Progress in Essential Oils

Brian M. Lawrence, Consultant

Spanish Marjoram Oil

Spanish marjoram oil is obtained by steam distillation of *Thymus mastichina* L. subsp. *mastichina* which can be found growing throughout the Iberian peninsula. Miguel et al. (2004a) collected samples of the herb from four different regions (Sesimbra, Arrabida, Mertola and S. Bras Alportel) of Portugal. The plants, which were collected at their full flowering stage, were each divided into flowers and leaves, and each was separately hydrodistilled. Analysis of the oils by GC-FID and GC/MS revealed that oils from three of the regions (Arrabida, Mertola and S. Bras Alportel were rich in 1,8-cineole while the oils from Sesimbra were found to be rich in linalool. A summary of the results of the leaf and flower oils from Sesimbra compared to a composite of the leaf and flower oils from the other regions can be seen in **T-1**.

The main constituents of the oils of *T. mastichina* produced from plants either collected from their natural habitat Miguel et al. (2004b) in October and May or cultivated and either fertilized or not that were harvested in May. The main constituents of these oils can be seen in **T-2**. As can be seen these oils are of the linalool-rich chemotype whereas the commercially available *T. mastichina* oil is 1,8-cineole-rich.

The volatile components of an aqueous extract of Spanish marjoram (*T. mastichina*) leaves were analyzed using SPME combined with GC/MS by Pérez et al. (2007). The components that were characterized were as follows:

1,8-cineole (24.40)[a]
linalool (0.26)
nopinone (0.26)
camphor (0.33)
borneol (1.50)
4-isopropenyltoluene[†] (1.05)
3,6-dimethyl-2,3,3a,4,5,7a-hexahydrobenzofuran[†] (0.33)
α-terpineol (2.41)

[a] = μg/g
[†]incorrect identification based on GC elution order

Galego et al. (2008) analyzed the oil of a Portuguese *T. mastichina* that was 1,8-cineole-rich. The composition of this oil was determined by GC-FID and GC/MS to be as follows:

α-thujene (0.3%)
α-pinene (6.0%)
camphene (5.5%)
β-pinene + sabinene (7.0%)
myrcene (1.2%)

T-1 The percentage composition of the leaf and flower oils of *Thymus mastichina* subsp. *mastichina* from different regions of Portugal

Compound	Sesimbra oils		Oils from other regions	
	Leaf	Flower	Leaf	Flower
α-pinene	0.9	0.9	2.7–3.8	2.8–4.8
camphene	1.6	1.0	0.3–5.9	0.2–5.3
sabinene	0.3	0.7	1.6–1.9	2.6–3.0
β-pinene	0.6	0.8	2.9–3.8	3.7–4.2
myrcene	0.4	0.4	0.7–0.9	1.2–1.5
α-terpinene	0.1	t	0.6–1.8	0.5–0.8
1,8-cineole	9.4	10.2	44.2–69.2	39.4–54.6
limonene	0.6	0.4	1.9–2.1	1.8–2.8
(E)-β-ocimene	0.7	0.8	0.3–2.5	0.9–3.5
γ-terpinene	0.2	0.1	0.8–1.3	0.9–1.2
trans-sabinene hydrate	–	–	0.1–1.6	0.6–2.5
cis-linalool oxide[f]	1.2	0.3	–	–
trans-linalool oxide[f]	1.0	t	–	–
linalool	68.5	73.5	0.9–6.3	1.3–13.7
camphor	3.0	1.9	0.3–11.0	0.1–6.9
δ-terpineol	1.4	0.2	1.1–1.6	1.4–2.0
borneol	0.3	0.6	0.5–4.2	0.4–3.7
terpinen-4-ol	0.3	0.2	1.4–3.8	0.6–3.3
α-terpineol	0.9	–	2.9–3.5	3.0–4.0
β-caryophyllene	0.4	0.6	0.4–0.7	0.9–2.2
bicyclogermacrene	0.7	1.0	–	–
γ-cadinene	0.4	0.5	0.2	0.1–0.6
elemol	0.9	1.0	0.6–2.0	2.5–3.1
T-cadinol	2.2	2.3	0–0.2	0–0.7

f = furanoid form t = trace (<0.05%)

Comparative percentage composition of oils produced from *Thymus mastichina* plants either collected from the wild or cultivated **T-2**		
Compound	**Wild oils**	**Cultivated oils**
α-pinene	1.1–1.9	0.5
camphene	3.3–3.4	0.9–1.1
β-pinene	0.6–1.0	0.2
p-cymene	0.2–0.4	1.4–2.0
1,8-cineole	9.2–10.8	1.1
(E)-β-ocimene	0.6–2.3	1.1–1.7
γ-terpinene	0.2	4.3–5.8
linalool	59.3–61.4	58.7–69.0
camphor	5.1–5.3	2.4–2.5
δ-terpineol + borneol	3.5–4.4	3.0–3.5
β-caryophyllene	0.1–0.2	0.6–0.9
bicyclogermacrene	0.6	1.3–1.5
γ-cadinene	0.1–0.7	1.1–1.6
elemol	0.9–2.0	3.7–6.6
T-cadinol	1.2–1.5	3.4–4.6

β-terpinene[†] (0.8%)
limonene (2.6%)
(E)-β-ocimene[‡] (0.1%)
1,8-cineole (41.0%)
(Z)-β-ocimene[‡] (0.9%)
γ-terpinene (0.9%)
terpinolene (0.2%)
trans-sabinene hydrate (1.1%)
linalool (3.9%)
cis-sabinene hydrate (0.5%)
camphor (6.9%)
terpinen-4-ol (3.2%)
trans-α-terpineol[‡‡] (1.2%)
borneol (6.5%)
cis-α-terpineol[‡‡] (4.5%)
isoborneol (0.1%)
dihydrocarvone[*,‡] (0.1%)
verbenone (0.3%)
β-caryophyllene (1.1%)

[*]correct isomer not identified
[†]compound does not exist naturally
[‡]incorrect identification based on GC elution order
[‡‡]compound cannot exist

Trace amounts (<0.05%) of tricyclene and myrtenal were also found in this oil.

A commercial oil reputed to be of *O. majorana* origin was screened for its insecticidal activity against head lice by Yang et al. (2009). The oil, which was analyzed by GC-FID and GC/MS, was determined to contain the following constituents:

α-thujene (2.4%)
α-pinene (2.5%)
camphene (0.1%)
sabinene (0.5%)
β-pinene (3.4%)
p-cymene (0.9%)
limonene (6.4%)
1,8-cineole (51.0%)
linalool (24.0%)
borneol (1.0%)
α-terpineol (1.7%)
linalyl acetate (0.8%)

bornyl acetate (3.0%)
α-terpinyl acetate (0.4%)
β-caryophyllene (0.7%)

It should be noted that the composition of this oil is very dissimilar to that normally encountered as marjoram oil. It must be assumed that the oil examined by the authors was probably one of Spanish marjoram origin (*T. mastichina not O. majorana*).

M.G. Miguel, F.L. Duarte, F. Venancio and R. Tavares, *Comparison of the main components of the essential oils from flowers and leaves of* Thymus mastichina *(L.) L. ssp.* mastichina *collected at different regions of Portugal*. J. Essent. Oil Res., **16**, 323–327 (2004a).

M.G. Miguel, C. Guerrero, H. Rodrigues, J.C. Brito, F. Duarte, F. Venancio and R. Tavares, *Main components of the essential oils from wild Portuguese* Thymus mastichina *(L.) L. ssp.* mastichina *in different developmental stages or under culture conditions*. J. Essent. Oil Res., **16**, 111–114 (2004b).

R.A. Pérez, T. Navarro and C. de Lorenzo, *HS-SPME analysis of the volatile compounds from spices as a source of flavour in 'Campo Real' table olive preparations*. Flav. Fragr. J., **22**, 265–273 (2007).

L. Galego, V. Almeida, V. Goncalves, M. Costa, I. Monteiro, F. Matos and G. Miguel, *Antioxidant activity of the essential oils of* Thymbra capitata, Origanum vulgare, Thymus mastichina, *and* Calamintha baetica. Acta Hort., **765**, 325–333 (2008).

Y.-C. Yang, S.H. Lee, J.M. Clark and Y.-J. Ahn, *Ovicidal and adulticidal activities of* Origanum majorana *essential oil constituents against insecticide-susceptible and pyrethroid/malathion-resistant* Pediculus humanus capitis *(Anoplura: Pediculidae)*. J. Agric. Food Chem., **57**, 2282–2287 (2009).

Lesser Galangal Oil

An oil known as lesser galangal oil, smaller galangal oil, Chinese galangal oil and false ginger oil is obtained by steam distillation of the rhizomes of *Alpinia officinarum* Hance, a stemless perennial herb native to southeastern Asia. Lawrence et al. (1969) used a combination of fractional distillation, Al_2O_3 and silver nitrate Al_2O_3 column chromatography, analytical GC, preparative GC and IR to examine the composition of a commercial oil of *A. officinarum*. The oil was found to contain the following constituents

α-thujene (0.1%)
α-pinene + methyl isovalerate (5.8%)
camphene (4.6%)
isobutyl isovalerate (0.2%)
β-pinene (6.6%)
myrcene (0.6%)
limonene (4.0%)
1,8-cineole (49.6%)
γ-terpinene (0.2%)
p-cymene (1.6%)
terpinolene (0.1%)
α-fenchyl acetate (0.5%)
α-copaene (0.4%)
camphor (1.0%)
linalool (0.3%)
bornyl acetate + α-santalene (0.6%)
trans-α-bergamotene (1.6%)
α-guaiene (0.7%)
β-elemene + terpinen-4-ol (2.2%)
β-caryophyllene + β-copaene (0.4%)
γ-elemene (0.1%)
(E)-β-farnesene + δ-terpineol (0.9%)
α-humulene (0.1%)
α-terpineol + α-amorphene (5.7%)
δ-guaiene (0.5%)
α-selinene + γ-muurolene (1.0%)
δ-cadinene + γ-cadinene (4.6%)
isobutyl benzoate + ar-curcumene (0.9%)
cis-calamenene (0.2%)
α-calacorene + benzyl acetone (0.1%)
(E)-nerolidol (0.1%)
2-phenethyl 2-methylbutyrate (0.3%)
caryophyllene oxide (0.3%)

Trace amounts (<0.05%) of α-cubebene, 2-phenethyl isobutyrate and butyl benzoate were also characterized in this oil.

Andersen et al. (1973) determined that two unknown sesquiterpene hydrocarbons from the oil of *A. officinarum* were structurally elucidated to be: zonarene (cadina-4,6-diene) (0.5%) and 10-epi-zonarene (10-epi-cadina-4,6-diene) (0.9%).

Lawrence (1979) re-examined some of the unknown constituents that were found in the originally analyzed oil of *A. officinarum* and found that the oil also contained the following additional constituents:

cyclosativene (0.4%)
α-corocalene (0.1%)
α-muurolene (0.5%)
selina-4,11-diene (0.5%)
γ-selinene (0.1%)
5α,7α,10β-selina-4(14),11-diene (0.2%)
selina-5,11-diene (0.1%)
isopinocamphone (0.1%)

Additional trace constituents (<0.05%) such as (E,E)-α-farnesene, cadalene, humulene epoxide II, selina-3,7(11)-diene, 7α,10β-selina-4,11-diene and myristicin were also characterized in this oil.

Gao et al. (1986) determined that 1,8-cineole was the major component of an oil of *A. officinarum* produced from rhizomes grown in China.

Ly et al. used a combination of GC-FID and GC/MS to analyze oils produced in the laboratory by hydrodistillation of both fresh and dried rhizomes obtained from a local market in Hanoi (Vietnam). First of all the hydrocarbons of each oil were separated from two oxygenated constituents using micro-column chromatography and gradient elution. The hydrocarbons characterized in the fresh rhizome oil were as follows:

α-thujene (0.1%)
α-pinene (1.7%)
camphene (0.1%)
β-pinene (2.6%)
myrcene (0.5%)
α-terpinene (0.1%)
p-cymene (0.1%)
limonene (2.0%)
γ-terpinene (0.4%)
terpinolene (0.1%)
β-caryophyllene (6.4%)
α-bergamotene* (1.3%)
β-farnesene* (0.1%)
α-humulene (0.5%)
germacrene D (0.2%)
zingiberene (0.2%)
β-bisabolene (2.6%)
pentadecane (2.4%)
α-farnesene* (0.8%)

*correct isomer not identified

In contrast the major hydrocarbons found in the dried rhizome oil were:

β-caryophyllene (2.9%)
α-bergamotene* (4.7%)
α-humulene (1.4%)
germacrene D (1.5%)
zingiberene (1.3%)
β-bisabolene (9.6%)
pentadecane (1.9%)
α-farnesene* (3.3%)
unknown (8.9%)

*correct isomer not identified

The comparative compositions of the oxygenated component fractions of the two oils can be seen in **T-3**.

A lab-distilled oil of the chopped fresh rhizomes of *A. officinarum* that were collected from Imphal (Manipur, India) was analyzed by Rana et al. (2010) using GC-FID and GC/MS. The components characterized in this oil were as follows:

2-heptanol (0.1%)
α-pinene (1.2%)
camphene (2.3%)
β-pinene (3.1%)
myrcene (0.6%)
α-phellandrene (0.2%)
α-terpinene (0.1%)
1,8-cineole (28.3%)
(Z)-β-ocimene (0.1%)
(E)-β-ocimene (0.3%)
γ-terpinene (0.5%)
cis-sabinene hydrate (0.1%)
linalool (0.4%)
α-fenchol (0.3%)
camphor (3.4%)
camphene hydrate (0.2%)
borneol (1.7%)
terpinen-4-ol (1.2%)
α-terpineol (6.7%)
α-fenchyl acetate (15.2%)
methyl thymol (0.1%)
methyl carvacrol (0.3%)
bornyl acetate (0.8%)
α-terpinyl acetate (0.8%)
methyl (E)-cinnamate (4.0%)
β-elemene (0.1%)
β-caryophyllene (0.3%)
trans-α-bergamotene (0.1%)
valencene (0.6%)
α-humulene (0.1%)
(E)-β-farnesene (0.4%)
γ-cadinene (0.2%)
β-sesquiphellandrene (0.2%)
elemol (0.4%)
germacrene B (0.1%)
(E)-nerolidol (0.2%)
caryophyllene oxide (0.1%)
carotol (8.9%)
γ-eudesmol (0.5%)
β-eudesmol (0.4%)
α-eudesmol (4.5%)
α-bisabolol (0.3%)
hexadecanoic acid (0.1%)

Trace amounts (<0.05%) of tricyclene, α-thujene, p-cymene, limonene and linalyl acetate were also characterized in this oil.

T-3 Comparative percentage composition of the oxygenated compound fractions of fresh and dried rhizome oils of *Alpinia officinarum*

Compound	Fresh rhizome oil	Dried rhizome oil
1,8-cineole	50.0	8.2
linalool	–	0.2
verbenol*	0.2	0.4
p-mentha-2,8-dien-1-ol*	0.2	0.3
terpinen-1-ol	0.6	0.7
terpinen-4-ol	1.6	1.4
p-cymen-8-ol	0.2	0.3
α-terpineol	1.2	0.9
piperitol*	0.3	0.4
trans-carveol	0.2	0.2
chavicol	2.0	5.3
bornyl acetate	0.1	0.3
chavicol acetate	1.2	5.9
2-hydroxy-1,8-cineole acetate[t]	11.2	0.4
thuj-4-en-2α-yl acetate[t]	0.3	–
eugenol	0.2	1.0
carvyl acetate*	–	0.2
citronellyl acetate	0.1	–
geranyl acetate	0.4	1.2
methyl eugenol	1.0	3.3
eugenyl acetate	0.3	3.7
(E)-nerolidol	0.1	0.4
caryophyllene oxide	0.1	1.3
spathulenol	0.7	2.5
guaiol	0.2	1.2
T-muurolol	–	0.4
4-hydroxy-cinnamyl acetate	0.1	2.3
α-bisabolol	0.3	2.6
farnesyl acetate*	0.2	2.4

*correct isomer not identified
t = tentative identification

B.M. Lawrence, J.W. Hogg and S.J. Terhune, *Essential oils and their constituents. Part II. The oil of* Alpinia officinarum *Hance*. Perfum. Essent. Oil Rec., **60**(2/3), 88–96 (1969).

N.H. Andersen, D.D. Syrdal, B.M. Lawrence, S.J. Terhune and J.W. Hogg, *Widespread occurrence of two heteroannular dienes of the cadalene skeleton*. Phytochemistry, **12**, 827–833 (1973).

B.M. Lawrence, unpublished data (1979).

H. Gao, Z-F. Sha and W-J. Sun, *Determination of eucalyptol in essential oils by GC*. Zhongcaoyao, **17**(8), 351–352 (1986).

T.N. Ly, R. Yamaguchi and K. Kato, *Volatile components of the essential oils in galanga (*Alpinia officinarum *Hance) from Vietnam*. Food Sci. Technol. Res., **7**, 303–306 (2001).

V.S. Rana, M. Verdeguer and M. Amparo Blazquez, *GC and GC/MS analysis of the volatile constituents of the oils of* Alpinia galanga *(L.) Willd and* A. officinarum *Hance rhizomes*. J. Essent. Oil Res., **22**, 521–524 (2010).

Wormwood Oil

The commercial oil obtained from perennial wormwood (ex *Artemisia absinthum* L.) is available only in limited quantities from Russia, Ukraine and the United States.

Arino et al. (1999) examined the chemical composition of two oils of *A. absinthum* produced in the laboratory from plants collected from Haro (La Rioja, Spain) were found to possess compositions dissimilar to the normally encountered α- and β-thujone-rich oils of commerce. The oils were found to be rich in (Z)-epoxy-β-ocimene (30.7–43.5%) and *cis*-chrysanthenyl acetate (34.3–41.6%).

Judzentiene et al. (2004) collected *A. absinthum* from six localities in the vicinity of Vilnius (Lithuania) and ten separate oils from these plants were subjected to analysis by GC/MS. Eighty-four constituents were characterized in these oils with those found in amounts greater than 1.0% were as follows:

α-pinene (t–4.4%)
sabinene (1.0–4.0%)
β-pinene (1.6–10.4%)
myrcene (t–6.0%)
p-cymene (0–1.6%)
1,8-cineole (0.6–7.1%)
γ-terpinene (0–1.0%)
trans-sabinene hydrate (0–11.0%)
linalool (t–4.7%)
α-thujone (0–23.5%)
β-thujone (t–30.7%)
endo-2-norborneol (0–4.0%)

trans-sabinol (0.1–6.4%)
cis-chrysanthenol (0–4.1%)
terpinen-4-ol (0–1.8%)
cis-chrysanthenyl acetate (0–11.1%)
trans-sabinyl acetate (8.8–36.0%)
isocaryophyllene (1.3–2.4%)
α-acoradiene (0–1.4%)
γ-curcumene (0–1.1%)
lavandulyl 2-methylbutyrate (t–2.0%)
γ-cadinene (0–1.2%)
geranyl isobutyrate (0–1.2%)
(Z)-nerolidol (0–2.1%)
geranyl butyrate (0–2.3%)
β-calacorene (0–3.2%)
(E)-nerolidol (0-1.1%)
selin-11-en-4α-ol (0–1.5%)
epi-α-bisabolol (0–1.9%)
chamazulene (0–1.4%)
(Z)-nuciferol (0–2.0%)
(E)-α-atlantone (0–1.1%)
nuciferol acetate* (0.6–3.0%)
lanceol acetate (t–4.3%)

*correct isomer not identified
t = trace (<0.1%)

It is interesting to note that only one oil contained *trans*-sabinene hydrate and one contained *cis*-chrysanthenyl acetate (this latter oil containing only a trace amount of β-thujone and no α-thujone).

The rest of the oils contained varying amounts of β-pinene, α- and β-thujone, and *trans*-sabinyl acetate.

Gholami et al. (2005) used GC-FID and GC/MS to analyze *A. absinthum* oil produced from plants grown in Iran. The composition of this thujone-rich oil was as follows:

α-pinene (18.0%)
sabinene (3.0%)
myrcene (1.5%)
limonene (0.5%)
(Z)-β-ocimene (0.6%)
pinene oxide† (0.3%)
terpinolene (0.5%)
α-pinene oxide (0.5%)
α-thujone (60.0%)
β-thujone (5.5%)
borneol (0.2%)
cis-limonene oxide (0.8%)
bornyl formate† (0.3%)
bornyl acetate (1.7%)
β-cedrene (0.6%)
γ-muurolene (0.3%)
caryophyllene oxide (0.5%)
globulol (5.0%)
α-cadinol (0.3%)

†incorrect identification based on GC elution order

Morteza-Semnani and Akbarzadeh (2005) analyzed a lab-distilled oil of *A. absinthum* collected in the vicinity of Behshar (Mazandaran Province, Iran) using GC-FID and GC/MS. The components characterized in this oil were:

α-pinene (2.4%)
sabinene (1.8%)
β-pinene (7.3%)
p-cymene (16.5%)
α-thujone (3.3%)
β-thujone (35.1%)
(Z)-myroxide* (1.5%)
pinocarvone (3.1%)
myrtenol (2.7%)
7-ethyl-3,6-dihydro-1,4-dimethylazulene (4.3%)
globulol (3.5%)
7-ethyl-5,6-dihydro-1,4-dimethylazulene (5.5%)
chamazulene (2.2%)
octadecane (3.3%)

*also known as 2,3-epoxy-2,6-dimethyl-octa-5Z,7-diene

Kordali et al. (2005) determined the composition of an oil obtained from *A. absinthum* which was collected from the Erzurum region (Turkey). The major compounds found in this oil in amounts greater than 1.0% were:

linalyl isobutyrate (1.4%)
β-selinene (2.0%)
geranyl isobutyrate (2.3%)
cis-sesquisabinene hydrate (2.7%)
geranyl butyrate (1.7%)
spathulenol (1.8%)
caryophyllene oxide (4.3%)
β-eudesmol (1.1%)
7-epi-α-eudesmol (1.3%)
chamazulene (17.8%)
hexahydrofarnesyl acetone (1.2%)
nuciferol propionate* (5.1%)
nuciferol butyrate* (8.2%)
lanceol valerate* (1.2%)

*correct isomer not identified.

Blagojevic et al. (2006) analyzed three oils produced from the aerial parts of *A. absinthum* plants that were collected in Southeastern Serbia. All three oils contained α- and β-thujone as the major component. The composition of one of the oils was as follows:

α-thujene (0.4%)
α-pinene (0.8%)
α-fenchene (2.3%)
sabinene (10.8%)
myrcene (0.3%)
α-phellandrene (0.5%)
p-cymene (6.7%)
α-thujone (1.8%)
β-thujone (63.4%)
bornyl acetate (0.3%)
linalyl acetate (0.1%)
linalyl butyrate (0.7%)
β-caryophyllene (1.2%)
β-selinene (2.9%)
linalyl isovalerate (4.5%)
geranyl isovalerate (1.1%)
geranyl 2-methylbutyrate (0.4%)
(E)-nuciferol butyrate (0.7%)

The constituents characterized in the other two oils in amounts greater than 1.0% were as follows:

sabinene (3.3–8.1%)
p-cymene (0.5–1.2%)
1,8-cineole (1.0–16.3%)
cis-linalool oxide[f] (0–1.5%)
trans-linalool oxide[f] (0–1.5%)
linalool (0.2–4.0%)
β-thujone (19.8–20.2%)
cis-β-epoxyocimene (0–10.7%)
trans-sabinol (0–2.5%)
lavandulol (0–1.2%)
terpinen-4-ol (1.7–2.3%)
pulegone (0–2.8%)
trans-sabinyl acetate (8.8–15.5%)
linalyl butyrate (1.2–1.8%)
β-caryophyllene (0–3.0%)
(Z,E)-α-farnesene (2.5–3.3%)
linalyl isovalerate (7.5–12.5%)
neryl isovalerate (0–4.4%)
neryl 2-methylbutyrate (0–3.7%)
geranyl isovalerate (1.5–12.9%)
geranyl 2-methylbutyrate (0.9–3.3%)
chamazulene (0–1.0%)
(Z)-nuciferol propionate (0.3–1.2%)
(E)-nuciferol butyrate (1.1–1.7%)

f = furanoid form

An oil of *A. absinthum* that was produced from plants collected during the flowering stage from Monodendri (Epirus, Greece) was analyzed by Basta et al. (2007). The components characterized in this oil in amounts greater than 1.0% were:

α-fenchene (1.3%)
β-pinene (2.1%)
p-cymene (16.8%)
1,8-cineole (8.9%)
linalool (2.6%)
p-methylacetophenone (0.9%)
β-caryophyllene (1.1%)
lavandulyl isobutyrate (1.3%)
ar-curcumene (1.4%)
β-selinene (1.8%)
neryl isobutyrate (2.4%)

- lavandulyl isovalerate (4.2%)
- caryophyllene oxide (25.3%)
- humulene epoxide II (1.6%)
- caryophylla-3,8(13)-dien-5β-ol (1.9%)
- chamazulene (2.9%)
- (Z)-lanceol acetate (7.3%)
- (E)-lanceol acetate (3.7%)
- heneicosane (1.2%)
- pentacosane (1.6%)

Rezaeinodehi and Khangholi (2008) determined that an oil produced from *A. absinthum* collected from Guilan province (Iran) contained:

- α-pinene (3.8%)
- sabinene (8.9%)
- β-pinene (23.8%)
- myrcene (4.0%)
- α-phellandrene (3.2%)
- α-terpinene (0.4%)
- p-cymene (1.9%)
- β-phellandrene (0.7%)
- 1,8-cineole (0.3%)
- (E)-β-ocimene (0.4%)
- γ-terpinene (0.7%)
- linalool (4.2%)
- α-thujone (0.9%)
- β-thujone (18.6%)
- isothujanol (0.9%)
- *trans*-pinocarveol (0.6%)
- terpinen-4-ol (1.5%)
- α-terpineol (0.3%)
- myrtenal (0.3%)
- germacrene D (3.1%)
- β-selinene (0.7%)
- α-dehydro-ar-himachalene (3.8%)
- γ-dehydro-ar-himachalene (0.6%)
- neryl isovalerate (0.8%)
- geranyl isovalerate (1.9%)
- cubenol (4.3%)
- α-cadinol (1.8%)
- chamazulene (0.9%)

Judzentiene et al. (2009) expanded their study on oils of *A. absinthum* produced from plants collected in the Vilnius (Lithuania) vicinity. In addition to the major components (those greater than 1.0%) found before, they also characterized the following unusual components:

- 9-geranyl-p-cymene (0.2–2.0%)
- 9-geranyl-α-terpinene (0–0.7%)
- 9-(15,16-dihydro-15-methylene)-geranyl-p-cymene (0.4–3.0%)
- 9-(15,16-dihydro-15-methylene)-α-terpinene (0.5–4.3%)

A. Arino, I. Arberas, G. Renobales, S. Arriaga and J.B. Dominguez, *Seasonal variation in wormwood* (Artemisia absinthium *L.*) *essential oil composition.* J. Essent. Oil Res., **11**, 619–622 (1999).

A. Judzentiene and D. Mockute, *Chemical composition of essential oils of* Artemisia absinthum *L. (wormwood) growing wild in Vilnius*. Chemija, **15**(4), 64–68 (2004).

M. Gholami, A. Azizi and P. Salehi, *Variations in essential oil components in cultivated and regenerated* Artemisia absinthium. Asian J. Chem., **17**, 2229–2232 (2005).

K. Morteza-Semnani and M. Akbarzadeh, *Essential oils composition of Iranian* Artemisia absinthium *L. and* Artemisia scoparia *Waldst. et Kit.* J. Essent. Oil Res., **17**, 321–322 (2005).

S. Kordali, A. Cakir, A. Mavi, H. Kilic and A. Yildirim, *Screening of chemical composition and antifungal and antioxidant activities of the essential oils from three Turkish* Artemisia *species*. J. Agric. Food Chem., **53**, 1408–1416 (2005).

P. Blagojevic, N. Radulovic, R. Polic and G. Stojanovic, *Chemical composition of the essential oils of Serbian wild-growing* Artemisia absinthium *and* Artemisia vulgaris. J. Agric. Food Chem., **54**, 4780–4789 (2006).

A. Basta, O. Tzakou, M. Couladis and M. Pavlovic, *Chemical composition of* Artemisia absinthium *L. from Greece.* J. Essent. Oil Res., **19**, 316–318 (2007).

A. Rezaeinodehi and S. Khangholi, *Chemical composition of the essential oil of* Artemisia absinthum *growing wild in Iran*. Pak. J. Biol. Sci., **11**, 946–949 (2008).

A. Judzentiene, F. Tomi and J. Casanova, *Analysis of essential oils of* Artemisia absinthum *L. from Lithuania by CC, GC(RI), GC/MS and* ^{13}*C-NMR*. Nat. Prod. Commun., **4**, 1113–1118 (2009).