Progress in Essential Oils

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Ammi visnaga Oil

The fruit (seed) oil of *Ammi visnaga* L., known as visnaga oil or khella oil, is a low-volume oil that possesses a fruity aroma that possesses some similarities to a green mixture of Roman chamomile and tagetes oils.

Stahl (1981) reported that the oil of *A. visnaga* contained linalool, *cis*- and *trans*-linalool oxide (furanoid form), α-terpineol, terpinen-4-ol, camphor and carvone.

Stahl and Sinnwell (1986) reported the isolation of a diterpenoid ester in *A. visnaga* oil at a level of 0.03%. Structural elucidation revealed that this compound was characterized as 4-acetyoxymethyl-2-[(5-methyl-1-methylene)-4-hexenyl]-1-methyl-1-(4-methyl-3-pentenyl)-cyclobutane.

Maupetit (1993) performed a detailed analysis of an oil of *A. visnaga* of Moroccan origin. Initially Maupetit separated the oil into a basic fraction (0.02%), a phenolic fraction (0.6%), an acid/lactone fraction (0.24%) and a neutral fraction (99%). The neutral fraction was further separated into a hydrocarbon fraction (7%), an ether/oxide fraction (3.8%), an alcohol fraction (23%), an ester fraction (65%) and a ketone fraction (0.14%). The hydrocarbon fraction contained:

α-pinene (1.1%)
camphene (0.4%)
β-pinene (0.1%)
sabinene (1.3%)
myrcene (0.2%)
limonene (2.2%)
(E)-β-ocimene (0.1%)
p-cymene (0.4%)
p-cymenene (0.1%)
δ-elemene (0.1%)
α-copaene (0.3%)
β-bourbonene (0.4%)

Trace amounts (<0.05%) of tridecane, (Z)-β-ocimene, γ-terpinene, α-bourbonene, germacrene D and β-bisabolene were additional hydrocarbons that were characterized.

The ether/oxide fraction contained:

1,8-cineole (0.2%)
cis-methyl-2-vinyl-2-isopropenyl-5-tetrahydrofuran (0.1%)
trans-methyl-2-vinyl-2-isopropenyl-5-tetrahydrofuran (0.1%)
2,2,6-trimethyl-vinyl-6-tetrahydropyran (0.1%)
cis-linalool oxide[f] (1.2%)
trans-linalool oxide[f] (1.1%)
cis-linalool oxide[p] (0.4%)
trans-linalool oxide[p] (0.5%)

[f]furanoid form; [p]pyranoid form

Trace amounts (<0.05%) of epoxy (Z)-β-ocimene and epoxy-(E)-β-ocimene were also found in this fraction. The alcohol fraction contained:

2-methylbutanol (0.3%)
isoamyl alcohol (0.2%)
3-methyl-1-buten-3-ol (0.1%)
linalool (17.8%)
terpinen-4-ol (0.2%)
lavandulol (0.1%)
α-terpineol (0.9%)
2,6-dimethyl-1,7-octadiene-3,6-diol (1.4%)
2,5,9-trimethyl-4,8-decadienol (0.2%)
nerol (0.2%)
p-cymen-8-ol (0.2%)
geraniol (0.2%)
geranyl linalool (1.0%)

Trace amounts (<0.05%) of 3-methyl-1-penten-2-ol, 1-hepten-3-ol, 1-nonen-4-ol and citronellol were also characterized in the alcohol fraction.

The ester fraction contained:

propyl valerate (0.2%)
amyl isobutyrate (11.0%)
amyl butyrate (0.2%)
amyl isovalerate (4.5%)
amyl valerate (9.7%)
isoamyl 2-methylbutyrate (12.3%)
prenyl isobutyrate (0.7%)
prenyl 2-methylbutyrate (0.2%)
prenyl isovalerate (0.2%)
ethyl 2-methylbutyrate (0.1%)
butyl isovalerate (3.2%)
butyl butyrate (0.1%)
isobutyl acetoacetate (0.1%)
isobutyl 2-methylbutyrate (5.9%)
isobutyl isovalerate (3.4%)
isoprenyl isovalerate (1.7%)
isoprenyl valerate (0.8%)
hexyl isovalerate (0.1%)
octyl isovalerate (0.1%)
decyl isobutyrate (0.1%)
decyl valerate (0.1%)
(Z)-4-decenyl acetate (0.2%)
isobornyl acetate (0.1%)
lavandulyl acetate (0.4%)
neryl propionate (0.1%)
linalyl isobutyrate (1.4%)
linalyl isovalerate (1.6%)
linalyl valerate (1.3%)
2,6-dimethyl-3-hydroxy-6-acetoxy-1,7-octadiene (0.1%)
benzyl isobutyrate (0.2%)
benzyl isovalerate (0.7%)
benzyl valerate (0.3%)
p-anisyl butyrate (0.2%)
propyl 4-methoxyphenylacetate (0.1%)
(Z)-3-hexenyl butyrate (0.1%)
(Z)-3-hexenyl valerate (0.1%)
(E)-2-octenyl isobutyrate (0.1%)
(E)-2-octenyl butyrate (0.1%)

dodecyl isobutyrate (0.1%)
dodecyl isovalerate (0.3%)
dodecyl valerate (0.1%)
geranyl propionate (0.1%)
geranyl isovalerate (0.1%)
geranyl valerate (0.1%)
citronellyl propionate (0.3%)
citronellyl isobutyrate (0.6%)
citronellyl isovalerate (0.3%)
citronellyl valerate (0.1%)
2-phenethyl isobutyrate (0.3%)
2-phenethyl isovalerate (0.5%)
2-phenethyl valerate (0.5%)
butyl 4-methoxyphenylacetate (0.1%)

In addition, trace amounts (<0.05%) of methyl p-anisate, propyl 2-methylbutyrate, amyl acetate, prenyl butyrate, isobutyl valerate, 2-methylbutyl propionate, hexyl isobutyrate, heptyl valerate, octyl isobutyrate, octyl valerate, (E)-2-octenyl acetate, 1-nonen-4-yl acetate, geranyl isobutyrate and sec-butyl α-methylthiobutyrate were also found in the ester fraction.

The ketone fraction contained hexahydrofarnesyl acetone (0.1%) and trace amounts (<0.05%) of α-thujone, β-damascenone and carvone.

Other constituents of this oil were methyl eugenol (0.1%) and 4-hydroxy-3,5-dimethoxy-1-phenylethanone (0.3%) and trace amounts (<0.05%) of methyl chavicol, phenol, o-cresol, p-cresol, 4-isopropylphenol, norvignagin, khellinol (norkhellin), 5,5-dimethyl-2(5H)-furanone, δ-octalactone, 5-methyl-5-vinyl-γ-butyrolactone and the following acids: isobutyric, 2-methylbutyric, isovaleric, tiglic, (E)-2-hexenoic, hexanoic, (E)-2-heptenoic, oenanthic, (E)-2-octenoic, octanoic, nonanoic, decanoic, dodecanoic, phenylacetic, benzoic, 4-methylbenzoic, 4-isopropylbenzoic (cuminic), p-anisic, 3,4-dimethoxybenzoic, nonadioic and α-campholytic. There were also a few coumarinic components such as heniarin, xanthotoxin, bergapten, khellin and visnagin found as trace constituents of the oil.

Zrira et al. (2002) analyzed a steam-distilled oil of *A. visnaga* produced from umbels collected in the region of Ouezzane (Morocco). The main components of this oil were:

nonadecene* (0.1%)
limonene (0.8%)
p-cymene (0.8%)
δ-terpinene (0.1%)
α-pinene (0.1%)
α-thujene (1.4%)
α-cubebene (0.2%)
β-bourbonene (0.9%)
β-bisabolene (0.1%)
butyl 2-methylbutyrate (0.1%)
2-methylbutyl 2-methylbutyrate (27.7%)
butyl butyrate (0.1%)
2-methylbutyl isobutyrate (16.6%)
butyl isobutyrate (1.0%)
decyl isobutyrate (0.1%)
amyl isovalerate (10.0%)
citronellyl acetate (0.8%)
geranyl acetate (0.7%)
neryl acetate (0.2%)
citronellyl butyrate (0.1%)
linalool (22.7%)
pulegone (0.2%)
1,8-cineole (0.3%)
cis-linalool oxide[f] (0.7%)
trans-linalool oxide[f] (0.7%)

f = furanoid form; *correct isomer not identified

In addition, the authors characterized a number of trace components (<0.1%) such as 4-ethyl-1-methylcyclohexane, 1-octadecene, 1-pentadecene, heneicosane, terpinolene, heptadecane, heptadecene, hexadecane,

nonadecane, tridecane, camphene, longifolene, α-terpinene, myrcene, β-pinene, allo-aromadendrene, aromadendrene, *trans*-calamenene, α-calacorene, α-cedrene, β-gurjunene, β-sesquiphellandrene, α-copaene, γ-cadinene, β-caryophyllene, β-cubebene, β-farnesene, α-himachalene, germacrene D, γ-cadinene, γ-himachalene, γ-muurolene, isoamyl isobutyrate, octyl isobutyrate, 2-phenethyl 2-methylbutyrate, anisyl isobutyrate, benzyl isobutyrate, 2-phenethyl isobutyrate, 2-phenethyl isovalerate, benzyl isovalerate, 2-phenethyl acetate, anisyl acetate, bornyl acetate, verbenyl acetate, geranyl butyrate, citronellyl formate, geranyl acetone, linalyl propionate, farnesyl acetate, citronellyl valerate, 2-heptadecanol, borneol, geraniol, lavandulol, terpinen-4-ol, thymol, carvacrol, 2-nonanone, 2-undecanone, camphor, carvone, *cis*-dihydrocarvone, 5-methyl-2-heptanone, methylacetophenone, pinocarvone, *trans*-dihydrocarvone, α-thujone, cuminaldehyde, myrtenal, (E)-anethole, methyl chavicol, himachalene oxide, caryophyllene oxide, rose oxide and epoxylinalool in the Moroccan oil.

Zrira et al. (2008) collected air-dried umbels of *A. visnaga* from the Souk Larbaa region in northern Morocco. These authors compared the composition of a hydrodistilled oil, the commercial oil that they previously analyzed and that of a volatile concentrate obtained by supercritical CO2. The data obtained from this study are presented in **T-1**.

Comparative percentage composition of a hydrodistilled oil, an industrial oil and a supercritical CO2 extract of *Ammi visnaga* **T-1**

Compound	HDO	INO	SFE
α-thujene	0.4	1.4	-
butyl isobutyrate	0.2	1.0	-
α-pinene	0.1	0.1	-
2-methylbutyl isobutyrate	1.6	16.6	-
p-cymene	0.7	0.8	-
isoamyl 2-methylbutyrate	0.1	-	1.0
2-methylbutyl butyrate	41.8	0.1	0.4
undecyl isobutyrate	-	-	3.0
dodecyl 2-methylbutyrate	-	-	2.3
limonene	0.7	0.8	-
1,8-cineole	1.5	0.3	0.5
isobutyl valerate	4.1	-	8.2
isoamyl butyrate	0.1	-	1.0
cis-linalool oxide[f]	0.7	0.7	1.4
trans-linalool oxide[f]	-	0.7	1.3
2-nonanone	-	t	0.5
amyl butyrate	-	-	0.5
geranyl linalool[†]	-	-	22.7
linalool	23.5	22.7	11.0
methylbutyl 2-methylbutyrate	10.0	27.7	8.2
amyl isovalerate	3.9	9.9	0.3
isoamyl valerate	0.4	0.1	3.6
(Z)-3-hexenyl butyrate	-	-	1.3
pulegone	0.2	0.1	-
(Z)-3-hexenyl valerate	-	-	0.6
α-cubebene	0.1	0.2	-
citronellyl acetate	0.4	0.7	-
neryl acetate	0.3	0.2	-
β-bourbonene	0.4	0.9	0.4
2-phenethyl isovalerate	-	t	0.6
linalyl valerate	0.1	-	2.3
citronellyl butyrate	t	t	1.7
citronellyl valerate	-	t	1.0
hexadecanoic acid	-	-	1.5
tetracosane	-	-	0.2
visnagin	-	-	6.1
khellin	-	-	6.1

HDO = hydrodistilled oil; INO = industrial oil; SFE = supercritical fluid CO2 extract; t = trace (<0.1%); f = furanoid form; [†]incorrect identification based on GC elution order

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S. Zrira, J-M. Bessiere, C. Menut, A. Elamrani and B. Benjilali, *Chemical composition of the essential oil of* Ammi visnaga *Lank from Morocco*. J. Essent. Oil Bear. Plants, **5**, 1-7 (2002).

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Artemisia annua, or Annual Wormwood, Oil

Artemisia annua L. is a fragrant annual herbaceous plant of both Asiatic and European origin that has become naturalized in North America. The plant is used in traditional herbal medicine in China, where it is known as Qingdao. The plant in full flower contains a non-volatile component known as *quinghaosu*, which is used to relieve fever and has been determined to be antimalarial (Wordenbag and Pras, 2002).

Mucciarelli and Maffei (2002) reported that the leaf oil of *A. annua* raised in a greenhouse in Torino (Italy) was found to have the following composition:

α-pinene (2.6%)
α-thujene (32.7%)
camphene (1.3%)
β-pinene (0.7%)
sabinene (0.5%)
α-terpinene (29.3%)

limonene (3.0%)
γ-terpinene (2.1%)
p-cymene (0.1%)
cis-thuj-2-en-4-ol[a] (1.1%)
terpinen-4-ol (2.8%)
α-terpineol (3.0%)
borneol (0.2%)
cis-sabinol (0.1%)
camphor (6.1%)
α-guaiene (1.6%)
germacrene D (1.1%)
β-caryophyllene (0.9%)

[a]probably a misidentification for *cis*-sabinene hydrate

An oil from the *Asha* cultivar of *A. annua* grown in an experimental garden in Lucknow (Uttar Pradesh, India) was examined using GC-FID and GC/MS by Jain et al. (2002). The oil, which was produced from plants harvested in full flower contained the following components:

(E)-2-hexenol (0.1%)
2-heptanone (0.1%)
santolinatriene (0.5%)
tricyclene (0.1%)
α-thujene (0.1%)
α-pinene (5.2%)
camphene (1.5%)
sabinene (0.3%)
β-pinene (0.6%)
dihydro-1,8-cineole (0.2%)
myrcene (0.1%)
α-terpinene (0.4%)
p-cymene (0.1%)
1,8-cineole (8.4%)
limonene (0.1%)
β-phellandrene (0.1%)
artemisia ketone (52.9%)
cis-sabinene hydrate (0.4%)
artemisia alcohol (3.5%)
linalool (0.3%)
α-thujone (0.1%)
trans-sabinene hydrate (0.2%)
trans-p-menth-2-en-1-ol (0.4%)
camphor (6.0%)
cis-p-menth-2-en-1-ol (1.1%)
pinocarvone (0.3%)
isomenthone (0.1%)
borneol (0.6%)
terpinen-4-ol (0.2%)
artemisyl acetate (0.2%)
α-terpineol (0.4%)
verbenone (0.2%)
trans-carveol (0.1%)
cuminaldehyde (0.2%)
perillaldehyde (0.1%)
bornyl acetate (0.1%)
neryl acetate (0.1%)
α-cubebene (0.3%)
α-copaene (1.1%)
β-bourbonene (0.2%)
β-elemene (0.1%)
bornyl isobutyrate (0.8%)
β-caryophyllene (0.1%)
germacrene D (0.5%)
β-selinene (0.1%)
bicyclogermacrene (0.1%)
(Z)-nerolidol (0.1%)
spathulenol (0.4%)
caryophyllene oxide (4.3%)
humulene oxide I (0.4%)
humulene oxide II (0.2%)
cedrol (0.1%)
10-epi-γ-eudesmol (0.1%)
T-cadinol (0.1%)
β-eudesmol (0.1%)
α-cadinol (0.7%)
α-bisabolol (0.1%)
cyclocolorene (0.1%)
phytol (0.1%)

Trace amounts (<0.1%) of yomogi alcohol and (E)-nerolidol were also found in this same oil.

An oil of annual wormwood (ex *A. annua*) produced in India was found by Vaze (2003) to contain the following components:

ethyl 2-methylbutyrate (0.27%)
(Z)-3-hexenol (0.02%)
santolinatriene (0.18%)
ethyl tiglate (0.03%)
tricyclene (0.06%)
α-thujene (0.04%)
α-pinene (3.83%)
propyl 2-methylbutyrate (0.10%)
camphene (1.02%)
sabinene (0.90%)
β-pinene (0.57%)
3-octanone (0.04%)
myrcene (0.16%)
dehydro-1,8-cineole (0.14%)
yomogi alcohol (1.25%)
p-cymene (0.50%)
limonene (0.80%)
1,8-cineole (12.07%)
santolina alcohol (0.36%)
artemisia ketone (38.51%)
sabinene hydrate[e] (0.45%)
(Z)-3-hexenyl isobutyrate (0.07%)
cis-linalool oxide[f] (0.08%)
artemisia alcohol (4.85%)
trans-linalool oxide[f] (0.12%)
linalool (1.82%)
α-thujone (0.19%)
β-thujone (0.06%)
trans-pinocarveol (2.83%)
camphor (11.19%)
pinocarvone (0.22%)
borneol (1.25%)
terpinen-4-ol (0.68%)

p-cymen-8-ol (0.09%)
α-terpineol (0.54%)
myrtenal (0.44%)
myrtenol (0.28%)
verbenone (0.31%)
carveol* (0.25%)
bornyl formate (0.06%)
(Z)-3-hexenyl 2-methylbutyrate (0.10%)
carvone (0.08%)
linalyl acetate (2.59%)
myrtenyl acetate (0.23%)
isobornyl acetate (0.10%)
lavandulyl acetate (0.18%)
α-copaene (0.53%)
geranyl acetate (0.08%)
benzyl 2-methylbutyrate (0.35%)
β-elemene (0.14%)
β-caryophyllene (0.74%)
α-humulene (0.06%)
(Z)-β-farnesene (0.08%)
geranyl tiglate (0.12%)
β-selinene (1.17%)
caryophyllene oxide (2.06%)
humulene epoxide* (0.17%)
β-eudesmol (0.11%)

*correct isomer not identified; ffuranoid form

Haider et al. (2004) determined that seedlings of *A. annua* that were transplanted monthly between January and June yielded oils of various amounts and compositions in the North Indian plains region of Uttar Pradesh (India). Seedlings that were transplanted in April and May gave the highest oil yields (1.5–1.6%) and possessed the following range in composition:

α-pinene (1.1–2.9%)
camphene (1.3–1.9%)
β-pinene (1.1–1.2%)
α-terpinene (2.8–3.1%)
myrcene (0.0–0.1%)
limonene (0.7–3.1%)
1,8-cineole (5.9–7.9%)
β-ocimene* (0.2–0.3%)
γ-terpinene (0.5–1.0%)
p-cymene (0.1–0.3%)
artemisia ketone (0.1–0.2%)
farnesene*† (0.0–0.1%)
trans-sabinene hydrate (0.5–0.6%)
camphor (55.9–57.0%)
linalool (0.9–2.0%)
artemisia alcohol (0.5–0.6%)
terpinen-4-ol (2.2–4.9%)
β-caryophyllene (2.5–5.0%)
α-terpineol (0.1%)
borneol (1.3–3.1%)
germacrene D (1.9–2.6%)
δ-guaiene† (1.3–3.8%)
β-eudesmol (0.1–0.2%)

*correct isomer not identified
†incorrect identification based on GC elution order

Comparative percentage composition of the oils of two cultivars of *Artemisia annua* **T-2**

Compound	Jeevansaksha oil	Suraksha oil
(E)-2-hexenal	-	0.1
(Z)-3-hexenol	0.2	t
hexanol	0.2	t
santolinatriene	-	0.4
tricyclene	t	0.3
α-thujene	0.1	0.1
α-pinene	0.3	5.2
camphene	0.5	1.5
1-octen-3-ol	0.4	0.1
sabinene	0.7	0.4
β-pinene	1.4	0.8
dehydro-1,8-cineole	0.3	0.1
myrcene	4.7	0.1
p-cymene	2.0	1.3
limonene	0.2	0.4
1,8-cineole	9.4	8.4
artemisia ketone	-	47.0
γ-terpinene	0.5	t
2-methyl-6-methylene-1,7-octadien-2-ol	0.5	t
artemisia alcohol	t	2.6
terpinolene	0.5	t
cis-sabinene hydrate	0.4	0.1
perillene	0.6	-
p-mentha-1(7),5-dien-2-ol	6.3	-
dehydrosabina ketone	0.3	-
chrysanthenone	0.3	0.3
2-methyl-6-methylene-2,7-octadien-5-one	1.5	-
camphor	13.5	5.9
trans-pinocarveol	0.5	1.0
amyl 2-methylbutyrate	0.2	-
2-pentenyl propionate*	0.3	-
trans-sabinol	7.1	t
trans-chrysanthenol	0.2	0.1
pinocarvone	0.3	0.5
4-epi-β-terpineol	0.4	t
artemisyl acetate	-	0.1
borneol	0.3	0.1
terpinen-4-ol	0.8	0.6
cis-pinocarveol	0.1	-
α-terpineol	1.2	0.1
verbenone	-	0.4
myrtenol	0.2	t
trans-carveol	0.4	0.1
cis-carveol	0.2	0.1
cuminaldehyde	0.1	0.1
carvone	0.1	t
hexyl isovalerate	0.2	-
linalyl acetate	0.2	0.1
carvone-8,9-oxide	0.2	t
thymol	0.1	t
trans-sabinyl acetate	0.1	-
carvacrol	0.1	t
(Z)-3-hexenyl tiglate	0.1	-
eugenol	0.3	t

Comparative percentage composition of the oils of two cultivars of *Artemisia annua*

T-2 (Contd.)

Compound	Jeevansaksha oil	Suraksha oil
benzyl isovalerate	0.4	0.1
(Z)-jasmone	0.4	t
α-copaene	0.1	1.4
β-elemene	0.3	0.1
methyl eugenol	0.2	t
β-caryophyllene	3.7	3.7
(E)-β-farnesene	3.9	0.3
α-humulene	0.4	0.3
γ-muurolene	0.8	0.7
germacrene D	4.4	0.8
β-selinene	0.7	1.6
bicyclogermacrene	0.6	0.1
δ-cadinene	0.1	0.1
cis-calamenene	0.2	0.3
δ-cadinene	0.1	t
(Z)-nerolidol	0.1	0.3
(E)-nerolidol	0.6	0.3
spathulenol	1.1	0.1
isocaryophyllene oxide	0.1	t
caryophyllene oxide	0.8	1.9
β-copaen-4α-ol	0.5	0.1
cedrol	0.1	0.2
cis-arteannuic acid	0.3	-
trans-arteannuic acid	0.6	-
isocedrol	-	0.3
cubenol	1.7	t
cedr-8(15)-en-9α-ol	1.9	t
α-cadinol	0.7	0.3
caryophylladienol*	1.0	-
α-bisabolol	0.3	0.1
(Z)-α-*trans*-bergamotol	1.3	0.2
cedr-9(15)-en-9α-ol acetate	0.3	0.1
(Z)-α-*trans*-bergamotol acetate	0.3	t
nootkatone	-	0.1
dihydroartemisinic acid	1.1	t
dihydroartemisinic lactone	3.0	t
eicosane	0.1	t
phytol	0.2	t
octadecanoic acid	0.1	t

*correct isomer not identified

As part of an antifungal screening program, Soylu et al. (2005) examined the effect of an oil of *A. annua* against foliar and oil-borne pathogens of tomato. The composition of this oil used in the screening study was as follows:

α-thujene (0.1%)
α-pinene (1.0%)
camphene (3.3%)
sabinene (1.2%)
myrcene (2.1%)
δ-3-carene (0.9%)
1,8-cineole (10.1%)
artemisia ketone (22.3%)
artemisia alcohol (1.4%)
cis-sabinene hydrate (0.3%)
camphor (31.7%)
pinocarvone (0.4%)
borneol (0.8%
terpinen-4-ol (1.3%)
α-terpineol (1.6%)
myrtenol (0.5%)
trans-carveol (0.2%)
carvone (0.2%)
eugenol (0.2%)
α-copaene (3.4%)
β-bourbonene (0.2%)
β-cubebene (0.1%)
β-caryophyllene (1.1%)
α-humulene (0.1%)
(E)-β-farnesene (0.3%)
δ-selinene† (1.7%)
germacrene D (0.3%)
β-selinene (1.1%)
β-gurjunene† (0.1%)
α-amorphene† (0.1%)
δ-cadinene (0.3%)
caryophyllene oxide (7.1%)
γ-selinene† (1.4%)
vulgarol B (1.1%)
aromadendrene† (0.6%)
isospathulenol (0.9%)
dehydroaromadendrane† (0.2%)

†incorrect identification based on GC elution order

Mukhtar et al. (2007) analyzed an oil of *A. annua* produced from plants grown in an experimental garden in New Delhi (India). The analysis contained numerous errors, so it will not be reviewed here other than the fact that the authors reported that the main constituents of the oil were:

p-cymene (12.9%)
1,8-cineole (15.1%)
α-terpineol (14.0%)
carvone (12.0%)

Goel et al. (2007) analyzed the petal, leaf and stem oils of the *Jwarhart* cultivar of *A. annua* of Indian origin. They found that the leaf oil was rich in camphor, although the full composition of which was determined to be as follows:

α-pinene (1.7%)
ethyl 2-methylbutyrate (0.6%)
camphene (1.0%)
β-pinene (0.7%)
sabinene (0.7%)
myrcene (2.3%)
α-phellandrene (0.1%)
α-terpinene (0.1%)
1,8-cineole (6.4%)
(Z)-β-ocimene (0.1%)
γ-terpinene (0.8%)
p-cymene (2.5%)
octanal (0.3%)
hexanol (0.2%)
santolina alcohol (0.3%)
yomogi alcohol (0.2%)
1-octen-3-ol (0.1%)
δ-elemene (0.7%)
cis-p-mentha-2,8-dien-1-ol (0.1%)
(Z)-3-hexenyl 2-methylbutyrate (0.1%)
chrysanthenone (0.2%)

camphor (23.2%)
trans-sabinene hydrate + linalool (0.9%)
pinocarvone (0.9%)
linalyl acetate (0.4%)
β-caryophyllene (2.6%)
terpinen-4-ol (0.9%)
hexyl tiglate (0.1%)
myrtenal (0.1%)
9-decenol* (0.2%)
trans-pinocarveol (0.1%)
trans-sabinol (0.3%)
β-guaiene* (0.4%)
(Z)-β-farnesene (0.1%)
(E)-β-farnesene (0.8%)
α-terpineol (1.3%)
germacrene D (3.4%)
β-selinene (0.6%)
bicyclogermacrene (0.8%)
4-epi-α-terpineol (1.1%)
δ-cadinene (0.2%)
γ-cadinene (0.2%)
myrtenol (0.1%)
cis-arteannuic alcohol (0.3%)
cis-calamenene (0.1%)

*correct isomer not identified

In comparison, the authors found that the petal oil contained the following major constituents:

myrcene (5.9%)
1,8-cineole (6.8%)
trans-sabinol (10.2%)
(E)-β-farnesene (5.4%)
p-mentha-1,4(8)-dien-3-ol (10.1%)

In contrast, the major constituents of the stem oil were:

β-caryophyllene (6.1%)
caryophyllene oxide (10.0%)
(Z)-*trans*-α-bergamotol acetate (5.9%)
9-epi-caryophylla-1(12),8(15)-dien-14-ol (8.7%)

Goel et al. (2007) also determined that the major constituents of the root oil of the same *Jwarharti* cultivar of *A. annua* grown in Delhi were as follows:

β-maaliene (6.3%)
β-caryophyllene (5.5%)
(E)-β-farnesene (6.7%)
cis-arteannuic alcohol (25.9%)

A comparison between the essential oils produced from the flowering plants of the artemisin-rich *Jeevanraksha* cultivar of *A. annua* and the artemisin-poor *Suraksha* cultivar was made by Goel et al. (2008). A summary of the results of this study are

Comparative composition of *Artemisia annua* oil with oils produced from distillation waters **T-3**

Compound	Oil	Pre-flowering hydrosol oil	Full-flowering hydrosol oil
(E)-3-hexenol[a]	t	0.2	0.1
α-pinene	0.7	t	0.4
camphene	1.5	0.1	0.2
sabinene	0.2	t	0.2
β-pinene	0.5	0.1	0.1
myrcene	0.1	-	0.5
dehydro-1,8-cineole	t	0.1	-
yomogi alcohol	-	2.5	1.2
(E)-3-hexenyl acetate[a]	0.1	-	-
α-terpinene	0.1	-	-
p-cymene	1.7	t	0.1
santolina alcohol	-	0.4	0.2
1,8-cineole	1.4	12.8	14.0
γ-terpinene	0.3	-	-
artemisia ketone	-	9.5	10.1
cis-sabinene hydrate	0.2	0.7	0.2
artemisia alcohol	-	11.4	2.0
linalool	0.2	1.1	3.9
trans-sabinene hydrate	0.2	1.0	0.6
dehydrosabinaketone	-	0.8	0.9
cis-p-menth-2-en-1-ol	-	0.2	0.2
trans-pinocarveol	-	3.0	5.4
trans-p-menth-2-en-1-ol	1.3	-	-
camphor	17.6	30.7	27.7
camphene hydrate	0.1	-	-
β-pinene oxide	-	0.7	2.5
sabinaketone	-	0.2	0.4
pinocarvone	0.3	3.2	3.8
δ-terpineol	-	0.9	1.0
borneol	0.9	3.9	1.8
terpinen-4-ol	0.6	2.4	3.4
p-cymen-8-ol	-	0.2	0.4
α-terpineol	0.5	5.8	6.1
myrtenol	-	0.1	0.2
verbenone	-	0.2	t
(E,E)-2,4-nonadienal	-	0.8	0.6
trans-carveol	0.3	0.8	0.5
methyl thymol	-	0.1	0.7
cis-carveol	t	0.2	0.3
carvone	-	0.3	0.3
cis-chrysanthenyl acetate	0.4	-	-
lavandulyl acetate	0.9	-	-
isobornyl acetate	-	0.7	0.2
thymol	1.5	-	-
trans-carvyl acetate	1.0	-	-
eugenol	t	1.1	1.1
cis-carvyl acetate	0.4	-	-
α-copaene	0.9	-	0.2
β-cubebene	0.7	-	-
benzyl valerate	-	0.3	0.3
β-caryophyllene	9.0	t	0.6
(E)-β-farnesene	10.2	-	0.3
α-humulene	0.1	t	t

Comparative composition of *Artemisia annua* oil with oils produced from distillation waters **T-3 (Contd.)**

Compound	Oil	Pre-flowering hydrosol oil	Full-flowering hydrosol oil
β-chamigrene	1.4	t	0.1
germacrene D	21.2	t	0.4
β-selinene	0.8	t	0.3
bicyclogermacrene	4.2	-	-
δ-cadinene	0.5	-	-
(E)-nerolidol	0.4	-	-
spathulenol	1.3	0.5	0.7
caryophyllene oxide	0.6	0.3	0.4
globulol	0.2	-	-
epi-cedrol	0.5	-	-
β-acorenol	-	0.2	-
cubenol	2.3	-	-
T-muurolol	0.7	-	-
kongol[b]	0.6	-	0.1
α-cadinol	0.5	-	-
elemol acetate	0.5	-	-
(Z)-α-santalol	1.3	-	-

t = trace (<0.1%); a - probably (Z)-isomer not (E)-isomer; b - more commonly known as selin-11-en-4α-ol

shown in **T-2**. Trace amounts (<0.1%) of octadecane, nonadecane, isoamyl acetate, hexyl tiglate, hexadecanoic acid, (Z)-β-ocimene , (E)-β-ocimene, (E)-anethole and β-epi-manool were found in one or both oils.

Bilia et al. (2008) examined the oil composition of the distillation water of *A. annua* produced from plants grown in Italy that were harvested at two different developmental stages using only GC/MS as their method of quantitative analysis. The oil obtained from hexane extracts of the distillation waters (hydrosols) obtained from pre-flowering and full-flowering plants was compared with an oil produced from plants harvested in full flower as can be seen in **T-3**. In addition, a trace amount (<0.1%) of α-campholenal were found in the oil and both hydrosol oils.

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Lebanon Cedarwood Oil and Extract

The taxanomic origin of Lebanon cedarwood—a tree which appears on the Lebanese flag—is *Cedrus libani* A. Rich. subsp. *libani* (syn. *Cedrus cedrus* (L.) Huth, *C. effusa* (Salisb.) Voss, *C. libanensis* Juss. ex Mirb., *C. libanitica* Trew ex Pilg., *C. libanotica* Link). *Cedrus libani* subsp. *libani* is native to the Jebel Alaonite Mountains in Syria and Lebanon at an elevation of 1,300–2,100 m. According to Masri (2009), *C. libani* subsp. *libani* can be found only to a limited extent in Akkar area, Jubail Mountains and the Chouf Mountains; Jabal Qammoua forest, Wadi Jahannam, Ehden, Bcharre, Tannourine-Hadeth, Jeij, Jabal el-Barouk Ain Zhalta, Bmohrain, Barouk and Masser el-Chouf. The other subspecies, namely *C. libani* A. Rich. subsp. *stenocoma* (O. Schwarz) P.H. Davis (syn. *C. libanica* Trew ex Pilg. subsp. *stenocoma* O. Schwarz), is found in the Taurus Mountains of Syria and southern Turkey, where it is fairly abundant.

Avcibasi (1977), cited in Baser and Demirçakmak (1995), examined a pet-ether extract of *C. libani* of Turkish origin and characterized the presence of β-ylangene, α-himachalene, γ-himachalene, β-himachalene, cuparene, α-ar-himachalene, ar-himachalene, β-ar-himachalene, libanone, 6,7-epoxyhimachalene, himachalol, (Z)-β-atlantone, (E)-β-atlantone, allohimacholol, 7-epi-himachalol, andirolactone, (E)-α-atlanton-6-ol and a number of other unused constituents.

Avcibasi et al. (1987) proposed the structures for α-torosol, β-torosol, irolactone and (E)-α-atlanton-6-ol as components of a Turkish *C. libani* extract. Avcibasi et al. (1988) also proposed the structures for atlantonic, dihydroatlantonic and lianotic acids, which were found as constituents of *C. libani* extract.

Baser and Demirçakmak (1995) analyzed oils of *C. libani* subsp. *stenocoma* produced either by water distillation or steam distillation from wood collected in Antolya (Turkey) or wood and roots collected from Tarsus (Içel, Turkey). A summary of the oil analyses are presented in **T-4**. In addition, trace amounts (<0.05%)

Comparative percentage composition of *Cedrus libani* subsp. *stenocoma* wood and root oils **T-4**

Compound	Wood oil A	Wood oil B	Root oil B
α-pinene	0.2	0.2	0.3
longipinene*	0.1	0.1	0.1
1-methyl-4-acetylcyclohex-1-ene	0.3	0.1	0.1
longifolene	0.6	0.4	0.4
α-himachalene	12.8	11.5	10.3
(Z)-β-farnesene	0.1	0.1	t
γ-himachalene	7.6	6.8	7.1
β-cedrene[a]	1.8	2.3	1.1
β-himachalene	38.2	34.3	27.5
8,9-dehydroisolongifolene[a]	0.9	0.3	0.3
cuparene	0.1	t	t
α-ar-himachalene	1.9	0.2	0.2
ar-himachalene	0.3	0.1	0.2
β-ar-himachalene	1.0	0.4	0.2
α-calacorene	0.2	0.1	0.1
libanone	0.2	0.1	0.2
oxidohimachalene	0.6	0.2	0.2
(Z)-10,11-dihydroatlantone	0.9	0.1	0.1
nerolidol*	0.1	0.2	0.1
isohimachalone[a]	1.0	0.1	0.1
(E)-10,11-dihydroatlantone	3.7	t	0.1
longiborneol	0.8	0.7	0.7
(Z)-β-atlantone	1.1	2.5	2.3
himachalol	1.2	8.8	9.7
(E)-β-atlantone	1.4	2.4	2.3
(Z)-γ-atlantone	1.1	0.4	0.3
(E)-γ-atlantone	1.0	0.5	0.5
allo-himachalol	1.8	2.3	2.2
(Z)-α-atlantone	1.1	2.1	2.8
(E)-α-atlantone	7.8	14.8	23.7

A = Artalya source; B = Tarsus source; t = trace (<0.05%); *correct isomer not identified; [a]tentative identification

of limonene, terpinolene, α-ylangene, camphor, sativene, α-gurjunene and cadalene were found in all three oils.

A methylene chloride extract of *C. libani* wood collected from B'shaare (Lebanon) was analyzed by Fleisher and Fleisher (2000) using GC/MS. The components characterized in the Lebanese wood extract were as follows:

α-longipinene (0.1%)
sativene (0.1%)
longifolene (0.5%)
α-cedrene (0.2%)
α-himachalene (14.2%)
γ-himachalene (6.9%)
β-himachalene (31.3%)
chamigrene (1.4%)
(Z)-α-bisabolene (0.4%)
occidentalol acetate (0.8%)
α-dehydro-ar-himachalene (0.8%)
β-vetivene† (0.4%)
γ-dehydro-ar-himachalene (1.4%)
oxidohimachalene (0.6%)
β-himachalene oxide (2.2%)
epoxyhimachalene* (0.5%)
longiborneol (0.8%)
guaiazulene (0.1%)
(Z)-γ-atlantone (0.4%)
(E)-γ-atlantone (0.6%)
atlantone* (0.8%)
(Z)-β-atlantone (0.6%)
(Z)-α-atlantone (0.3%)
(E)-α-atlantone (2.8%)
manool (5.6%)

*correct isomer not identified; †incorrect identification based on GC elution order

In addition, trace amounts (<0.1%) of camphene, 4-methyl-3-penten-2-one, δ-3-carene, α-terpinene, limonene, γ-terpinene, p-cymene, terpinolene, fenchone, α-gurjunene, α-ylangene, β-gurjunene, camphor and α-calacorene were also characterized in this extract.

An oil produced from the wood of *C. libani* subsp. *libani* collected from Hadath Eljebeh-Tanourine Reserve (Lebanon) was analyzed by Loizzo et al. (2007). The components characterized in this oil were as follows:

α-himachalene (10.5%)
g-himachalene (9.1%)
α-himachalene (21.9%)
γ-dehydro-ar-himachalene (0.4%)
longiborneol (0.8%)
himachalol (22.5%)
allo-himachalol (3.2%)
(Z)-γ-atlantone (1.7%)
(E)-γ-atlantone (1.7%)
(Z)-α-atlantone (2.1%)
(E)-α-atlantone (0.8%)
manool (1.7%)

Finally, it was interesting to note that Kolesnikova et al. (1980) found that heptane was the major constituent of the bark oil of *C. libani*.

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Calamus Oil

As part of a search for natural germination inhibitors, Kuroyanagi (1996) found that a methanolic extract of calamus root inhibited the germination of lettuce seed. As a result, they found that calamus root extract contained eight hitherto unknown sesquiterpenoid components. The components that were structurally elucidated were 2-hydroxyacorenone, 2-acetoxyacorenone, epi-acorone, 1-hydroxy-epi-acorone, epi-acorenone, 1-hydroxyacorenone, acorusdiol and acorusnol. In addition, the authors characterized a number of known calamus constituents such as acorenone, acorone, isocalamenediol, (E)-asarone, asaraldehyde and 1-(2,4,5-trimethoxyphenyl)-propane-1,2-dione.

An oil of calamus of Polish origin was found by Gora et al. (1997) to contain the following major components:

camphene (7.4%)
camphor (8.1%)
acorenone (28.8%)
(Z)-asarone (9.3%)

The composition of Romanian calamus oil was examined by Oprean et al. (1998). In addition to characterizing (E)-asarone and (Z)-asarone in the oil. The authors were unable to definitively characterize any other constituents in the oil.

An oil produced from wild *A. calamus* roots collected along the coastline of Beysehir Lake (Konya Province, Turkey) was the subject of analysis by Özcan et al. (2002). The composition of this oil was found to be as follows:

α-pinene (0.3%)
camphene (0.8%)
β-pinene (0.3%)
sabinene (0.2%)
hexanal (1.4%)
limonene (0.1%)
p-cymene (0.1%)
cis-sabinene hydrate (0.1%)
camphor (5.9%)
linalool (1.3%)
α-gurjunene (0.8%)
β-gurjunene (2.5%)
β-caryophyllene (0.6%)
terpinen-4-ol (0.2%)
isocomenene (0.4%)
α-acoradiene (0.3%)
β-acoradiene (0.7%)
α-terpineol (0.2%)
valencene (0.5%)
viridiflorene (0.3%)
α-selinene (1.5%)
δ-cadinene (0.2%)
ar-curcumene (0.4%)
2,6-di-epi-shyobunone (2.6%)
isoshyobunone (13.0%)
shyobunone (0.5%)
muurol-5-en-4α-ol (0.4%)
caryophyllene oxide (0.7%)
preisocalamenediol (17.3%)
humulene epoxide II (0.9%)
elemol (0.6%)
cedrol (0.6%)
spathulenol (1.4%)
1,4(Z)-1,7(E)-acorenone (0.3%)
1,4(E)-1,7(E)-acorenone (10.5%)
acorenone B (0.2%)
α-cadinol (0.2%)
β-asarone[a] (2.4%)
γ-asarone[b] (0.3%)
acorone (0.2%)
isoacorone (0.1%)

[a]also known as (Z)-asarone
[b]also known as sekishone, eusarone or 1,2,4-trimethoxy-5-(2-propenyl)-benzene

Trace amounts (<0.1%) of the furanoid forms of *cis*- and *trans*-linalool oxides and β-cedrene were also found in this same oil.

Raina et al. (2003) examined the rhizome oil of *A. calamus* grown at a field station (Pantnagar, Uttarakhand, India). The components identified in this oil were:

(Z)-β-ocimene (0.1%)
linalool (0.1%)
α-terpineol (0.4%)
linalyl acetate (0.2%)
linalyl propionate (0.1%)
δ-elemene (0.3%)
β-caryophyllene (0.2%)
(Z)-methyl isoeugenol (0.6%)
β-gurjunene (0.4%)
ar-curcumene (0.1%)
α-muurolene (0.4%)
(Z)-α-bisabolene (0.1%)
β-bisabolene (1.2%)
α-cadinene (0.1%)
α-calacorene (0.1%)
(Z)-isoelemicin (1.1%)
caryophyllene oxide (0.1%)
(Z)-asarone (83.2%)
(E)-asarone[a] (9.7%)
α-bisabolol (0.6%)
heptadecane (0.3%)
benzyl benzoate (0.2%)
octadecane

[a]also known as β-asarone

Trace amounts of octane, nonane, decane, elemicin, germacrene B and α-cadinol were also found in this oil.

Venskutonis and Dagilyte (2003) analyzed an oil produced from calamus rhizomes collected from Lithuania. Although they did not present any quantitative data they did identify α-pinene, camphene, β-pinene, limonene, p-mentha-2,4(8)-diene, *cis*- and *trans*-furanoid forms of linalool oxide, linalool,

Comparative percentage composition of a supercritical fluid CO_2 extract, a hydrodistilled oil and a steam-distilled oil of *Acorus calamus* rhizomes **T-5**

Compound	SF $CO_{2\ extract}$	Hydrodistilled oil	Steam-distilled oil
tricyclene	-	-	t
α-pinene	t	t	0.3
camphene	0.2	0.2	1.6
sabinene	-	-	0.1
o-cymene	-	-	t
sylvestrene	-	-	0.2
linalool	-	-	0.5
camphor	0.6	1.2	1.0
bornyl acetate	t	t	0.2
α-cubebene	t	t	t
α-copaene	t	t	0.2
β-elemene	t	0.2	0.4
1,7-di-epi-α-cedrene	-	-	0.2
longifolene	-	1.2	0.1
1,7-di-epi-β-cedrene	1.1	-	3.8
β-cedrene	0.4	0.4	1.3
β-gurjunene	1.0	0.9	2.7
trans-α-bergamotene	0.4	0.4	1.2
aromadendrene	0.5	0.4	1.1
α-himachalene	1.1	1.1	2.6
allo-aromadendrene	-	-	0.6
β-acoradiene	t	0.3	0.6
γ-curcumene	0.4	0.6	1.2
ar-curcumene	-	-	0.6
cis-β-guaiene	-	-	1.5
shyobunone*	3.3	2.5	2.9
α-selinene	1.4	1.8	3.9
trans-β-guaiene	-	-	0.4
(Z)-α-bisabolene	0.2	-	-
shyobunone*	2.6	7.0	7.8
δ-cadinene	0.4	0.7	1.7
trans-calamenene	-	t	-
α-calacorene	1.4	1.1	2.0
cis-sesquisabinene hydrate	-	0.5	0.6
β-calacorene	0.4	0.4	0.5
(E)-nerolidol	0.6	0.8	0.7
spathulenol	0.9	1.9	1.2
caryophyllene oxide	0.3	1.4	1.0
(Z)-sesquilavandulol	11.0	13.0	14.7
tetradecanal	-	1.0	2.6
β-asarone	5.5	5.1	4.7
dehydroxy-isocalamenediol†	7.7	3.5	3.2
selin-11-en-4α-ol	0.7	2.8	1.3
cadalene	1.0	1.0	0.5
α-asarone	1.0	-	-
acorenone	13.4	21.6	11.5
oplopanone	1.2	-	-
aristolone	0.8	1.6	-
isoacorone	11.6	1.4	0.3
acorone	2.0	-	0.7
crypto-acorone†	5.0	-	-

*correct isomer not identified, t = trace (0.1%), †doubtful correct identification

camphor, terpinen-4-ol, bornyl acetate, δ-elemene, geranyl acetate, β-elemene, 1,7-di-epi-β-cedrene, β-cedrene, β-gurjunene, two isomers of prezizaene, *trans*-α-bergamotene, (Z)-methyl isoeugenol, α-acoradiene, β-acoradiene, ar-curcumene, β-selinene, two shyobunone isomers, α-selinene, (E)-methyl isoeugenol, zingiberene, *cis*-calamenene, 6,11-oxido-acor-4-ene, selina-3,7(11)-diene, (E)-nerolidol, β-calacorene, (Z)-isoelemicin, oxido-himachalene, germacrene D-4-ol, aristolen-1α-ol, spathulenol, caryophyllene oxide, α-cedrol, humulene epoxide II, β-asarone, T-muurolol, α-cadinol, two isomers of calacorene hydrate, cadalene, α-asarone, acorenone, two isomers of calamenenediol, aristolone, and acorone isomers.

Marongiu et al. (2005) compared the composition of a supercritical fluid CO_2 extract, a water-distilled oil and a steam-distilled oil of *A. calamus* rhizomes obtained from Haryana State, India. A summary of their results can be seen in **T-5**.

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