamomilla* | α-Bisabolol, spathulenol, bisabolol oxide | Farnesene tr | >9 | 0.03-0.13 | Light/dark | Szöke et al. 1981 |
| *T. vulgare (5)* | (+)-Davone 95; separate oil: artemisia ketone 40, artemisia alcohol 25, γ-campholenol 10 | Yomogi alcohol 8 | <6 ea. | n.s. | Bact/fungicide | Héthelyi et al. 1981 |
| *C. yoshinaganthum*<br>*C. cuneifolium*<br>*C. indicum* | Myrtenol 55, germacene-D 11, caryophyllene oxide 2<br>1,8-Cineole 23, camphor 15, sabinene 6, α-pinene 6, T-muurolol 7<br>Germacrene-D 9, α-selinene 8, bornyl acetate 8, myrcene 6, 1,8-cineole 6, α-cadinol 5 | 3 acetylenic compounds<br>Valeranone 2<br>ar-Curcumene tr | 26<br>27<br>33 | n.s. | IR, 1H-NMR, GC-MS | Uchio et al. 1981<br>Ibid.<br>Ibid. |
| *Art. rehan* | Davanone 44, camphor 25, trans-ethyl cinnamate 3, eudalene 2, bornyl acetate 2 | Chamazulene 0.3 | 11 | 0.2 | Ethiopia | Abegaz and Yohannes 1982 |
| *M. chamomilla* | cis/trans-EN-IN-dicycloether; no sesquiterpenes | α-Bisabolol tr | >12 | 0.14 | Iberia | Bisson et al. 1983 |
| *S. oblongifolia* | Artemisia ketone 18, α-trans-bejarol 13, cis-bejarol 10, elemol 5, β-maaliiene 5 | Oplopenone 3, herniarin 1 | 25 | n.s. | Iberia | de Pascual et al. 1983b |
| *Art. arbuscula* | Artemiseole 29, methyl santolinate 15, santolina triene 15, 1,8-cineole 15, camphor 7 | Isolyratol n.s., arbusculone n.s. | >15 | n.s. | Nevada, USA | Epstein and Gaudioso 1984 |
| *T. vulgare* | Bornyl acetate 74, camphor 30, umbellulone 25 + 4 compounds (insect repellants) | 8% unidentified | 20 | 0.22 | LC, GC-MS | Schearer 1984 |
| *Art. herba alba* | 1,8-Cineole 5-50, thujone 1-27, camphor 0.1-25, artemisia alcohol 0.4-10 | Santolina alcohol 0.7-6 | 42 | n.s. | Geotypes | Feuerstein et al. 1986, 1988 |
| *S. chamaecyparissus* | Camphor 25, allo-aromadendrene 19, p-cymene+1,8-cineole 10, α-muurolene 7 | Thujone 0.2 | 39 | 0.4 | Valencia | Villar et al. 1986 |
| *A. abrotanoides* | 1,8-Cineol + camphor (33) | n.s. | 50 | n.s. | CGC-MS | Bicchi et al. 1988 |
| *Art. annua* | (Callus:parent plant) β-phellandrene, myrcene, 3,3-dimethylallyl alcohol | trans-Chrysanthemyl alcohol tr | | | | Baig et al. 1989 |
| *T. macrophyllum*<br>*T. corymbosum*<br>*T. cilicium* | (Leaf, flower) p-methyl benzyl alcohol, γ- and Δ-cadinene<br>(Leaf, flower) γ- and Δ-cadinene<br>(Leaf, flower) γ-cadinene, trans-β-farnesene | n.s. | 53<br>33<br>32 | n.s. | Anti-bacterial, -coagulant -fibrinolytic | Thomas 1989a,b,c,d<br>Ibid.<br>Ibid. |
| *Art. monosperma* | Dibenzofuran 36, 1-phenyl-bicyclo-[3.3.1]-non-2-en-9-ol benzoate 25 | Diphenylamine 2 | n.s. | n.s. | Larvicidal | Hifnawi et al. 1990 |
| *C. morifolium* | Chrysanthenone, 1,8-cineol, aromadendrene, β-selinene, β-chamigrene, β-bergamontene | Kikuketone A,B tr | 18-27 | n.s. | GC-MS | Ito et al. 1990 |
| *Art. dracunculus* | Estragole 47-80, 1,8-cineole 6-11, cis-β-ocimene 3-10, trans-β-ocimene 0.1-7 | α-Pinene 0.5-1 | n.s. | n.s. | GCL-MS | Dmitriev et al. 1991 |
| *A. ptarmica* | (Root) 3 ponticaepoxides, (+)-(4S,6´R)-β-sesquiphellandrene | n.s. | 40 | n.s. | GC-MS | Kuropka et al. 1991 |
| *Art. pallens* | cis-Davanone 38, nerol 10, geraniol 5, cis-hydroxy-davanone 3, cinnamyl cinnamate 2 | trans-Davanone 5 | 53 | 0.38 | South India | Misra et al. 1991 |
| *T. annuum* | Myrcene-(+)-α-phellandrene 18, chamazulene 11, camphor 10, β-pinene 8 | 16% unstable structures | 43 | 0.4 | IR, GC-MS | Barrero et al. 1992 |
| *A. millefolium* | (Leaves:flower) 1,8-cineole (25:29), trans-sabinene hydrate (10), sabinene (10) | Germacrene-D (7:0.7) | 54 | 0.4 | GC-MS | Figueiredo et al. 1992 |
| *A. abrotanoides*<br>*A. grandifolia* | (Infrageneric variation); main components: α-thujone, 1,8-cineole<br>Main components: camphor, α-thujone, β-thujone, 1,8-cineole | n.s.<br>n.s. | 50<br>60 | n.s. | GC-MS | Hanlidou et al. 1992a,b<br>Ibid. |
| *A. millefolium*<br>*A. collina*<br>*A. pannonica* | (2n=54); sabinene 12, β-pinene 12, borneol and α-terpineol 8, β-caryophyllene 7<br>(2n=36); chamazulene 24, β-caryophyllene 22, sabinene 15, germacrene D 11<br>(2n=72); Pinacarvone and linalool 26, borneol and α-terpineol 19, 1,8-cineole 14 | Chamazulene 0.01<br>(E)+(Z)-jasmone tr.<br>Pinan-3-one <0.01 | 106<br>92<br>109 | n.s. | GC-MS | Hoffman et al. 1992<br>Ibid.<br>Ibid. |
| *A. millefolium* | Wild populations: 1,8-cieneole, camphor, borneol, lavandulol | n.s. | 38 | n.s. | Greece | Kokkalou et al. 1992 |

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|---|---|---|---|---|---|---|
| *S. chamaecyparissus* | Cultivated, insular, peninsular populations; artemisia ketones (28-36), T-cadinol (5-24) | Camphor (9-25) | 62-94 | n.s. | Geotypes | Perez and Velasco 1992 |
| *Art. judaica* | Artemisia ketone 0-41, camphor tr-20, Artemisia alcohol 0-31, (E)-ethyl cinnamate 4-9 | Davanone 0.2-0.9 | 62 | 0.5 | Sinai | Ravid et al. 1992 |
| *Art. salsoloides* | Camphor 42, 1,8-cineole 17, camphene 5, terpinen-4-ol 5, β-thujone 3 | cis-Chrysanthenol 0.45 | 109 | 0.5 | Himalayas | Weverstahl et al. 1992a |
| *Art. moorcroftiana* | α-Thujone 13, artemisia ketone 10, β-pinene 8, 1,8-cineole 6, camphor 5, β-thujone 4 | Vulgarone B 3 | n.s. | n.s. | Green odour | Weverstahl et al. 1992b |
| *A. biebersteinii* | (Aerial part) 1,8-cineole 46, camphor 18, α-terpineol 8, borneol 3, sabinene 3 | Thymol 0.1 | 47 | 0.8 | Turkey | Chialva et al. 1993 |
| *An. nobilis* | (Flower bud, aerial part, cell suspension) α-farnesene 0-91, 3-OH 2-butanone 0-72 | Nerolidol 0-1.2 | 30 | 0.08-0.3 | Crown galls | Fauconnier et al. 1993 |
| *T. longifolium* | Aerial part: trans-sabinyl acetate 43, trans-sabinol 13; root: terpinen-4-ol 26, sabinene 23 | Neothujyl alcohol 0.6 | 49 | 0.3:0.1 | Blue/yellow | Kaul et al. 1993 |
| *Art. absinthium* | Normal root: α-fenchene, β-myrcene 6; hairy root: neryl isovalerate 47, neryl butyrate 6 | β-pinene 1 | 6 | 1.4:0.7 | Transgenic | Kennedy et al. 1993 |
| *Art. petrosa* | Wild plants: 1,8-Cineole, β-pinene, borneol | n.s. | 41 | n.s. | Greece | Souleles 1993 |
| *†* | (Z)-3-hexen-1-ol acetate 19-55, (Z),(E)-α-farnesene/β-myrcene 3-14 (53% monoterpenes) | 3-36% unidentified | 43 | n.s. | Headspace | Storer et al. 1993 |
| *S. sieberi* | Camphor 44, 1,8-cineole 19, camphene 5, terpinen-4-ol 3, α-terpineol 2 | Bisabolene derivatives tr | >37 | n.s. | Flowering | Weverstahl et al. 1993 |
| *Art. annua* | China: artemisia ketone 64, Artemisia alcohol 8; Vietnam: camphor 22, germacrene-D 18 | Artemisinin 0.2-1 | n.s. | n.s. | Seeds | Woerdenbag et al. 1993 |
| *Art. annua* | Artemisia ketone 59, camphor 16, 1,8-cineole 10, germacrene-D 2, pinacarvone 2 | Artemisia alcohol 0.15 | 35 | n.s. | Geotypes | Ahmad and Misra 1994 |
| *Art. argentea* | (Aerial part) α-phellandrene 25-27, isopinocamphone 7-12, β-eudesmol 8 | Chamazulene tr | 50 | 0.2-0.25 | Madeira | Figueiredo et al. 1994 |
| *Art. apiaceae* | Primarily camphene, camphor borneol, caryophyllene | n.s. | 34 | 0.23-0.37 | Korean | Kim and Jang 1994 |
| *A. spp. (10)* | Primarily β-pinene, 1,8-cineole, camphor (mono-); germacrene D (sesqui-) | Bisabolene oxide tr | n.s. | n.s. | Geotypes | Maffei et al. 1994 |
| *Art. afra* | (Vegetative) cis-2,7-dimethyl-4-octene-2,7-diol 19, 1,8-cineole 18, tricosane 14 | α-Thujone 1.66 | 21 | 0.3-1.4 | GC-MS | Moody et al. 1994 |
| *C. recutita* | 19 cuticular waxes; bisabolol oxide A 50, bisabolol oxide B 17, cis-dicycloether 10 | Matricine 4 | 53 | 1.2 | SCFE | Reverchon and Senatore 1994 |
| *S. neapolitana* | γ-Muurolene 32, α-pinene 16, borneol 9 | Ylangene 0.1 | 41 | 0.3 | Italy | Senatore and de Feo 1994 |
| *A. asplenifolia* | (Parent plant:in vitro) β-pinene (47:46), 1,8-cineole (10:10), β-caryophyllene (13:14) | Camphor <0.1 | 13 | n.s. | GC-MS | Wawrosch et al. 1994 |
| *An. nobilis* | (E,E)-α-farnesene 21-57, germacrene D 10-28 (growth stage and light-dependent) | Angelic acid tr.-5 | 11 | n.s. | GC-MS | Asai et al. 1995 |
| *A. millefolium* | Germacrene-D (11-42), eugenol (9-36), p-cymene (0.1-41) | ~55% unidentified | 19 | 0.001 | GC-MS | Figueiredo et al. 1995 |
| *A. biebersteinii* | (Aerial parts) piperitone 4-50, 1,8-cineole 11-30, camphor 9-17, α-terpineol+borneol 1-5 | Grandisol 0.4 | 31 | 0.55-0.85 | Turkey | Küsmenoglu et al. 1995 |
| *Art. umbelliformis* | α-Thujone 68, β-thujone 18, 1,8-cineole 2, sabinyl acetate 2 | Artemisia ketone tr | 62 | n.s. | Italy | Mucciarelli et al. 1995 |
| *Art. campestris I* | Caryophyllene oxide 18, unknown alcohol 11, α-pinene 15, β-pinene 10, limonene 5 | Artemisia alcohol tr | | | | Ibid. |
| *Art. genipi* | α-Thujone 80, β-thujone 10 | Spathulenol 0.8 | | | | Ibid. |
| *Art. petrosa* | α-Thujone 70, β-thujone 17, spathulenol 4 | Ascaridole 0.2 | | | | Ibid. |
| *Art. vallesiaca* | Camphor 41, borneol 28, 1,8-cineole 15, camphene 7 | γ-Selinene tr | | | | Ibid. |
| *Art. absinthium* | cis-Epoxy-ocimene 25, trans-chrysanthenyl acetate 22, camphor 17, spathulenol 8 | Bisabolol oxide 5 | | | | Ibid. |
| *Art. chamaemelifolia* | Unknown alcohol 27, trans-nerolidol 23, carvacrol 16, 1,8-cineole 15, spathulenol 3 | α-Bisabolol 3 | | | | Ibid. |
| *Art. glacialis* | Camphor 32, 1,8-cineole 15, spathulenol 9, caryophyllene oxide 6, camphene 6 | Yomogi alcohol 0.2 | | | | Ibid. |
| *Art. campestris II* | 1,8-cineole 19, spathulenol 18, α-pinene 17, epi-cubenol 14, β-pinene 11 | trans-Nerolidol 0.2 | | | | Ibid. |
| *Art. alba* | Camphor 39, cuminaldehyde 14, isopinocamphone 10, camphene 4, bornyl acetate 4 | Myrtenol 0.3 | | | | Ibid. |
| *Art. abrotanum* | 1,8-Cineole 34, bisabolol xide 18, ascaridole 16, trans-nerolidol 4, p-cymene 8 | Terpinen-4-ol 2.2 | | | | Ibid. |
| *Art. annua* | 1,8-Cineole 23, α-pinene 20, pinocarveol 6, carvacrol 4 | Nojigiku alcohol 0.1 | | | | Ibid. |
| *Art. verlotiorum* | Caryophyllene oxide 21, borneol 18, camphor 11, 1,8-cineole 11, spathulenol 8 | Cuminaldehyde 3.4 | | | | Ibid. |
| *Art. vulgaris* | Camphor 48, camphene 9, verbenone 9, trans-verbenol 7, β-caryophyllene 4 | α-Copaene 1.1 | | | | Ibid. |
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| *S. canescens* | (Aerial parts) p-cymene 20, α-pinene 15, myrcene 13, sabinene 12, α-terpineol 8 | Santolindiacetylene 0.9 | 16 | 0.75 | Antioxidant | Utrilla et al. 1995 |
| *A. millefolium*<br>*A. wilhelmsii* | Dry plant; α-bisabolol 23, spathulenol 12, cis-nerolidol 6, cis-carveol 5, trans-carveol 4<br>Camphor, borneol, linalool, 1,8-cineole, chrysanthenol acetate, carvacrol | Campherenone 2 | 21 | 0.4 | TLC, GC<br>GC-MS, Iran | Afsharypuor et al. 1996a,b<br>Ibid. |
| *M. perforata* | (Flower head) 2Z,8Z-matricaria ester (75) and other polyines | Fatty acids 0.3 | >50 | n.s. | GC, GC-MS | Bar and Schultze 1996 |
| *Arg. pinnatifidum+1* | (Flower:vegetative leaf) β-myrcene (28-39:50-62), germacrene-D (15-17:10) | cis-Chrysanthenyl acetate tr | 45 | <0.05-0.1 | GC, GC-MS | Barroso et al. 1996 |
| *T. parthenium* | Camphor 43-62, chrysanthenyl acetate 14-24, parthenolide (migraine prophylactic) tr | 0% thujones (toxic) | 46 | 0.3-0.83 | Development | Hendriks et al. 1996 |
| *Aj. tenuifolia* | (Leaf, stem); camphor 32, pulegone 15, 1,8-cineole 13 | n.s. | 49 | n.s. | Phytoinhibitor | Zhen et al. 1996 |
| *M. chamomilla* | (Flower) biologically active coumarin herniarin, eleanolic acid, stigmasterol, β-sitosterol | n.s. | n.s. | n.s. | Hydrodistilled | Ahmad and Misra 1997 |
| *Art. annua* | Camphor 7-44, artemisia ketone 6-26, germacrene-D 14-24, β-caryophyllene 5-15 | 1,8-Cineole 1-14 | 30 | 0.4-0.9 | Finland | Holm et al. 1997 |
| *C. morifolium* | Chrysanthediol A, chrysanthediacetate A,B,C, taraxasterol, apigenin, luteolin | Triterpenoid esters tr | 30 | n.s. | Dry flowers | Hu and Chen 1997a,b |
| *Art. absinthium* | Normal root: linalyl 3-methyl butanoate 37, nerol 13; hairy root: MW196 25, MW238 23 | Estragol 0.23 | 42 | n.s. | Hairy roots | Nin et al. 1997 |
| *C. boreale* | Also C. morifolium; petal: 11-13% reducing sugar; borneol 28, camphor 25, 1,8-cineole 8 | n.s. | n.s. | n.s. | Ornamental | Park and Kwon 1997 |
| *C. cinerariaefolium* | Trans-β-Farnesene 41, β-cubenene 17, Δ-nerolidiol 14 | Maize weevil repellants | 12 | n.s. | GC-MS | Saggar et al. 1997 |
| *A. eriophora* | 1,8-Cineole 34, α-pinene 8, β-pinene 6, α-terpineol 5 linalol 5, β-sabinene 3 | Yomogi alcohol 0.1 | 90 | 1.2 | Iranian | Weyerstahl et al. 1997 |
| *Art. roxburghiana* | 1,8-Cineole 17, camphor 15, α-thujone 10, germacrene-D 6, sabinene 3, camphene 3 | Estragole tr | 108 | n.s. | Himalayas | Bicchi et al. 1998 |
| *M. decipiens* | (Z,Z)-Matricaria ester (1) 33, 1,8-cineole 11, (Z,E)-Matricaria ester (3) 9 | Viridiflorol 0.3 | 27 | 0.2 | TLC-HPLC | Javidnia and Shafiee 1999 |
| *C. maximum* | (Blooming aerial part) Limonene, caryophyllene oxide, xanthene, p-cymene | Ftalan tr. | 63 | n.s. | Poland | Józefczyk et al.1999 |
| *Art. asiatica* | 1,8-Cineole 40, selin-11-en-4α-ol 12, terpinen-4-ol 11, borneol 6, α-terpineol 4 | Eugenol 0.2 | 86 | 0.6-0.95 | GC, GC-MS | Kalemba 1999 |
| *T. polycephalum* | (Flower:leaf) camphor (59:54), camphene (15:11), 1,8-cineole (10:8), borneol (3:6) | Dihydroparthenolide 1 | 10:10 | 0.41:0.45 | GC, GC-MS | Nori-Shargh et al. 1999 |
| *S. rosmarinifolia* | Capillene 35, β-phellandrene 15, myrcene 13, β-pinene 8, sabinene 6, ar-curcumene 4 | Capillin 0.4 | 66 | 1.94 | Aerial parts | Palá et al. 1999 |
| *C. morifolium Yuba* | (Z)-3-hexenyl acetate, 1,8-cineole, α-terpinene, camphor (affecting cabbage moth flight) | Chrysanthenone tr | 10 | n.s. | Leaves | Rojas 1999 |
| *Art. annua* | Glanded: α-pinene 27, pinocarvone 16; glandless germacrene-D 50, β-caryophyllene 25 | Artemisia ketone 11 | 78:45 | 0.24:0.06 | Leaves | Tellez et al. 1999 |
| *T. fruticulosum* | 1,8-Cineole 17, camphor 13, (-)-lavandulol 11, (-)-lavandulyl acetate 9, terpinen-4-ol 7 | Isohumbertiol A-D tr | 97 | n.s. | Dry plants | Weyerstahl et al. 1999 |
| *B. major* | Carvone 52-68, α-thujone (with insecticidal activity) 9-16 | Methyl costate tr | 78 | 1-15-1.3 | Seasonal/PP | Bylaitė et al. 2000 |
| *C. viscidehirtum* | β-Farnesene, 25 limonene 22 | Thymol 0.3 | 37 | 0.2 | Dry plants | Khallouki et al. 2000b |
| *A. millefolium* | (Vegetative:flower bud:flower) sabinene (15:16:26), β-pinene (5:2:16), α-thujone (3:4:9) | Chamazulene tr | 25 | 0.1-0.3 | Dry plants | Rohloff et al. 2000 |
| *Art. santolina* | Lavandulol 37, 1,8-cineole 16, linalool 14 | Lavandulyl acetate 10 | 66 | n.s. | | Rustaiyan et al. 2000 |
| *A. serbica* | β-sabinyl acetate 40, camphor 34, 1,8-cineole 9, ethyl acetate 3, artemisia ketone 2 | α- and β-thujone (tr-1.2) | 15 | 0.2 | GC, GC-MS | Simić et al. 2000 |
| *Art. annua* | 1,8-Cineole 13, trans-sabinene hydrate 7, 4-methyl-2,3-dihydrofuran 7, p-cymene 6 | Globulol tr | 59 | n.s. | GLC, GC-MS | Ali et al. 2000 |
| *Art. desertii*<br>*Art. diffusa* | Piperitone 52, camphor 16<br>Camphor 58, verbenone 13 | 1,8-cineole 12<br>Piperitone 7 | n.s. | n.s. | GC-MS | Ahmad and Misra 2001<br>Ibid. |
| *Art. campestris* | (4 locations) β-pinene 24-28, p-cymene 17-22, α-pinene 4-11, spathulenol 0-10 | Terpinen-4-ol 1.7-2.2 | 20 | 0.65 | Tunisia | Akrout et al. 2001 |

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| *C. coronarium* | Camphor 29, α-pinene 15, β-pinene 10, lyratyl acetate 10 | Chamazulene 5 | 15 | n.s. | Antifungal 12 | Alvarez-Castellanos et al. 2001 |
| *T. armenum* | (Leaf:herb) 1,8-cineole (31:11), camphor (9:27), α-pinene (4-0.5) | Sabinaketone tr | 64:77 | 0.62-0.67 | GC, GC-MS | Başer et al. 2001 |
| *T. balsamita* | Carvone 52, α-thujone 12, germacrene-D 3 | Trans-dihydrocarvone | 74 | 0.38 | | Ibid. |
| *T. chiliophyllum* | Camphor 17, cis-chrysanthenol acetate 16, α-thujone 13, linalool 4, hotrienol 3 | Heneicosane | 50 | 0.40 | | Ibid. |
| *T. haradjani* | Camphor 16, 1,8-cineole 10, terpinen-4-ol 7, α-terpineol 4, | T-cadinol | 102 | 0.55 | | Ibid. |
| *M. recutita* | EN-IN-dicycloether 20, apigenine-7-glycoside 20 | Chamazulene 10 | n.s. | n.s. | Postharvest | Böttcher et al. 2001 |
| *S. canescens* | Artemisia ketone 61, camphor 20, α-pinene 2 | SDA tr. | 28 | 0.13-0.79 | Tissue culture | Casado et al. 2001a,b |
| *S. insularis* | ($CO_2$:hydrodistilled) β-myrcene 15:17, β-phellandrene 9:8, spathulenol 5:5 | Khusimone 0.3 | 44:61 | n.s. | Supercritical | Cherchi et al. 2001 |
| *Art. absinthium* | $C_{10}H_{16}O$ 54, β-thujone 12, β-sabinene 2 | 28% unidentified | 6 | n.s. | Acaricidal | Chiasson et al. 2001 |
| *T. vulgare* | β-Thujone 88-92, camphor 1 | 6-10% unidentified | 5 | n.s. | Acaricidal | Ibid. |
| *A. millefolium* | (July:Sept) β-caryophyllene (39:26), germacrene-D (8:9), p-cymene (7:12) | Camphor (4:7) | 33:35 | n.s. | Headspace | Cornu et al. 2001 |
| *Arg. adauctum3x ssp* | (adauctum: caryophyllene oxide 12, borneol 5; gracile: santolina triene 20, chamazulene 8; erythrocarpon: geranyl isovalerate 45, geranyl caproate 9 | (Z)-β-santalol 0-1.3 | 138 | 0.2-0.4 | GC, GC-MS | Couladis et al. 2001 Ibid. |
| *B. suaveolens* | (Essential oil:aromatic water) carvone (44:75), α-thujone (16:6), 1,8-cineole (3:4) | Selin-11-en-4-α-ol | 80:27 | n.s. | GC, GC-MS | Gallori et al. 2001 |
| *T. argyrophyllum* | (Leaf:flower) α-thujone (52:63), 1,8-cineole (11:4), β-thujone (5:4), camphor (3:2) | Yomogi alcohol (0.6:1) | 68:49 | 1.03:0.96 | GC, GC-MS | Gören et al. 2001 |
| *T. argenteum* | Caryophyllene oxide 13, α-thujone 12, β-caryophyllene 5, caryophylladienol II 4 | Spathulenol 1.2 | 48 | 0.04 | | Ibid. |
| *T. praeteritum* | (Subsp. praeteritum:massicyticum) α-thujone (0:51), 1,8-cineole (12:4), β-thujone (0:10) | Cinnamaldehyde (0.1:0) | 46:70 | 1.09:0.92 | | Ibid. |
| *Arg. adauctum* | β-Pinene 27, santolinatriene 23 | n.s. | 60 | n.s. | GC-MS | Palá et al. 2001b |
| *C. recutita* | (Flower) cis- and trans-dicycloether 30, α-bisabolol/chamazulene 21, β-farnesene 9 | γ-Cadinene 1-2 | 8 | n.s. | Supercritical | Povh et al. 2001 |
| *Art. marschaliana* | (Aerial part) α-pinene 25, germacrene-D 24, bicyclogermacrene 15, spathulenol 10 | Longifulene 0.4 | 20 | 0.2 | Iranian plants | Ahmadi et al. 2002 |
| *Art. judaica* | (Aerial part) piperitone 45, trans-ethyl cinnamate 21, ethyl-3-phenyl propionate 11 | 2,6-Dimethyl phenol 1.4 | 25 | 1.4 | Antioxidative | El-Massry et al. 2002 |
| *T. santolinoides* | (Aerial part) thymol 18, trans-thujone 18, trans:cis-chrysanthenyl acetate 13: 9 | 1,8-Cineole 5 | n.s. | n.s. | Antimicrobial | El Shazly et al. 2002 |
| *Art. campestris* | (Aerial part) γ-terpinene, capillene, 1-phenyl-2,4-pentadyene, spathulenol | Methyleugenol tr | 51 | n.s. | Phenology | Juteau et al. 2002a,b |
| *Art. annua* | Camphor 44, germacrene-D 16, trans-pinocarveole 11, β-selinene 9, β-caryophyllene 9 | Artemisia ketone 3 | 26 | 0.5 | GC-MS | Ibid. |
| *Art. afra* | (Aerial part) Thujanone 53, camphor 16, 1,8-cineole 14, camphene 3 | β-Thujene 0.2 | 15 | n.s. | Antimicrobial | Muyima et al. 2002 |
| *Art. sieberi* | Camphor 49, 1,8-cineole 11, bornyl acetate 6, trans-verbenol 3, lavandulol 3 | Chrysanthemyl acetate 0.7 | 40 | 1.02 | GC-MS | Sefidkon et al. 2002 |
| *Art. santolina* | Neryl acetate 13, bornyl acetate 11, trans-verbenol 10, lavandulol 9, linalool 7 | Globulol 1.5 | 39 | 0.83 | | Ibid. |
| *Art. aucheri* | Verbenone 22, camphor 21, 1,8-cineole 8, trans-verbenol 8, piperitone 3 | Spathulenol 0.9 | 26 | 0.84 | | Ibid. |
| *A. setacea* | 1,8-Cineole 19, sabinene 11, camphor 5, α-pinene 4, bisabolone oxide 4, terpinen-4-ol 3 | trans-Pinocarveol 1 | 27 | n.s. | Leaves and flowers | Ünlü et al. 2002 |
| *A. teretifolia* | 1,8-Cineole 20, borneol 12, camphor 11, thujone 5, sabinene 5, trans-piperitol 3 | Thymol 0.7 | 28 | n.s. | | Ibid. |
| *A. santolina* | 1,8-Cineole 18, camphor 18, 4-terpineol 7, p-cymene 4, trans-sabinene hydrate 3 | Santolina triene 1.3 | 45 | 0.18 | GC, GC-MS | Bader et al. 2003 |
| *A. biebersteinii* | cis-Ascaridole 36, p-cymene 32, carvenone oxide 6, camphor 5, carvacrol 1 | Terpinolene tr | 34 | 0.20 | | Ibid. |
| *Arg. pedemontana* | Chemotype 1: Camphor 49, 1,8-cineole 13 | Chemotype 2: davanone 28 | 56 | n.s. | GC-MS | Perez et al. 2003 |

*A. Achillea*, *Arg. Argyranthemum*, *Art. Artemisia*; *B. Balsamita*, *C. Chrysanthemum*, *M. Matricaria*, *S. Santolina*, *T. Tanacetum*. TNC = total number of identified compounds; [1]= 1 x var. *sinense* Makino, 1 x var. *sinense* Makino forma *esculentum* Makino (Ruouri giku). **†** = *D. zawadskii* x *D.*X *grandiflora*. HPLC high performance liquid chromatography; $^{1}$H NMR nuclear magnetic resonance, GC-MS gas chromatography-mass spectroscopy, LC liquid chromatography, TLC thin layer chromatography. PP = plant part; n.s. not specified; tr = trace amounts.

steroids, and terpenoids have a commercial application in the pharmaceutical and bio-medical fields, and are part of drugs, dyes, flavours, fragrances and insecticides (Verpoorte et al., 2002). Naturally-occurring sesquiterpenes, for example, serve a function in allelopathy, fungal pheromones, phytoalexins, phytotoxins, allomones, juvenile hormones, picrotoxins and essential oils.

Volatile oil-containing drugs and essential oils have been used for a long time both in folk medicine and in therapeutics, traditional and alternative. Essential oils, volatile secondary metabolites responsible for the odours of aromatic plants, are used in perfumery, as aroma products, flavouring agents in foods and beverages, in cosmetic products and as drugs. There is an increasing global trend in the consumption of self-prescribed herbal and natural products (and thus non-regulated) for treating numerous ailments such as cancer, and even by healthy individuals as a preventative. This, however, poses a serious health risk since oils from different locations may differ in their chemical composition, affecting thus their biological activity.

The quality and yield of essential oils (Table 1), usually extracted by steam distillation, from Anthemideae plants is influenced by the harvesting season (Cornu et al., 2001), fertilizer and the pH (ideal in acidic, pH 4.5-5.4) of soils (Alvarez-Castellanos and Pascual-Villalobos, 2003), the choice and stage of drying conditions (Tateo and Riva, 1991), the geographic location (Maffei et al., 1994), chemotype or subspecies (Gören et al., 2001), choice of plant part or genotype (Mishra et al., 1999; Nori-Shargh et al., 1999; Keskitalo et al., 2001) or extraction method (Scalia et al., 1999). Circumventing variation in essential oils and secondary metabolites derived from plants of different origin can be achieved by tissue culturing select genotypes and checking for somaclonal variation by doing RAPD analysis. Principal compounds in essential oils can be purified after extraction, and where synthetic means of producing these compounds is not commercially available, their value and demand increases (Table 2). This is of particular interest since molecular farming and bioreactor systems would allow for the potential mass production of these compounds or oils.

## A NEW ERA OF PHARMACOLOGY: THE ROLE OF MEDICINAL AND AROMATIC PLANTS

Pharmacology is the study of drugs: their preparation, properties, uses and effects while pharmacotherapeutics is the study of the use of drugs in the diagnosis, prevention, and treatment of diseases. Incidences of food borne illnesses are still a major problem, even in developed countries. It is estimated that there are up to 81 million cases of illnesses and up to 9,000 deaths in the USA alone (Alzoreky and Nakahara, 2002).

Consequently there is a constant search for new and effective techniques to eliminate food contaminants borne by microorganisms, and to reduce food toxicity, one of these being the inclusion of plant (including medicinal and aromatic) extracts in foodstuffs. Many pathogenic organisms can be controlled with antibiotics, but due to increased resistance associated with the use of antibiotics, especially in tissue culture sterility and transformation experiments, new and effective antimicrobial agents from non-microbial sources are needed. Moreover, the demand for herbal plants as alternatives to synthetic drugs (due to the side effects that they may elicit) is on the increase.

This review highlights the importance of a number of species within the Anthemideae from which vital medicinal, phytochemical, ethno-pharmacological or economically important essential oils and secondary metabolites have been isolated.

## SECONDARY METABOLITES FROM SPECIES IN THE *CHRYSANTHEMUM* COMPLEX

### *Achillea* spp

The members of the *Achillea millefolium* group contain substantial amounts of secondary compounds such as flavonoids, bitter substances, essential oil and proazulenes. These have been found in *A. millefolium* (yarrow) and chamomile (*Anthemis*, *Matricaria*, *Chamomilla*), *A. asplenifolia*, *A. roseoalba*, *A. colina* and *A. ceretanica* and are claimed to have antiphlogistic and anti-inflammatory activities. Yarrow, one of the most common Compositae species, exhibits a characteristic aromatic odour, and its leaves appear greenish-grey due to the presence of numerous trichomes. The essential oil (derived by steam distillation) from the leaves, and particularly that from flower heads is a source of medicinal preparations. *A. santolina* leaf infusion is used for intestinal colics (abdominal pain and stomache-ache), anaemia, dysentery, tonic, vermifugal for wound-healing and as a carminative while the essential oil has insecticidal, nematicidal, antibacterial, antispermatogenic, antifungal, molluscicidal and cercaricidal properties while various *A. millefolium* members serve as a herbal bile remedy (Bader et al., 2003). A hepatoprotective function results from the use of silybokhol (a complex remedy based on a concoction of essential oils and extracts from different herbal and aromatic plants, attributed to the presence of chamazulene) in which the presence of biologically active flavonoids stimulates the production of superoxide dismutase and catalase which inactivate active forms of oxygen, preventing superoxidation of lipids and damage to the liver (Lebedev et al., 2001). The capacity of *A. falcata* oils to inhibit *Agrobacterium tumefaciens*, the most common and popular vector in transgenic experiments provides a natural alternative to conventional *Agrobacterium*-eliminating antibiotics (Al

**Table 2.** Principal compounds and secondary metabolites in excess of 40% (relative value) in essential oils of Anthemideae members (Table 1), and their economic value (in yen).

| Compound | Value* | Bioactivity(ies)*1 |
|---|---|---|
| Artemisia ketone | n.a. | n.t. |
| *cis*-Ascaridole | n.a. | Analgesic; ancylostomicide; anthelmintic; antiflatulent; carcinogenic; carminative; fungicide; nematicide; pesticide; sedative; vermifuge |
| Bornyl acetate | 11-56 | (-)-Chronotropic; (-)-inotropic; antibacterial; antifeedant; antispasmodic; antiviral; expectorant; flavor; insectifuge; myorelaxant; pesticide; sedative |
| Camphor | 14-305 | Allelopathic; analgesic; anesthetic; antiacne; antidiarrheic; antidysenteric; antiemetic; antifeedant; antifibrositic; antineuralgic; antioxidative, antipruritic; antiseptic; antispasmodic; CNS-stimulant; cancer-preventive; carminative; convulsant; cosmetic; counterirritant; decongestant; deliriant; ecbolic; emetic; epileptigenic; expectorant; fungicide; herbicide; insect-repellent; insectifuge; irritant; nematicide; occuloirritant; P450-2B1-inhibitor; pesticide; respirainhibitor; respirastimulant; rubefacient; stimulant; transdermal; verrucolytic; vibriocide |
| Capillene | n.a. | Seed germination inhibitor |
| Carvone *2 | 140-800 | Allergenic; antiacetylcholinesterase; antiseptic; CNS-stimulant; cancer-preventive; carminative; flavor; insecticide; insectifuge; motor-depressant; nematicide; perfumery; pesticide; sedative; trichomonicide; vermicide |
| *β*-Caryophyllene | 2,100-2,260 | Aldose-reductase-inhibitor; antiacne; antiasthmatic; antibacterial; anticariogenic; antiedemic; antifeedant; anti-inflammatory; antispasmodic; antistaphylococcic; antistreptococcic; antitumor; candidicide; flavor; fungicide; insectifuge; irritant; perfumery; pesticide; sedative; termitifuge |
| Chrysanthediol A | n.a. | n.t. |
| 1,8-Cineole*2 | 60-780 | (-)-Chronotropic; (-)-inotropic; acaricide; allelopathic; allergenic; anesthetic; anthelmintic; antiacetylcholinesterase; antiallergic; antibacterial; antibronchitic; anticariogenic; anticatarrh; anticholinesterase; antifatigue; antihalitosic; anti-inflammatory; antilaryngitic; antinociceptive; antipharyngitic; antirheumatic; antirhinitic; antiseptic; antisinusitic; antispasmodic; antistaphylococcic; antitussive; antiulcer; CNS-stimulant; candidicide; carcinogenic; choleretic; convulsant; counterirritant; cytochrome-P450-inducer; decongestant; degranulant; dentifrice; edemagenic; expectorant; flavor; fungicide; gastroprotective; Gram(+/-)icide; hepatotonic; herbicide; hypotensive; inflammatory; insectifuge; irritant; myorelaxant; nematicide; neurotoxic; P450-inducer; perfume; pesticide; rubefacient; secretogogue; sedative; spasmogenic; surfactant; testosterone-hydroxylase-inducer; trichomonicide |
| (+)-Davone | n.a. | n.t. |
| Davanone | n.a. | n.t. |
| Estragol | 19 | Anesthetic; anticonvulsant; genotoxin; myorelaxant; hepatocarcinogen |
| Lavandulol | n.a. | n.t. |
| Myrtenol | 58-4,300 | n.t. |
| *α*-Phellandrene | n.a. | Hyperthermic; irritant; spasmogenic; tumor-promoter |
| Piperitone | n.a. | Antiasthmatic; flavor; herbicide; herbicide; insectifuge; perfumery; pesticide |
| Sabinene | n.a. | Perfumery |
| *β*-Sabinyl acetate | n.a. | Epileptogenic/convulsant |
| *α*-Thujone | 315 | Abortifacient; antibacterial; emmenagogue; epileptogenic/convulsant; insecticide; larvicide; pesticide |
| *β*-Thujone | 315 | Abortifacient; antibacterial; emmenagogue; epileptogenic/convulsant; insectifuge; pesticide |

* In Japanese yen (per 100 mg) (100 yen = 0.96 US$) based on information from ICN, Janssen, Merck, Pharmacia, Sigma-Aldrich and Wako Chemicals, price varying depending on purity; *1 Drawn primarily from http://www.ars-grin.gov/duke/chem-activities.html. (see site for details and specifications). *2 per ml. n.a. = not available in commercially pure form. n.t. = not tested (or unknown).

Kurdi et al., 2000). Oils from *A. millefolium* and *A. fragrantissima* inhibited the growth of mycotoxigenic fungi *Aspergillus flavus*, *A. parasiticus*, *A. ochraceus* and *Fusarium moniliforme* (Soliman and Badeaa, 2002).

Trichomes are the source of proazulene (the precursor of chamazulene), but cell suspension cultures, hairy root or root tissue cultures are the source of numerous other metabolites (Lourenço et al., 1999). While cell suspension cultures show the capacity to biotransform mono- and sesquiterpenes, their main constraint is a low oil yield.

## *Anthemis* spp. (syn. *Chamaemelum*, *Matricaria*)

The genus *Anthemis*, comprising ca 130 species, is a floral element of the Mediterranean, but some species are found in SW Asia and South Africa. Some chamomile species are used as phytoremediation species and thus serve as important essential oil producers in normally barren areas. Camomile is a major herbal plant and *A. nobilis*, native to Northern and Western Europe and West Asia, and is one of the important medicinal herbs cultivated globally. Its flowers have long been used for medicinal purposes and its essential oil, usually obtained form the entire aerial part, is used as a fragrance in shampoos, soap, perfumes, in aromatherapy and massages. *A. nobilis* has long been used in the pharmaceutical, food, aromatic and cosmetic industries as a scent or flavor in camomile tea, which has a sedative effect, bath products, candy, beverage, cigarettes, and others. Allergic and systemic contact dermatitis or conjunctivitis has been reported after the consumption of chamomile tea. *Anthemis* is often used as a homeopathic remedy against nausea, vomiting, indigestion, and loss of appetite. Interest in the genus *Matricaria* has increased since its constituents have high therapeutic effects as sedative or anti-inflammatory and antimutagenic or antigenotoxic, antiphlogistic (resulting from azulene), antilisteric, antiepileptic, mitogenic, spasmolytic (attributed to the flavonoids), anxiolytic (caused by chrysin), antimycobacterial, insecticidal and antimicrobial agents (Ahmed and Elela, 1999; Quarengui et al., 2000; Zanoli et al., 2000).

Numerous phytochemical studies pertain to the essential oil of *A. nobilis* grown in the field with >100 substances so far having been identified. In these reports angelates comprise approximately 65% of the total essential oil with isobutyl angelate predominating (~30% of essential oil). Estragol is the compound responsible for genotoxic properties of *A. nobilis* essential oils while geraniol has been implicated in apoptosis-like cell death (Izumi et al., 1999).

Oils from chamomile (*C. recutita*) are extracted by steam distillation or by supercritical fluid extraction (SCFE; Reverchon and Senatore, 1994). SCFE utilizes $CO_2$ as a solvent since it is cheap, easy to use and shows a great affinity to lipophylic compounds to be extracted and is useful since it is difficult to reproduce chamomile oil from flowerheads due to the many thermally labile compounds such as matricine, without which the oil would result in a different composition and aroma. Typically a blue, viscous liquid with distinct off-notes is obtained by steam distillation. Oils from *C. recutita* have numerous active substances: chamazulene, (–)-*α*-bisabolol, bisabololoxides, bisobolonoloxide A, *trans*-*β*-farnesene, *α*-farnesene, spathulenol, *cis*/*trans*-*N*-in-dicycloethers, and compounds with pharmacological effects: flavonoids, coumarins, mucilages, mono- and oligosaccharides (Máday et al., 1999).

## *Artemisia* spp

*Artemisia*, a large genus of the Anthemideae, has been the subject of numerous chemical and biological studies, yielding primarily sesquiterpene lactones, coumarins and acetylenes as the main metabolites. Plants of the genus *Artemisia* produce many eudesmanolides, the group of sesquiterpene lactones that exhibit the highest antibacterial activity and anti-inflammatory properties, while the insecticidal properties of many of its species is due to the presence of 1,8-cineole (Aggarwal et al., 2001). *Artemisia* is used for the crafting of aromatic wreaths, and as a source of essential oils used in the flavouring of vermouth. Mugwort is commonly used in traditional European medicine as a choleretic and for amenorrhoea and dysmenorrhoea.

*α*-Thujone, absinthin and anabsinthin are the principal active ingredients and *α*-thujone the toxic principle of wormwood oil, and these plant-derived pesticides have been shown to repel fleas, house flies and mosquitoes (Höld et al., 2000). *α*- and *β*-thujone are the active ingredients in herbal medicines and seasonings for food and drinks.

Analysis of *A. annua* oils revealed a great difference in the 3 main components, artemisia ketone, 1,8-cineole and camphor, depending on the global phytogeographic origin and can be grouped into: Hungarian oil with 33-75% artemisia ketone and 15-56% artemisia alcohol, Vietnamese oil with 9-22% camphor and 4-19% germacrene-D, Chinese oil with 64% artemisia ketone, French oil with 12-55% artemisia ketone, 5-15% 1,8-cineole, 4-16% *α*-pinene and 2-19% germacrene-D, Yugoslavian oil with 37-52% artemisia ketone, and North American oil with 37% artemisia ketone and 32% 1,8-cineole. Furthermore, the oils of *Artemisia* species can be classified according to their primary constituents, suggesting the use of essential oils for taxonomic classification and clarification (Table 1): *A. abyssinica* (camphene, *α*-phellandrene), *A. annua* (artemisia ketone, *α*-pinene, camphor), *A. absinthium* (neryl isovalerate, linalyl 3-methyl butanoate), *A. afra* (thujanone), *A. apiaceae* (camphene), *A. arborescens* (*β*-thujone, chamazulene), *A. arbuscula* (artemiseole), *A. argentea* (*α*-phellandrene, isopinocamphone), *A. asiatica* (1,8-cineole, selin-11-en-4α-ol), *A. aucheri* (verbenone), *A. campestris* (*β*-pinene, *γ*-terpinene), *A. capillaris* (*ε*-cadinene, thujone), *A. dracunculus* (estragole, methylchavicol), *A. edgeworthii* (*ar*-curcumene, terpinene-4-ol), *A. fukudo* (*α*- and *β*-thujone), *A. herba alba* (1,8-cineole, *β*-thujone), *A. jacutica* (chamazulene), *A. judaica* (piperitone), *A. lagopus* (palustrol), *A. marschaliana* (*α*-pinene, germacrene-D), *A. molinieri* (ascaridole, *p*-cymene), *A. monosperma* (dibenzofuran), *A. moorcroftiana* (*α*- and *β*-thujone), *A. pallens* (*cis*-davanone), *A. petrosa* (1,8-cineole, borneol, *β*-thujone), *A. rehan* (davenone, camphor), *A. roxburghiana* (1,8-cineole, camphor), *A. rubripes* (camphene, *p*-cymene), *A. santolina* (lavandulol, neryl acetate), *A. selengensis* (*α*- and *β*-pinene), *A. sieberi* (camphor), *A. stolonifera* (*β*-caryophyllene, 1,8-cineole), *A. thuscula* (davanone, camphor), *A. vulgaris* (*β*-caryophyllene).

In addition to the production of artemisin and related sesquiterpenes that are produced in specialized plastids in the apical and subapical cells of capitate glandular trichomes, *A. annua* yields an aromatic essential oil that is rich in monoterpenes. *β*-Caryophyllene, a common

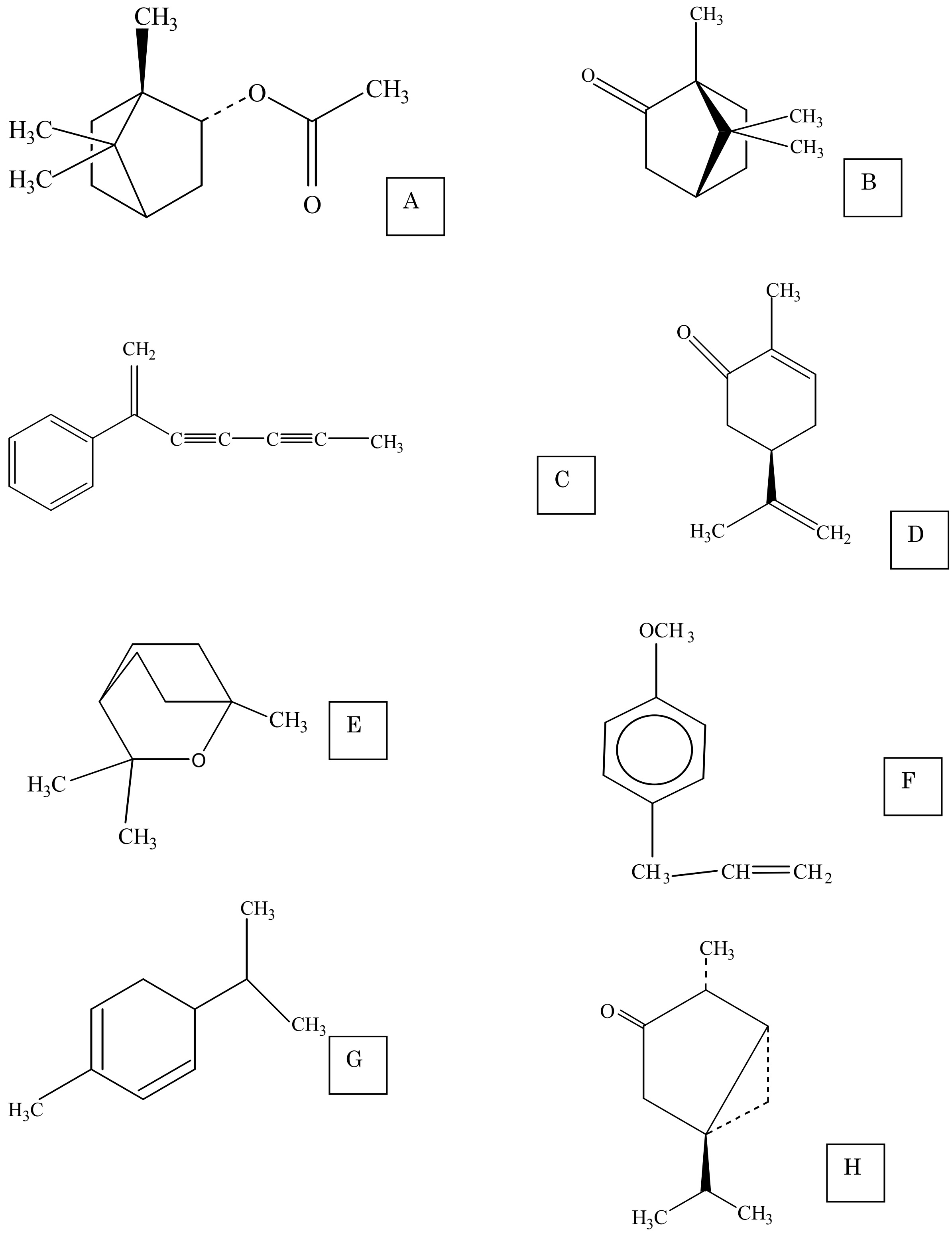


**Figure 1.** Chemical structure of some principle (> 40% of oil, relative %) compounds in Anthemideae species essential oils. A) bornyl acetate, B) (D) camphor, C) capillene, D) R-(–)-carvone, E) 1,8-cineole, F) estragol, G) *α*-phellandrene, H) *β*-thujone.

sesquiterpene widely distributed in plants possesses anti-inflammatory and anticarcinogenic activities while also playing a role in plant defense (Tellez et al., 1999). *A. annua* oils which have antibacterial activity against Gram-positive *Enterococcus hirae* and the fungi *Candida albicans* and *Saccharomyces cerevisiae* (Juteau et al., 2002b), have been used to coat urea to reduce the loss of nitrogen in soil fertilization systems (Kiran and Patra, 2003).

*A. glabella* essential oils have pronounced anti-inflammatory properties and slight antiproliferative and analgetic properties (Seidakhmetova et al., 2002). *A. afra* (a South African medicinal plant traditionally used for ailments of an infectious or septic nature) essential oils possesses antibacterial, antifungal, antiringworm and antioxidative properties (Pujar et al., 2000). *A. scoparia* essential oils serve in the treatment of tuberculosis and as insecticides, this latter property arising from the action of 1-phenyl-2,4-hexadiene (Xu et al., 1993). *A. asiatica* essential oil shows insecticidal and antimicrobial activity (Kalemba, 1999). *A. nilagirica* essential oil showed strong antimycotic activity against *Epidermophyton floccosum* and *Trichophyton violaceum*, keratinophilic fungi that cause cutaneous diseases (Kishore et al., 2001). *A. persica* oils are used in flavour and perfumery industries, in beverages and foods.

## *Balsamita* spp

*Balsamita major* (syn. *Achillea ageratum*, *Chysanthemum balsamita*, *B. foemina*, *B. mas*, *B. suaveolens*, *B. vulgaris*, *Pyrethrum balsamita*, *Tanacetum balsamita*) or costmary, Asian in origin, is a yellow-flowering plant grown in Europe, Asia and Australia since the Middle Ages. The name 'Balsamita' or 'balsam herb' is due to a soft, pleasant and aromatic balsamic odour of the volatile oil contained in the glands on the lower surface of the leaves.

Domestically in Europe they have been used to flavour different dishes including fatty minced meat, game, poultry, lamb, fish, curd, potato, soups, sauces, beverages and cakes. *C. balsamita* essential oils also serve as a hepatoprotector by reducing liver steatosis while antibiotic and allergenic properties have also been reported (Tkachenko et al., 1999).

*B. major* can be divided into two or three chemotypes based on the dominant terpene in the essential oil: camphor-type, carvone-type or camphor-thujone type. Costmary essential oil, whose composition is dependent on season and plant part, has insecticidal activity against aphids resulting from a synergistic effect of levo carvone and pyrethrin I (Williams et al., 1999).

## *Chrysanthemum cinerariaefolium*

Pyrethrum (*C. cinerariaefolium*), a paramedicinal plant, is the source of a number of compounds, collectively called pyrethrins, which are industrially extracted from dried inflorecences, with Kenya, Australia and Tasmania, Tanzania, Rwanda, Papua New Guinea and India being the primary producer countries. Pyrethrins are a mixture of six monoterpene esters produced by esterification of two acids (chrysanthemic acid and pyrethric acid). The esters of chrysanthemic acid (chrysanthemates) or pyrethric acid (pyrethrates) are collectively termed pyrethrins group I or II, respectively, consisting of pyrethrin I/II, cinerin I/II and jasmolin I/II. Whether the pyrethrins are extracted by Soxhlet (light petroleum in hydro-distillation) or by supercritical $CO_2$ extraction, the yield does not exceed 2% of total dry weight, although the ratio of pyrethrins I : II changes.

In agriculture the search for substances that can slow down the loss of nitrogen from the soil, such as essential oil-coated urea, have tremendous implication for economic and sustainable agriculture in developing countries (Kiran and Patra, 2003). Moreover when powdered *C. coronariaefolium* is added as a flower waste in fertilization, it acts as a nitrification inhibitor, and results in higher essential oil yields of *Mentha arvensis*, another herbal and medicinal plant (Ram et al., 1995).

## *Chrysanthemum coronarium*

*C. coronarium* and *C. segetum* are widely distributed in the Mediterranean, western Africa and Asia. *C. coronarium* is regarded in East Asia as a health vegetable because the edible portion contains abundant nutrients as well as a fresh flavour. This species is also used as a folk medicine, whose biologically-active substances need to be elucidated to increase the value of this vegetable. *C. coronarium* var. *coronarium* is an ornamental, often found as a common weed, while *C. coronarium* var. *spatiosum* is used as a Chinese vegetable (chop-suey). Green leaves and stems of *C. segetum* are also consumed as vegetables. Flowerheads of *C. coronarium* are often used as chamomile adulterants while in Japan the leaves are used for suppression of fishy odours in foods such as Japanese-style soup, yuzu or in Japanese pepper.

## *Chrysanthemum morifolium*

The flowering heads of *C. morifolium* are used as a herbal tea in Chinese traditional medicine and folklore. They are also used as an insecticide, parasiticide, in Parkinsonism, and nervous ailments such as headaches, tinnitus and night blindness. In Japan they are a traditional edible flower used in liquor 'Kikuka-shu' and in tea 'Kikubana-cha'. Contrarily, though, airborne and contact dermatitis results from coming into contact with various parts of the plant. Sesquiterpene lactones, flavonoids, coumarins, pyrethrins, alkaloids, essential oil and the numbing principle, *N*-isobutyl-6-(2-thienyl)-2E,4E-hexadienamide have been isolated from *C. morifolium* and flavonoids (gossypitrin, quercimetrin) and coumarins (herniarin, umbelliferone, scopoletin) from *C. segetum*. Anti-HIV agents (7 flavonoids and acacetin-7-*O*-*β*-D-galactopyranoside) have been isolated from *C.*

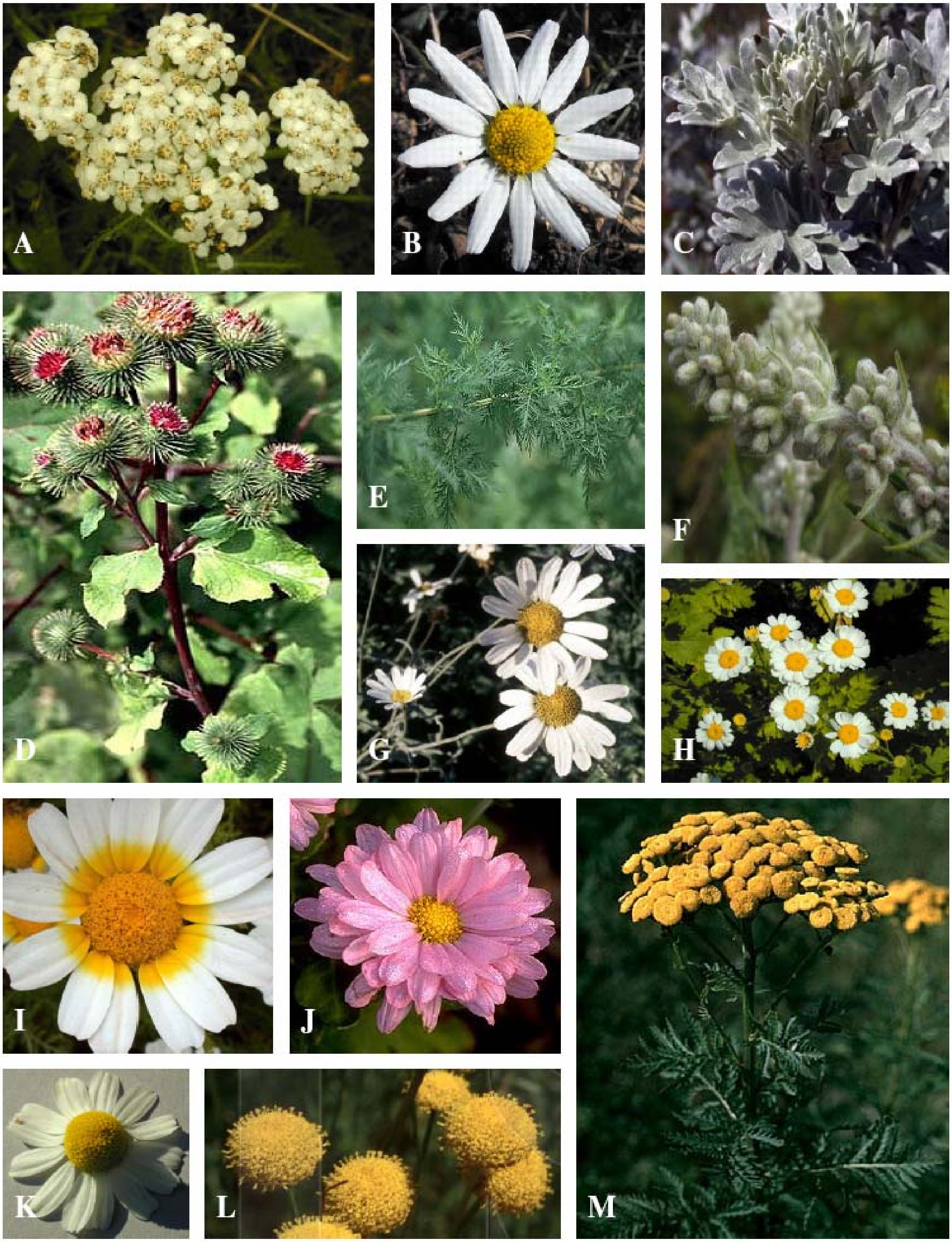


**Figure 2.** Representative members of the Anthemidae from which essential oils or secondary metabolites of pharmacological importance are derived. A) *Achillea millefolium*, B) *Anthemis cotula*, C) *Artemisia absinthium*, D) *Arctium lappa*, E) *Artemisia annua*, F) *Artemisia vulgaris*, G) *Chrysanthemum cinerariaefolium*, H) *Tanacetum parthenium*, I) *Chrysanthemum coronarium*, J) *Dendranthema grandiflora*, K) *Matricaria recutita*, L) *Santolina rosmarinifolia*, M) *Tanacetum vulgare*.

*morifolium*, which also has antiallergic, antibacterial, antifungal, antiviral, antispirochetal, anti-inflammatory, anticarcinogenic (caused by triterpene triols and diols) or tumor-inhibition, lens aldose reductase inhibition and antioxidant activities (Murayama et al., 2002).

## *Santolina* spp

*S. chamaecyparissus* is a shrub with yellow inflorescences widely used in Mediterranean folk medincine. The flowers are used for their analgesis, anti-inflamatory, antiseptic, antispasmodic, bactericidal, fungicidal, digestive and vulnerary properties, and is used in phytotherapy for different kinds of dermatitis. Several products (acetylenes, essential oils, flavonoids, sesquiterpenes) obtained from *Santolina* spp. have been investigated for their biological activities, both from *in planta* and callus cultures, albeit with lower yields in the latter. Coumarins from *S. oblongifolia* have anti-inflammatory properties attributed to the action of apigenin, luteolin, quercetin, herniarin, scopoletin, scopolin and aesculetin (Silvan et al., 1998). *S. insularis* essential oil obtained *in toto* had strong antiviral activity on Herpes simplex virus types 1 and 2 (de Logu et al., 2000). *S. insularis* oils derived by supercritical $CO_2$ extraction are superior to those derived from hydrodistillation or liquid $CO_2$ extraction. The essential oils of *S. rosmarinifolia* show great differences at the subspecies level and with a change in season (Palá et al., 2001a), where in ssp. *rosmarinifolia* and *canescens*, the major components are monoterpenes, while in ssp. *pectinata* and *semidentata* they are sesquiterpenes (Palá et al., 1999).

## *Tanacetum* spp

*Tanacetum* species, totaling over 200 and distributed over Europe and West Asia and growing up to altitudes of 2,000 meters contains several strongly scented annual and perennial species. It had been used as an insecticide as well as an insect repellant by native Americans after its introduction into North America in the 18$^{th}$ century. Interest is increasing in species of *Tanacetum* due to its essential oils (stomachic, cordial and used as a food preservative), bitter substances and the presence of sesquiterpene lactones, which exhibit biological activities like cytotoxicity, growth regulating, antimicrobial effects and allergic contact dermatitis. Antibacterial activity by sivasinolide, a sesquiterpene lactone from *T. densum* is effective against *Bacillus subtilis* and *Klebsiella pneumoniae* (Gören et al., 1992).

*Tanacetum* products are widely distributed in health food shops, while tansy extracts can be effectively used as antioxidants in rapeseed oil (Bandonienė et al., 2000). Epileptogenic properties (i.e. powerful convulsants) of tansy have been known for a long time since it has highly reactive monoterpene ketones such as camphor, pinocamphone, thujone, 1,8-cineole, pulegone, sabinylacetate and fenchone (Burkhardt et al., 1999). *T. corymbosum* essential oil exhibit anticoagulant properties and antifibrinolytic activity (Thomas, 1989b).

Several terpenoids were identified in tansy oils: *α*-pinene (the major component of turpentine, an oleoresin), *α*-terpinene, *γ*-terpinene, *α*-cubenene, dihydrocarvone, artemisia ketone, chrysanthenyl acetate, borneol, *α*- and *β*-thujone, chrysanthenone, camphor and carvone. Even though the active principles behind the mosquito repellant activity of *Tanacetum* oils could not be identified, camphor and bornyl acetate were the most active repellants against potato beetles (Schearer, 1984), while other *Tanacetum* (var. *argyrophyllum* or *praeteritum*) had antibacterial and antifungal activity, probably attributed to the action of the sesquiterpene lactones (Gören et al., 1996b) or in the case of var. *argenteum*, cytotoxic and antifeedant activities (Gören et al., 1996a).

*Tanacetum* contains similar compounds to *C. coronarium*, although quantities of *α*- and *β*-pinene are lower; *T. parthenium* (feverfew) has a high camphor (44%) and trans-chrysanthemyl acetate (23%) content, while *T. vulgare* (chemotype-dependent) contains lyratyl acetate, thujone and germacrene. One *T. vulgare* contained 95% davanone (Appendino et al., 1984). Other *Tanacetum* extracts, chamazulene and dihydrochamazulenes, of blue colour are used in the perfumery (cosmetic) and pharmaceutical industries. Natural camphor exists as both (–)-form and (+)-form, the former less common than the latter. (*1R*)(+)-Camphor is crystallized from the essential oil by distilling the wood of *Cinnamomum camphora*, but the (*1S*)(–) form has been found in *Tanacetum* and *Artemisia*. (–)-Camphor is the main constituent of *T. balsamita* (=*Balsamita major*), having a characteristic minty smell, also of spearmint.

## Future perspectives

This review summarizes and characterizes the importance of essential oils found from a wide range of Anthemidae genera. A number of compounds in these oils (and the oils themselves) have medicinal, (ethno) pharmacological properties and are used in the cosmetic, flavour and fragrance industries. Moreover, some compounds of commercial interest constitute high percentages of the essential oil, and their purification may lead to a success in molecular farming using bioreactor systems.

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