Progress in Essential Oils

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Manuka Oil

Manuka oil is produced in New Zealand by steam distillation of the fresh leaves and small branches of *Leptospermum scoparium* J. R. Forst et F. Forst collected from the wild. *Leptospermum scoparium* is known to exist in at least three varietal forms such as *L. scoparium* J. R. Forst et G. Forst var. *rotundifolium* Maiden et Betche, *L. scoparium* var. *scoparium* and *L. scoparium* var. *eximium* J. R. Forst et G. Forst. The three varieties of *L. scoparium* can be found in Australia.

In1979, Flynn et al. reported that *L. scoparium* var. *rotundifolium* contained the following constituents:

α-thujene (0.1%)
α-pinene (30.8%)
β-pinene (1.9%)
myrcene (trace)
α-terpinene (0.1%)
limonene (1.2%)
1,8-cineole (25.4%)
γ-terpinene (0.3%)
p-cymene (2.3%)
terpinolene (trace)
linalool (0.4%)
terpinen-4-ol (1.3%)
β-caryophyllene (0.5%)
isoborneol (0.9%)
α-terpineol (4.7%)
α-terpinyl acetate (1.3%)
aromadendrene (0.6%)
allo-aromadendrene (1.0%)
myrtenol (0.3%)
neral (0.1%)
cuminyl alcohol (0.3%)
geraniol (1.6%)
γ-muurolene (0.5%)
globulol (1.1%)
viridiflorol (2.0%)
γ-eudesmol (2.7%)
α-eudesmol (4.5%)
β-eudesmol (7.1%)

Twenty years later, Brophy et al. (1999) examined the oil composition of the other two varieties of *L. scoparium*. The composition of these oils is shown in Table I.

As can be seen, the varietal oils of *L. scoparium* of Australian origin do not possess the typical manuka triketone oil composition as was originally reported by Briggs et al. (1938 and 1945).

In 1997, Perry et al. showed that manuka oil produced from *L. scoparium* of different origins in New Zealand varied quite a lot in composition (Table II). Although the authors did not identify many components of the oils, they did show that East Cape oils were the richest in triketones.

Also in 1997, Melching et al. examined the sesquiterpene hydrocarbon fraction of manuka oil. In this fraction they identified the following hydrocarbons:

α-cubebene
α-copaene
α-gurjunene
β-caryophyllene
aromadendrene
α-humulene
allo-aromadendrene
β-selinene
α-selinene
δ-cadinene
cadina-1,4-diene

In addition, they determined that the following enantiomeric forms of five other sesquiterpene hydrocarbons were also found in this fraction, e. g.:

(-)-cadina-3,5-diene
(-)-bicyclosesquiphellandrene
(-)-cadina-1,4-diene
(-)-zonarene
(-)-trans-calamenene

Porter and Wilkins (1998) reported the results of a GC and GC/MS analysis of manuka oil produced in New Zealand. The components identified in this somewhat uncommon oil were found to be:

α-thujene (0.03%)
α-pinene (1.31%)
β-pinene (0.12%)
myrcene (0.24%)
p-cymene (0.16%)
1,8-cineole (0.22%)
limonene (0.10%)
γ-terpinene (0.16%)
terpinolene (0.05%)
linalool (0.10%)
isoamyl 2-methylbutyrate (0.05%)
isoamyl isovalerate (0.13%)
2-methylbutyl isovalerate (0.05%)
isoprenyl isovalerate (0.24%)
terpinen-4-ol (0.04%)
α-terpineol (0.09%)
isoamyl tiglate (0.09%)
isoprenyl tiglate (0.03%)
α-cubebene (3.95%)
α-ylangene (0.32%)
α-copaene (5.86%)
β-elemene (0.55%)
α-gurjunene (1.02%)
β-caryophyllene (2.63%)
aromadendrene (2.09%)
cadina-3,5-diene (4.88%)
α-copaene (0.37%)
allo-aromadendrene (0.80%)
δ-amorphene (3.81%)
α-amorphene (0.33%)
β-selinene (3.67%)
α-selinene + viridiflorene (4.35%)
α-muurolene (0.77%)
α-farnesene* (0.84%)
calamenene* (14.42%)
δ-cadinene (6.02%)
flavesone (4.91%)
cadina-1,4-diene (5.94%)
(E)-nerolidol (0.24%)
spathulenol (0.52%)
caryophyllene oxide (0.25%)
viridiflorol (0.46%)
ledol (0.23%)
isoleptospermone (4.62%)
leptospermone (15.54%)

* correct isomer not identified

The authors also compared oils produced from plant material (fresh foliage) harvested from different locations in New Zealand. The major compounds found in the oils

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Table I. Comparative percentage composition of *Leptospermum scoparium* var. *scoparium* and *L. scoparium* var. *eximium*

Compound	var. *scoparium* oil	var. *eximium* oil
α-pinene	12.2	18.1
α-fenchene	trace	trace
camphene	trace	trace
β-pinene	0.7	0.7
sabinene	trace	trace
myrcene	0.3	0.3
α-terpinene	0.1	0.1
limonene	0.5	1.4
β-phellandrene	trace	trace
1,8-cineole	2.9	0.1
(Z)-β-ocimene	trace	0.1
γ-terpinene	1.3	0.1
(E)-β-ocimene	0.5	0.8
p-cymene	1.2	trace
terpinolene	0.3	0.2
linalool	4.0	4.4
β-elemene	0.2	0.1
β-caryophyllene	4.8	1.7
terpinen-4-ol	0.9	0.4
aromadendrene	0.2	trace
α-bulnesene	0.1	trace
allo-aromadendrene	1.0	0.3
α-humulene	3.9	0.4
viridiflorene	2.9	0.3
α-terpineol	1.1	3.0
β-selinene	0.3	0.3
α-selinene	0.2	0.3
bicyclogermacrene	9.2	0.8
δ-cadinene	0.6	0.9
geraniol	0.2	0.5
palustrol	0.7	0.4
caryophyllene oxide	0.4	0.3
(E)-nerolidol	0.2	0.4
(E)-methyl cinnamate	trace	trace
globulol	4.6	3.3
viridiflorol	2.3	4.3
spathulenol	3.2	1.8
γ-eudesmol	5.3	13.6
α-eudesmol	5.7	11.5
β-eudesmol	5.5	13.8

produced from these different environments varied in the amounts of calamenene, triketones, eudesmols (not noted anywhere else in the paper) and α-pinene. An oil rich in α-pinene appeared to be more like a kanuka oil than manuka oil; however, the authors did not discuss this point.

This same year, Porter et al. (1998) collected seeds from a natural population of *L. scoparium* in Nelson province and raised shrubs in an experimental garden in Riwaka (NZ). Fresh foliage harvested from these shrubs was steam distilled to yield an oil that was found to contain:

α-thujene (1.5%)
α-pinene (3.4%)
β-pinene (2.1%)
myrcene (0.2%)
linalool (5.2%)
α-cubebene (3.9%)
α-copaene (4.2%)
β-elemene (11.1%)
β-caryophyllene (3.8%)
α-selinene (4.3%)
calamenene* (6.3%)
δ-cadinene (2.8%)
elemol (1.2%)
γ-eudesmol (2.5%)
β-eudesmol (3.2%)
α-eudesmol (2.9%)

* correct isomer not identified

In 1999, Reichling et al. determined that the main constituents of a sample of manuka oil obtained in Germany were as follows:

α-pinene (0.80%)
myrcene (0.23%)
1,8-cineole (0.35%)
β-caryophyllene (1.18%)
aromadendrene (2.51%)
allo-aromadendrene (0.48%)
β-selinene (10.70%)
calamenene* (20.85%)
leptospermone (19.19%)
isoleptospermone (5.68%)

*correct isomer not identified

Also in 1999, Christoph et al. examined the composition of sixteen different commercial samples of manuka oil that were available in Germany. Using a combination of GC and GC/MS, the authors identified 47 components, which accounted for about 95% of the oil. The quantitative variation in oil constituents was found to be as follows:

α-pinene (1.3-11.0%)
β-pinene (0.1-0.3%)
myrcene (0.3-0.6%)
limonene (trace-0.3%)
1,8-cineole (0.2-1.0%)
γ-terpinene (trace-0.4%)
p-cymene (0.2-0.7%)
terpinolene (trace-0.1%)
isoamyl isovalerate (0.1-0.2%)
α-cubebene (3.0-4.4%)
isoamyl tiglate (trace-0.1%)
α-ylangene (0.2-0.3%)
α-copaene (4.7-6.5%)
α-gurjunene (0.8-1.2%)
β-cubebene (trace-0.3%)
linalool (trace-0.4%)
β-elemene (0.6-1.6%)
β-caryophyllene (2.0-3.2%)
terpinen-4-ol (trace-0.2%)
aromadendrene (1.6-2.2%)
cadina-3,5-diene (3.0-10.0%)
allo-aromadendrene (0.7-0.9%)
δ-amorphene (2.0-4.2%)
α-humulene (0.3-0.4%)
γ-muurolene (0.9-1.4%)
viridiflorene (0.6-1.1%)
germacrene D (trace-0.5%)
β-selinene (2.8-5.1%)
α-selinene (2.7-5.0%)
bicyclogermacrene (trace-1.0%)
(E,E)-α-farnesene (0.7-1.5%)
δ-cadinene (4.8-7.2%)
γ-cadinene (trace-0.1%)
cadina-1,4-diene (4.0-5.3%)
trans-calamenene (0.6-18.5%)
α-calacorene (0.3-0.5%)
γ-calacorene (0.5-0.9%)
caryophyllene oxide (0.2-0.6%)
flavesone (1.3-5.8%)
isoleptospermone (1.4-4.7%)
cubenol (0.1-1.5%)
globulol (trace-1.5%)
leptospermone (8.7-19.4%)
viridiflorol (0.1-0.4%)

spathulenol (0.3-0.9%) T-muurolol (trace-0.2%)
T-cadinol (trace-0.1%)

As four of the oils differed from the other twelve in that their triketone content was only ca. 15% as compared to ca. 25% for the twelve, the authors noted that as manuka oil originates from two regions in New Zealand (East Cape or Coromandel), regional differences could account for the difference in triketone (flavesone, isoleptospermone and leptospermone) content; however, in this reviewer's view this question still remains unanswered.

Table II. Variation in composition of various samples of *Leptospermum scoparium* oils

Compound	Australian	Northern	East Cape	Southern
α-pinene	17.3	22.5	0.7	2.9
β-pinene	2.5	6.0	0.1	0.5
myrcene	0.8	4.7	1.1	3.8
p-cymene	4.2	0.8	0.2	0.6
1,8-cineole	19.9	1.6	0.3	0.7
linalool	1.0	1.5	0.2	2.4
(E)-methyl cinnamate	0.2	-	-	3.3
flavesone	0.1	0.1	8.3	0.1
isoleptospermone	0.4	-	5.3	0.5
leptospermone	0.6	0.8	18.9	1.7

L. H. Briggs, A. R. Penfold and W. F. Short, *Leptospermone*. Part I. J. Chem. Soc., 141, 1193-1195 (1938).

L. H. Briggs, C. H. Hassall and W. F. Short, *Leptospermone*, Part II. J. Chem. Soc., 148, 707-709 (1945).

T. M. Flynn, E. V. Lassak and M. P. Smyth, *The volatile leaf oils of three species of Leptospermum*. Phytochemistry, 18, 2030-2031 (1979).

S. Melching, N. Bülow, K. Wihstutz, S. Jung and W. A. König, *Natural occurrence of both enantiomers of cadina-3,5-diene and δ-amorpheneI*. Phytochemistry, 44, 1291-1296 (1997).

N. G. Perry, N. J. Brennan, J. W. van Klink, W. Harris. M. H. Douglas, J. A. McGimpsey, B. M. Smallfield and R. E. Anderson, *Essential oils from New Zealand manuka and kanuka: chemotaxonomy of Leptospermum*. Phytochemistry, 44, 1485-1494 (1997).

N. G. Porter, P. E. Smale, M. A. Nelson, A. J. Hay, J. W. van Klink and C. M. Dean, *Variability in essential oil chemistry and plant morphology within a Leptospermum population*. New Zealand J. Bot., 36, 125-133 (1998).

N. G. Porter and A. L. Wilkins, *Chemical, physical and antimicrobial properties of essential oils of Leptospermum and Kunzea ericoides*. Phytochemistry, 50, 407-415 (1998).

J. J. Brophy, R. J. Goldsack, A. R. Bean, P. I. Forester and B. J. Lepschi, *Leaf essential oils of the genus Leptospermum (Myrtaceae) in eastern Australia. Part 5. Leptospermum continentale and allies*. Flav. Fragr. J., 14, 98-104 (1999).

J. Reichling, M. Harkenthal and R. Saller, *Wirkung ausgewählter ätherischer Öle*. Erfahrungsheilkunde, 6, 357-366 (1999).

F. Christoph, K-H. Kubeczka and E. Stahl-Biskup, *The composition of commercial manuka oils from New Zealand*. J. Essent. Oil Res., 11, 705-710 (1999).

Spanish Sage Oil

A sample of Spanish sage oil was analyzed by Zani et al. (1991). It was found to contain:

α-pinene (3.85%)
camphene (5.14%)
β-pinene (6.93%)
myrcene (0.79%)
δ-3-carene (1.19%)
limonene (3.48%)
1,8-cineole (30.61%)
α-thujone (3.21%)
β-thujone (0.61%)
camphor (12.25%)
borneol (3.15%)
α-terpineol (1.36%)
β-caryophyllene (3.55%)
α-humulene (6.10%)

Six years later, Mathé et al. (1997) used a combination of GC and GC/MS to analyze an oil of *Salvia lavandulaefolia*. It was found to contain the following constituents:

α-thujene (0.4%)
α-pinene (2.7%)
β-pinene (6.8%)
myrcene (5.8%)
α-terpinene (0.4%)
p-cymene (0.4%)
1,8-cineole (47.0%)
γ-terpinene (1.1%)
terpinolene (0.5%)
camphor (12.6%)
borneol (2.2%)
terpinen-4-ol (0.7%)
α-terpineol (0.3%)
bornyl acetate (0.6%)
β-caryophyllene (4.9%)
α-humulene (1.0%)
caryophyllene oxide (0.3%)
viridiflorol (4.5%)

In 1999, Foray et al. examined a lab-distilled oil of *S. lavandulaefolia*. The components identified in this oil were as follows:

α-pinene (2.5%)
camphene (4.0%)
sabinene (0.5%)
β-pinene (1.2%)
myrcene (1.8%)
limonene (1.9%)
1,8-cineole (25.5%)
linalool (0.5%)
camphor (39.0%)
linalyl acetate (10.2%)
α-terpinyl acetate (0.8%)
β-caryophyllene (1.1%)
α-humulene (0.4%)

Also in 1999, Guillén and Manzanos examined the composition of a methylene chloride extract of the aerial parts of *S. lavandulaefolia* using GC and GC/MS. The identified components are summarized as follows:

α-pinene (0.5%)
camphene (0.4%)
β-pinene (0.1%)
myrcene (0.2%)
α-terpinene (0.1%)
p-cymene (0.1%)
limonene (0.3%)
1,8-cineole (2.8%)
linalool (0.1%)
camphor (2.9%)
borneol (1.5%)
terpinen-4-ol (0.1%)
α-terpineol (0.8%)
geraniol (0.1%)
bornyl acetate (0.7%)
α-cubebene (0.1%)
α-copaene (0.2%)
α-gurjunene (0.1%)
β-caryophyllene (0.8%)
aromadendrene (0.1%)
α-humulene (0.6%)
allo-aromadendrene (0.1%)
ar-curcumene (0.1%)
β-selinene (0.2%)
α-selinene (0.1%)
α-muurolene (0.1%)
γ-cadinene (0.4%)
δ-cadinene (0.6%)
cadina-1,4-diene (0.1%)
spathulenol (0.1%)
caryophylenol II (0.6%)
viridiflorol (3.3%)
β-gurjunene epoxide (0.4%)
a caryophyllenol* (0.1%)

an aristolenol* (0.3%)
neophytadiene (0.1%)
6,10,14-trimethyl-2-pentadecanone (0.1%)
pimara-8(9),15-diene (0.1%)
abieta-8,11,13-trienal (0.2%)
abieta-6,8,11,13-tetraen-12-ol* (0.1%)
ferruginol* (0.8%)
abieta-8,11,13-trien-19-ol* (0.8%)
abieta-8,11,13-trien-19-oic acid (6.5%)
barbatusol* (0.6%)
12-hydroxy-abeita-8,11,13-trien-12-ol-20-al* (0.7%)
rosmadial* (1.5%)
dimethylsalvicanol* (13.9%)
carnosic acid (2.7%)
squalene (0.2%)
cirsimaritin (0.3%)
β-sitosterol (1.2%)
β-amyrin (0.8%)
3,5-dihydroxy-6,7,8-trimethoxyflavone (1.8%)
hexadecanoic acid (0.3%)
oleic acid (0.1%)
pentacosane (0.7%)
heptacosane (0.3%)
octacosane (0.3%)
ethyl hexacosane* (0.1%)
nonacosane (2.3%)
methyl octacosane (0.1%)
triacontane (0.2%)
ethyl octacosane* (0.3%)
methyl nonacosane* (0.1%)
henitriacontane (2.7%)
ethyl nonacosane* (0.1%)
methyl triacontane (0.5%)
dotriacontane (1.0%)
ethyl triacontane* (0.8%)
methyl henitriacontane* (0.2%)
tritriacontane (5.3%)
tetratriacontane (1.9%)
ethyl dotriacontane* (0.3%)
pentatriacontane (0.6%)

* correct isomer not identified

In addition the authors also found trace amounts of the following compounds in the same methylene chloride extract:

tricyclene
α-thujene
4-methylene-1(1-methylethyl) bicyclo[3.1.0]hex-2-ene
sabinene
α-phellandrene
γ-terpinene
terpinolene
p-mentha-1,5,8-triene
cis-sabinene hydrate
α-fenchol
campholenal
trans-pinocarveol
isoborneol
p-cymen-8-ol
myrtenol
methyl chavicol
bornyl formate
trans-carveol
5-hydroxy-1,8-cineole
thymol
methyl isopropylphenol*
carvacrol
2,5-bornanedione†
eugenol
geranyl acetate
(Z)-jasmone
geranyl propionate
geranyl butyrate
β-cadinene†
β-gurjunene
α-cadinene
cadalene
palustrol
an aristolenol*
manoyl oxide
methyl abeta-8,11,13-trien-10-oate
abieta-8,11,13-triene-11,12,20-triol*
linoleic acid
octadecanoic acid

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

F. Zani, G. Massimo, S. Venvenuti, A. Biandri, A. Albasini, M. Melegari, G. Vampa, A. Bellotti and P. Mazza, *Studies on the genotoxic properties of essential oils with Bacillis subtilis rec-assay and Salmonella/microsome reversion assay*. Planta Med., 57, 237-241 (1991).

I. Mathé, G. Nagy, A. Dobos, V. V. Miklossy and G. Janicsak, *Comparative studies of the essential oils of some species of sect. Salvia. In: Proceedings of 27th International Symposium on Essential Oils, Vienna 1996*. Edits., Ch. Franz, A Mathé and G. Buchbauer, pp. 244-247, Allured Publ., Carol Stream, IL (1997)

L. Foray, C. Bertrand, F. Pinguet, M. Soulier, C. Astre, C. Marion, Y. Pélissier and J-M. Bessiére, *In vitro cytotoxic activity of three essential oils from Salvia species*. J. Essent. Oil Res., 11, 522-526 (1999).

M. D. Guillén and M. J. Manzanos, *Extractable components of the aerial parts of Salvia lavandulaefolia and composition of the liquid smoke flavoring obtained from them*. J. Agric. Food Chem., 47, 3016-3027 (1999).

Eucalyptus globulus Oil

The 1,8-cineole content of *Eucalyptus globulus* of Chinese origin was determined by Gao et al. (1986) to be 73.21%.

Five years later, Hedges and Wilkins (1991) used the hyphenated technique of GC-FTIR-MS as the method of choice to examine a eucalyptus oil of Australian origin (obtained commercially) which whey referred to as *Eucalyptus australiana*. As this oil was of Australian origin, it was either *E. globulus* or more probably *E. polybractea* not this unknown species. Although the authors did not present quantitative data (even unstandardized area percent), they did indicate that the oil contained 1,8-cineole (70%). The components identified by Hedges and Wilkins are listed as follows:

α-pinene
1,8-cineole
limonene†
α-terpinene‡
2,3-dimethylcyclohexanol
cis-linalool oxide*‡
terpinolene
α-p-dimethylstyrene†
α-pinene oxide†
linalool
isoamyl isovalerate†
α-fenchyl alcohol†
α-campholenal†
3,3,6,6,tetramethyltricyclo [3.1.0.02.4]hexane†
trans-verbenol†
2,5-dimethylbenzaldehyde†††
borneol††††
terpinen-4-ol†
1-methylphenylethanone†
α-terpineol†††
α-hexyl-cinnamaldehyde††††
4-isopropenyl-1-methyl-cyclohexene††††
p-mentha-1(7)8(10)-dien-9-ol†
carvone
1-isopropyl-2-methylene cyclohexanone†
geraniol
isobornyl acetate
α-terpinyl acetate‡
β-patchoulene ‡
geranyl propionate
β-gurjunene‡
aromadendrene‡
allo-aromadendrene‡

† MS matches and IR indicates isomer
‡ MS matches and IR does not
††† MS indicates isomer and IR matches
†††† MS does not match and IR does

This footnote to the data is most misleading for the readers of the original paper.

The authors concluded their report by stating that "GC-FTIR-MS has proven to be a valuable technique for the analysis of Eucalyptus oil". They went on to say that "half of the resolved peaks can be identified using general-purpose spectral libraries without the need for standards or sample preparation." Although this reviewer agrees that GC-FTIR-MS is an extremely useful technique, this presentation is not a very valuable contribution because of the large number of anomalies. Examination of the data presented and comparing it with retention index data and previously published analyses of 1,8-cineole-rich eucalyptus

oils, it would appear that the following constituents were misidentifications:

2,3-dimethylcyclohexanol
3,3,6,6-trimethyltricyclo [3.1.0.02.4]hexane
2,5-dimethylbenzaldehyde
1-methylphenyl ethanone
α-hexylcinnamaldehyde
4-isopropenyl-1-methylcyclo-hexene
p-mentha-1(7),8(10)-dien-9-ol
1-methylethyl-2-methylene-cyclohexanone
β-patchoulene

It is hoped that most of the essential oil analysts could perform better analysis than the one reported above by using a combination of GC (for retention indices) and GC/MS (for component identity confirmation).

In 1994, Dethier et al. screened the leaf oils of Burundian *Eucalyptus* species for their compositions using both GC and GC/MS. The components characterized in the oil of *E. globulus* were as follows:

α-pinene (8.8%)
β-pinene (0.5%)
myrcene (0.3%)
α-phellandrene (0.1%)
p-cymene (0.8%)
1,8-cineole (63.8%)
limonene (3.9%)
(E)-β-ocimene (0.1%)
γ-terpinene (0.1%)
terpinolene (0.1%)
linalool (0.2%)
borneol (0.2%)
terpinen-4-ol (0.8%)
α-terpineol (5.8%)
α-copaene (0.2%)
α-gurjunene (0.6%)
aromadendrene (3.6%)
allo-aromadendrene (0.8%)
α-selinene (0.2%)
γ-cadinene (0.1%)
caryophyllene oxide (0.3%)
globulol (1.3%)
γ-eudesmol (0.6%)
β-eudesmol (1.3%)
α-eudesmol (1.7%)

The following year, Chalchat et al. (1995) compared the composition of leaf oils of *E. globulus* obtained from plants harvested along the Adriatic and Mediterranean coasts. Furthermore, they also examined the composition of oils produced from branches with leaves, bare branches, buds and fruit of the same *E. globulus*. A summary of the results of these studies are shown in Table III.

An oil of *E. globulus* of Argentinean origin, which was found (Zygadlo et al. 1995) to possess some antioxidant activity, contained the following two major components:

α-pinene (10.4%)
1,8-cineole (80.0%)

Li and Madden (1995) analyzed the leaf oils of *E. globulus* obtained from trees harvested in Tasmania and Victoria and found that they contained the following components:

α-pinene (16.1-21.2%)
α-phellandrene (trace)
α-terpinene (trace)
limonene (4.2-4.7%)
1.8-cineole (44.6-52.4%)
(Z)-β-ocimene (trace-0.4%)
γ-terpinene (0.8-0.9%)
p-cymene (0.9-2.3%)
terpinolene (trace)
isoamyl isovalerate (trace)
trans-p-menth-2-en-1-ol (trace)
pinocarvone (1.5-1.9%)
β-caryophyllene (0.3-1.8%)
aromadendrene (1.9-2.1%)
terpinen-4-ol (0.4-1.2%)
allo-aromadendrene (0.5-0.6%)
trans-pinocarveol (1.4-2.7%)
α-terpinyl acetate (0.9-1.1%)
α-terpineol (2.5-3.2%)
piperitone (trace)
trans-piperitol (trace)
globulol (5.6-5.7%)
viridiflorol (0.7%)
spathulenol (0.6-0.7%)
γ-eudesmol (trace)
α-eudesmol (trace-0.5%)
β-eudesmol (0.3-0.4%)

Although linalool is a minor constituent of *E. globulus* oil, Casablanca and Graff (1996) determined that its enantiomeric distribution in the oil was:

(R)-(-)-linalool (100%) : (S)-(+)-linalool (0%)

In 1997, Silvestre et al. analyzed the leaf oils of *E. globulus* ssp. *globulus* that were produced from trees harvested in the maritime and inland regions of Portugal between May and November (1991-1992). The oils were found to contain 23 components that ranged as follows:

isovaleraldehyde (0-0.7%), (0.1%)a
α-pinene (1.5-26.7%), (14%)
β-pinene (0-3.4%), (0.4%)
myrcene (0-1.2%), (0.3%)
limonene (0-13.2%), (3.6%)
p-mentha-2,4(8)-diene (0-1.6%), (0.3%)
1,8-cineole (47.7-75.8%), (63.8%)
p-cymene (0-2.7%), (0.5%)
terpinolene (0-0.4%), (0.1%)
terpinen-4-ol (0.1-10.1%), (3.1%)
α-terpinyl acetate (0-4.7%), (0.6%)
aromadendrene (0-7.1%), (2.0%)
geranyl acetate (0-7.3%), (1.4%)
viridiflorene (0-5.5%), (0.9%)
neryl acetate (0-3.0%), (0.6%)
2-phenethyl isovalerate (0-2.5%), (0.2%)
α-bisabolol (0.1-3.8%), (0.6%)
globulol (0-9.8%), (3.0%)
guaiol (0-4.6%), (0.3%)
ledol (0-4.9%), (0.4%)
spathulenol (0-1.7%), (0.3%)
γ-eudesmol (0-3.7%), (0.5%)
β-eudesmol (0-5.5%), (0.8%)

a = mean value

The authors used principal component analysis and cluster analysis to divide the oils into four groups such as:

Group I: oils rich in monoterpene hydrocarbons
Group II: oils rich in 1,8-cineole and terpinen-4-ol
Group III: oils rich in α-terpinyl, geranyl and neryl acetates and β-bisabolol
Group IV: oils rich in tricyclic sesquiterpene alcohols

Also in 1997, Chalchat et al. (1997) examined the composition of a lab-distilled oil of *E. globulus* leaves produced from trees found in Rwanda using GC/MS. The composition of the oil was found to be as follows:

α-pinene (6.23%)
α-thujene (0.03%)
α-fenchene (0.01%)
camphene (0.04%)
β-pinene (0.19%)
sabinene (0.02%)
α-phellandrene (0.01%)
myrcene (0.09%)
α-terpinene (0.02%)
limonene (3.10%)
1,8-cineole (71.20%)
(E)-2-hexenal (0.13%)
(Z)-β-ocimene (0.02%)
γ-terpinene (3.20%)
p-cymene (8.23%)
terpinolene (0.06%)
(Z)-3-hexenol (0.18%)
α-p-dimethylstyrene (0.05%)
α-cubebene (0.03%)
α-gurjunene (0.02%)
pinocarvone (0.04%)
linalool (trace)
β-gurjunene (0.06%)
β-caryophyllene (0.03%)
terpinen-4-ol (1.46%)
allo-aromadendrene (0.10%)
trans-pinocarveol (0.20%)
α-terpineol (0.11%)
α-terpinyl acetate (3.10%)
trans-p-mentha-1(7),8-dien-2-ol (0.05%)
trans-carveol (0.03%)
p-cymen-8-ol (0.07%)
cis-p-mentha-1(7),8-dien-2-ol (0.03%)
epi-globulol (0.04%)

Table III. Percentage composition of various oils of *Eucalyptus globulus*

Compound	Leaf Oil A	Leaf Oil B	Leaf/Branch Oil B	Fruit Oil B	Bud Oil A	Bare Branch Oil A
isovaleraldehyde	-	-	0.10	-	-	-
α-pinene	2.54-17.85	3.16	0.05	3.61	-	7.78
α-thujene	0-1.10	0.17	0.05	-	11.95	trace
β-pinene	0.11-0.35	0.08	0.05	0.10	0.30	0.38
sabinene	0.03-0.20	0.12	0.06	-	0.54	trace
α-phellandrene	0.09-1.52	-	trace	2.11	0.01	0.12
myrcene	0.21-0.23	-	0.06	0.21	0.07	0.15
α-terpinene	0.03-1.15	0.07	trace	0.22	-	trace
limonene	2.03-4.23	0.70	0.20	1.10	3.10	1.81
1,8-cineole	20.02-50.30	36.60	4.10	15.31	36.95	56.96
β-phellandrene	0-1.00	trace	-	0.50	-	-
p-menthatriene*	trace-0.03	trace	-	-	-	-
(Z)-β-ocimene	trace-0.06	-	-	-	-	-
γ-terpinene	0.33-1.45	0.04	trace	0.18	trace	0.05
(E)-β-ocimene	0-trace	trace	trace	trace	-	-
p-cymene	0.65-27.22	trace	3.08	6.44	8.04	0.46
terpinolene	0.03-0.28	trace	trace	0.20	trace	0.01
isoamyl isovalerate	-	0.09	0.04	0.46	0.05	0.01
cis-linalool oxide†	-	-	trace	-	-	-
α-p-dimethylstyrene	0-0.75	0.03	trace	-	-	-
trans-linalool oxide†	-	-	trace	-	-	-
1-hexen-3-ol[a]	-	trace	0.10	-	-	-
α-cubebene	trace-0.19	trace	0.10	0.34	0.27	0.11
α-copaene	trace-0.06	0.05	trace	0.08	0.10	0.08
camphor	-	-	trace	-	-	-
α-gurjunene	0-1.14	0.04	0.10	trace	trace	trace
β-bourbonene	-	0.04	0.05	2.40	1.57	0.42
pinocarvone	-	1.12	-	-	0.10	0.05
carvenone	-	-	-	trace	-	-
sabina ketone	0-1.02	-	-	-	-	-
cis-p-menth-2-en-1-ol	0-0.42	1.12	1.20	-	-	-
linalool	trace-0.54	0.45	0.84	-	-	-
β–cubebene	-	-	-	trace	-	-
β-gurjunene	0-0.05	0.31	-	0.47	trace	0.42
β-elemene	-	-	trace	-	-	-
β-caryophyllene	0-0.08	0.08	trace	-	-	-
eremophilene	-	1.36	-	-	-	-
terpinen-4-ol	0-5.95	-	4.10	-	-	-
aromadendrene	0-7.23	9.95	1.50	23.33	16.57	8.24
bulnesene*	0-0.21	0.25	-	0.44	0.34	0.40
trans-p-menth-2-en-1-ol	0-1.38	-	0.70	-	-	-

Table III continues on page 30

globulol (0.11%)
viridiflorol (0.03%)
γ-eudesmol (0.01%)
thymol (trace)
α-eudesmol (0.05%)
β-eudesmol (0.11%)

Muselli et al. (1997) compared the major component composition of *E. globulus* oil produced by hydrodiffusion and hydrodistillation. The results of this study can be found in Table IV.

An oil of *E. globulus* that was screened for its antimalarial activity by Milhau et al. (1997) was found to contain the following components:

α-pinene (4.3%)
β-pinene (0.7%)
myrcene (0.5%)
α-phellandrene (0.9%)
p-cymene (4.7%)
1,8-cineole (78.9%)
(E)-β-ocimene (0.5%)
γ-terpinene (0.5%)
α-p-dimethylstyrene (0.5%)
linalool (0.6%)
α-fenchol (0.4%)
trans-pinocarveol (3.9%)
pinocarvone (0.4%)
borneol (0.5%)
p-cymen-8-ol (0.4%)
terpinen-4-ol (0.7%)
α-terpineol (1.8%)

Also in 1997, Zhao et al. analyzed two samples of the residue from the fractional distillation of *E. globulus* leaf oil produced in China. Fractional distillation of *E. globulus* is performed to boost the 1,8-cineole content to a level greater than 70% thereby making it acceptable commercially. The components identified in these residues were as follows:

α-pinene (trace-0.79%)
p-cymene (trace)
limonene (trace)
1,8-cineole (0.76-3.49%)
γ-terpinene (trace)
2-phenethanol (trace)
trans-pinocarveol (0.31-1.10%)
2,6-dimethyl-1,5,7-octatrien-3-ol (trace)
borneol + myrcenol (trace-1.15%)
terpinen-4-ol (0.52-2.09%)
α-terpineol (5.46-27.91%)
neral or geranial (trace)
α-phellandrene epoxide (trace-0.30%)
limonen-10-al (0.22-0.35%)
trans-carveol (0.51-1.00%)
2-methylene-5-isopropenyl-cyclohexanol (trace)
cis-sabinol (trace-2.45%)
geraniol (trace-2.85%)
carvacrol (trace)
bornyl acetate (trace)
tridecane (trace)
α-terpinyl acetate (6.46-16.42%)
geranyl acetate (0.78-1.01%)
6,10,11,11-tetramethyltricyclo [5.3.0.1(2,3)]undec-1(7)-ene† (trace)
α-copaene (1.78-1.93%)
tetradecane (trace)
6,10,11,11-tetramethyltricyclo [5.3.0.1(2,3)]undec-7-ene† (trace)
α-gurjunene (2.30-3.77%)
β-caryophyllene (0.65-0.85%)
γ-muurolene (1.26-1.96%)
aromadendrene (17.30-26.82%)
α-humulene (0.28-0.40%)
allo-aromadendrene (4.41-6.75%)
pentadecane (0.27-0.40%)
α-guaiene (0.96-1.48%)
ledene (1.83-3.08%)
2-isopropyl-5-methylenebicyclo[4.4.0]dec-1-ene* (0.23-0.34%)
β-cadinene (0.65-0.75%)
myrtenyl propionate (trace)
epi-globulol (1.44-1.95%)
di-epi-palustrol† (0.80-1.00%)
geranyl propionate (trace)
ledol (6.02-7.31%)
T-cadinol (trace)
β-eudesmol (1.02-1.08%)
heptadecane (trace)
octadecane (trace)
nonadecane (trace)

*correct isomer not identified
† doubtful component identity

Saeed and Sabir (1997) screened eucalyptus oil for their antimicrobial characteristics. As part of their study, the authors reported that a Pakistani *E. globulus* oil contained the following constituents:

cumene (trace)
α-pinene (0.3%)
camphene (0.4%)
β-pinene (0.4%)
γ-terpinene (1.2%)
p-cymene (0.6%)
1,8-cineole (23.6%)
borneol (0.2%)
α-terpineol (2.9%)
citronellol (13.6%)
cryptone (8.6%)
terpinolene (0.5%)
linalyl acetate (1.8%)
isopulegol (0.2%)
α-phellandrene (0.6%)
β-caryophyllene (16.7%)
β-cubebene (0.1%)
linalool oxide* (1.9%)
β-phellandrene (3.6%)

As the above compounds were supposedly listed in elution order from a polar column, and many were characterized only by TLC, this analysis should be ignored. It is only included in this review because it is published and therefore could be quoted.

An oil produced from *E. globulus* of Zambian origin was analyzed by Chisowa (1997) and determined to possess the following composition:

isovaleraldehyde (0.6%)
α-pinene (14.0%)
β-pinene (0.7%)
myrcene (0.7%)
α-terpinene (trace)
limonene (5.7%)
1,8-cineole (70.1%)
(Z)-β-ocimene (trace)
γ-terpinene (0.5%)
(E)-β-ocimene (trace)
p-cymene (0.8%)
terpinolene (trace)
hexenyl acetate* (trace)
(Z)-3-hexenol (trace)
pinocarvone (trace)
linalool (trace)
aromadendrene (0.6%)
terpinen-4-ol (0.4%)
trans-pinocarveol (0.3%)
neral (trace)
α-terpineol (1.9%)
geranial (0.1%)
geraniol (0.3%)
viridiflorol (0.5%)
γ-eudesmol (0.1%)
α-eudesmol (0.2%)
β-eudesmol (0.4%)

*correct isomer not identified

In 1999, Reichling et al. determined that a commercial sample of 1,8-cineole-rich eucalyptus oil contained the following components:

a-pinene (4.17%)
camphene (0.10%)
β-pinene (0.60%)
myrcene (0.43%)
α-phellandrene (0.35%)
p-cymene (1.57%)
1,8-cineole (87.82%)
γ-terpinene (1.08%)
terpinolene (0.19%)
terpinen-4-ol (0.42%)
α-terpineol (1.44%)
aromadendrene (0.29%)

Jimenez-Carmona and Luque de Castro (1999) compared the composition of a hydrodistilled oil with that of a subcritical water extract of *E. globulus* leaves collected from a wild population found in Concepción (Chile). The results of this comparison are shown in Table V. As can be seen, this analysis is not very useful because the authors supposedly identified only 24.46% of the oil and 66.21% of the extract and some of their identifications were indeed suspect as they were strictly computer assisted MS database comparisons. It was of interest, however, to note that the conditions used for the subcritical extraction were 50 bar, 150°C for 20 minutes with a flow rate of 2mL/min.

Another comparison between a lab-distilled oil and an

Table III. Percentage composition of various oils of *Eucalyptus globulus* (continued from page 28)

Compound	Leaf Oil A	Leaf Oil B	Leaf/Branch Oil B	Fruit Oil B	Bud Oil A	Bare Branch Oil A
allo-aromadendrene	0-1.56	0.35	2.37	3.32	1.88	1.32
β-guaiene*	-	-	trace	-	-	-
cryptone	0-7.33	2.37	17.80	0.13	0.11	-
trans-pinocarveol	0-1.08	6.90	-	trace	-	0.55
γ-gurjunene	-	-	-	0.20	trace	-
carvotanacetone	-	-	-	0.16	-	0.05
α-humulene	0-0.08	0.10	trace	trace	trace	-
β-vetivene	-	-	0.37	trace	-	trace
viridiflorene	0-0.17	-	-	0.66	0.36	0.03
β-spathulene	0-0.91	0.10	-	-	-	-
ledene	0-1.06	0.13	-	3.63	0.10	-
phellandral	0-4.85	0.52	9.38	-	-	-
α-terpineol	0-2.26	0.58	-	2.27	4.66	5.26
piperitone	-	-	-	trace	trace	-
α-guaiene	-	-	-	0.39	0.29	0.15
α-selinene	0-trace	-	-	0.30	0.29	0.11
β-selinene	0-0.19	-	-	-	-	-
germacrene D	-	-	-	trace	-	-
δ-selinene	-	-	trace	trace	-	-
γ-muurolene	-	-	-	trace	-	-
cis-piperitol	-	0.24	-	-	-	-
γ-selinene	-	-	-	trace	-	-
α-muurolene	-	-	0.32	-	-	-
γ-cadinene	0-0.21	-	-	trace	0.26	0.17
α-elemene[a]	-	-	trace	-	-	-
δ-cadinene	0-0.09	0.08	-	0.62	0.10	-
nerol	-	-	-	0.10	trace	0.12
cuminaldehyde	trace-3.35	1.03	5.12	-	-	-
α-cadinene	-	-	0.56	-	-	-
p-mentha-1,5-dien-7-ol	-	0.22	0.23	-	-	-
cyclongifolene[a]	0-0.04	-	-	-	-	-
cis-p-mentha-1(7), 5-dien-2-ol	0.18-0.20	0.67	trace	trace	0.10	0.09
trans-carveol	-	0.28	-	-	0.08	0.10
p-cymen-7-ol	-	0.43	-	trace	0.37	trace
trans-p-mentha-1(7), 5-dien-2-ol	trace-0.18	0.61	-	-	-	trace
p-cymen-8-ol	0-1.10	-	1.80	-	-	-
palustrol	-	0.16	-	0.16	0.07	0.09
p-mentha-1(7),8-dien-2-ol	-	-	0.17	-	-	-
ledol	-	-	-	trace	-	-

Table III continues on page 32

Table III. Percentage composition of various oils of *Eucalyptus globulus* (continued from page 30)

Compound	Leaf Oil A	Leaf Oil B	Leaf/Branch Oil B	Fruit Oil B	Bud Oil A	Bare Branch Oil A
caryophyllene oxide	-	0.21	0.52	-	-	-
p-mentha-1,5-dien-7-ol[a]	0-0.36	-	-	-	-	-
γ-eudesmol	0-0.16	0.51	trace	0.55	trace	0.17
2-phenethyl 2-methylbutyrate	-	-	-	trace	-	-
epi-globulol	0-0.77	1.49	0.38	3.10	0.12	0.11
methyl eugenol	0.15-0.31	0.39	0.51	-	-	-
globulol	0.29-3.40	8.02	2.04	14.98	3.05	0.75
viridiflorol	0-0.66	1.62	-	2.17	0.53	0.16
β-eudesmol	0-0.36	0.37	-	0.84	0.18	0.33
spathulenol	0.12-2.09	4.60	17.00	0.20	-	0.23
T-muurolol	-	-	0.24	0.12	-	-
T-cadinol	-	-	-	0.28	-	-
thymol	0-0.42	0.54	3.50	0.28	0.14	-
isospathulenol	0-trace	0.48	0.77	trace	-	-
α-cadinol	-	0.12	0.10	0.20	-	-
5-epi-neointermedeol	-	0.12	0.54	0.22	0.04	-

A = Adriatic Coast
B = Mediterranean Coast
* correct isomer not identified
† furanoid form
[a] incorrect identification based on elution order

extract was reported by Della Porta et al. (1999). In this analysis, the authors compared the composition of a hydrodistilled oil with that of a supercritical fluid CO2 extract. However, they used the process to fractionate the volatile constituents away from the waxes. The components identified in the wax fraction were as follows:

docosane (0.1%)
tetracosane (0.2%)
pentacosane (0.8%)
hexacosane (0.7%)
heptacosane (5.6%)
octacosane (2.0%)
nonacosane (28.5%)
triacontane (1.2%)
henitriacontane (2.3%)
dotriacontane (24.8%)
pentatriacontane (11.8%)
hexatriacontane (21.9%)

It was surprising to this reviewer that no waxes between C_{20} and C_{29} were found. Table VI shows the comparative results of the analyses of the volatile portion of the extract and the oil.

More recently, Betts (2000) examined the headspace of single fresh leaves of *E. globulus* using solid phase microextraction. He found that the headspace volatiles were:

α-pinene (16.84-24.27%)
β-pinene (0.58-0.90%)
myrcene (0-0.34%)
α-phellandrene (0.15-1.01%)
p-cymene (0.36-0.75%)
1,8-cineole (59.98-61.32%)
limonene (6.75-9.10%)
γ-terpinene (0.26-0.72%)
α-terpinyl acetate (2.10-5.36%)
β-caryophyllene (0.05-0.75%)
aromadendrene (2.58-4.97%)
α-humulene (0-0.30%)
germacrene D (0.69-1.09%)

This same year, Dagne et al. (2000) examined the composition of a number of oils of *Eucalyptus* species growing in Ethiopia. Among these oils the authors analyzed *E. globulus* oil and found that the major components in the oil were as follows:

α-thujene (0.6%)
α-pinene (15.2%)
β-pinene (1.6%)
myrcene (1.6%)
α-phellandrene (0.7%)
limonene (7.8%)
β-phellandrene (0.8%)
1,8-cineole (57.5%)
γ-terpinene (0.4%)
terpinen-4-ol (0.7%)
α-terpineol (2.0%)
α-terpinyl acetate (5.3%)

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

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M. Dethier, A. Nduwimanna, Y. Cordier, C. Menut and G. Lamaty, *Aromatic plants of tropical Africa. XVI. Studies on essential oils of five Eucalyptus species grown in Burundi*. J. Essent. Oil Res., 6, 469-473 (1994).

J-C. Chalchat, J. L. Cabard, M. S. Gorunovic, V. Djermanovic and V. Bulatovic, *Chemical composition of Eucalyptus globulus oils from the Montenegro coast and East coast of Spain*. J. Essent. Oil Res., 7, 147-152 (1995).

Table IV. Comparative percentage composition of a hydrodistilled oil of *Eucalyptus globulus* with a hydrodiffused oil

Compound	Hydrodistilled Oil	Hydrodiffused Oil
α-pinene	17.1	8.5
β-pinene	0.7	0.6
myrcene	0.8	0.9
limonene	5.9	7.3
1,8-cineole	65.8	64.4
γ-terpinene	0.5	0.6
p-cymene	0.4	0.5
aromadendrene	1.2	2.4
allo-aromadendrene	0.3	0.6
α-terpineol	1.3	1.5
α-terpinyl acetate	1.6	3.0
geraniol	0.4	0.6
epi-globulol	0.3	0.6
globulol	1.1	2.9

Table V. Comparison between the composition (%) of a distilled oil and a subcritical water extract of *Eucalyptus globulus* leaves

Compound	Oil	Extract
α-pinene	2.32	9.78
β-pinene	0.11	0.64
myrcene	0.16	0.94
1,8-cineole	18.57	46.92
terpinen-4-ol	0.23	0.77
linalyl propionate	1.11	4.72
nerol or geraniol	0.40	0.82
2-hydroxy-1,8-cineole acetate	0.27	0.44
tricyclo(7.3.0^{6-8}.0^{1-9})-2,7,7^{1}-10-tetramethyl-9-dodecene†	0.46	0.93
bicyclo(4.4.0)2-(2-hydroxy-propyl)-6-methyl-1-decene†	0.83	0.25

† probably misidentification

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Parsley Leaf Oil

In 1997, Pino et al. analyzed a parsley leaf oil that was produced from plants grown in Cuba. Using GC/MS as the method of analysis the oil was determined to contain the following constituents:

α-pinene (0.03%)
β-pinene (0.01%)
myrcene (0.84%)
α-phellandrene (0.09%)
p-cymene (0.03%)
β-phellandrene (1.60%)
limonene (0.06%)
γ-terpinene (0.03%)
α-p-dimethylstyrene (0.28%)
terpinolene (0.72%)
benzyl alcohol (0.02%)
p-mentha-1,3,8-triene (3.90%)
p-mentha-1,4,8-triene (0.05%)
citronellal (0.03%)
p-menthatriene* (0.03%)

Table VI. Percentage composition of the oil and supercritical fluid CO_2 extract of *Eucalyptus globulus* leaves

Compound	Oil	Extract
α-pinene	6.9	10.5
camphene	0.2	0.3
p-mentha-1,3-diene	0.2	0.1
β-pinene	0.1	0.3
α-phellandrene	trace	trace
o-cymene	0.2	0.2
p-cymene	0.1	trace
limonene	trace	trace
1,8-cineole	48.2	62.6
(Z)-β-ocimene	trace	trace
(E)-β-ocimene	trace	0.1
γ-terpinene	0.1	trace
fenchone	trace	trace
α-p-dimethylstyrene	0.5	0.7
isoamyl isovalerate	0.2	0.4
α-thujone	0.1	trace
α-campholenal	0.1	0.1
p-mentha-1,3,8-triene	3.8	1.6
camphor	1.7	1.4
borneol	0.1	trace
umbellulone	0.6	0.2
terpinen-4-ol	0.1	0.3
α-terpineol	0.3	0.1
myrtenol	-	trace
methyl chavicol	0.1	trace
trans-carveol	0.1	trace
cis-carveol	0.4	0.2
(Z)-tagetenone	0.1	trace
neral	-	trace
carvone	0.1	0.1
p-anisaldehyde	trace	trace
(E)-anethole	trace	trace
isobornyl acetate	0.3	0.2
α-cubebene	0.1	trace
α-ylangene	0.1	trace
β-cubebene	0.1	0.1
cyperene	0.3	0.3
longifolene	0.2	0.2
α-gurjunene	0.3	0.2
β-caryophyllene	0.1	0.1
thujopsene	0.3	trace
β-gurjunene	0.8	0.2
trans-α-bergamotene	1.1	0.4
aromadendrene	13.7	8.0
α-cadinene†	0.1	trace
allo-aromadendrene	2.9	1.8
γ-gurjunene	0.2	0.1
β-selinene	0.3	0.2
valencene	1.0	0.7
spathulenol	2.0	1.3
globulol	0.6	0.4
viridiflorol	0.7	0.4
guaiol	7.6	4.2
α-eudesmol	1.2	0.8
α-cadinol	0.6	0.5

† incorrect identification based on elution order

p-cymen-8-ol (0.09%)
thymol (0.02%)
β-elemene (0.61%)
β-caryophyllene (0.24%)
γ-elemene (0.21%)
trans-β-begamotene (0.02%)
α-humulene (0.03%)
(Z)-β-farnesene (0.11%)
α-amorphene (0.02%)
germacrene D (1.09%)
myristicin (63.90%)
β-sesquiphellandrene (1.04%)
elemicin (1.70%)
isoelemicin* (0.02%)
elemol (0.02%)
nerolidol* (0.03%)
carotol (1.42%)
guaiol (0.28%)
apiole (14.40%)

* correct isomer not identified

This same year, Valterova et al. (1997) analyzed the headspace volatiles of seedlings of *P. crispum*. The compounds identified in this study were:

α-pinene (2.6%)
camphene (0.2%)
β-pinene (1.7%)
sabinene (0.5%)
δ-3-carene (0.5%)
myrcene (24.4%)
α-phellandrene (0.5%)
α-terpinene (0.3%)
limonene (1.8%)
β-phellandrene (58.3%)
γ-terpinene (0.4%)
(E)-β-ocimene (3.8%)
p-cymene (0.8%)
terpinolene (0.7%)
allo-ocimene* (3.6%)

* correct isomer not identified

The authors also determined the enantiomeric distribution of some of the above listed monoterpene hydrocarbons. Using chiral GC analysis they found the following distributions:

(-)-α-pinene (47%) : (+)-α-pinene (53%)

(-)-β-pinene (51%) : (+)-β-pinene (49%)

(-)-sabinene (55%) : (+)-sabinene (45%)

(-)-limonene (59%) : (+)-limonene (41%)

(-)-β-phellandrene (1%) : (+)-β-phellandrene (99%)

The following year, Masanetz and Grosch (1998) determined the concentration of the seventeen most important odorants in two cultivars of parsley. Also, using a combination of their and other published threshold results, the authors calculated the odor-activity values of these same constituents in a volatile concentrate isolated from a methylene chloride extract of the minced fresh leaves of each cultivar ("Hamburger Schnitt" and "Mooskrause"). A summary of the results of this study can be seen in Table VII. It should be noted that the higher the odor-activity value the more important it is to the aroma of fresh parsley leaves. Furthermore, the authors combined all of the constituents at their actual level of occurrence and found that removal of p-mentha-1,3,8-triene and myrcene caused the mixture to totally lose its parsley leaf character. In a follow-up paper, the same authors (Masanetz and Grosch

Table VII. Comparative concentration and odor-activity values of the seventeen most important components of fresh parsley leaf

	Concentration[a]		Odor-Activity Value	
Compound	**HS**	**MK**	**HS**	**MK**
p-mentha-1,3,8-triene	393,285	56,350	26,219	3,757
myrcene	17,980	24,070	1,284	1,719
2-isopropyl-3-methoxypyrazine	1.4	1.8	350	450
2-sed-butyl-3-methoxypyrazine	7.7	10.0	2,567	3,333
myristicin	57,800	178,200	1,927	5,940
1-octen-3-one	3.0	8.5	6.0	170
1,5-(Z)-octadien-3-one	1.0	0.9	833	750
linalool	694	282	116	47
(2E,4E)-decadienal	1,058	853	5,290	4,265
(Z)-6-decenal	5,898	2,962	17,347	8,712
methanethiol	260	175	1,300	875
(Z)-3-hexenal	200	248	800	992
p-methylacetophenone	624	116	26	5
(Z)-3-hexenyl acetate	164	58	21	7
(Z)-3-hexenol	433	375	11	10
β-phellandrene	204,190	184,635	5,672	5,129
α-p-dimethylstyrene	15,805	7,185	187	85

[a] mg/kg fresh weight HS = cultivar "Hamburger Schnitt" MK = cultivar "Mooskrause)

1998) compared the concentration and odor-activity values of the twenty-seven most important odor constituents of the dried Moosekrause cultivar of *P. crispum*. These results are shown in Table VIII. As with the other study of Masanetz and Grosch, the higher the odor-activity value the more important the contribution to the overall odor of this dried parsley cultivar.

This same year, a sample of Egyptian parsley herb oil was subjected to analysis by GC and GC/MS (El-Nikeety et al. 1998). This oil was found to contain:

α-pinene (6.94%)	5-undec-5-yne† (0.06%)
camphene (0.06%)	p-cymene (0.82%)
β-pinene (4.57%)	α-p-dimethylstyrene (5.35%)
sabinene (0.63%)	β-caryophyllene (0.05%)
α-phellandrene (1.46%)	α-humulene (0.53%)
limonene (5.36%)	β-bisabolene (0.21%)
β-phellandrene (19.47%)	α-terpineol (0.13%)
γ-terpinene (0.17%)	elemicin (0.15%)
terpinolene (2.78%)	myristicin (8.79%)
p-mentha-1,3,8-triene (6.20%)	apiole (0.20%)
myrcene (23.75%)	4-methylpyridinamine† (0.40%)

† identification doubtful, requires corroboration

In 1999, Hashem and Sahab also examined the composition of *P. crispum* oil produced in Egypt. The found that the oil contained the following constituents:

α-pinene (6.94%)	p-mentha-1,3,8-triene (17.10%)
camphene (0.11%)	(Z,Z)-α-farnesene (1.94%)
β-pinene (4.57%)	myristicin (39.70%)
myrcene (23.80%)	globulol (1.11%)
α-phellandrene (1.26%)	dillapiole (4.03%)
p-cymene (0.86%)	epi-α-bisabolol (0.71%)

Also in 1999, Lopez et al. examined the headspace of parsley plants, callus tissue cultures and cell suspensions using GC/MS. They found that callus tissue cultures produced nonanal, decanal, limonene, acetophenone and benzothiazole (the latter three compounds were not detected in the plant), whereas cell suspensions produced nonanal and decanal. However, production of volatiles from the plants, callus tissue cultures and cell suspensions was time dependent. A summary of the volatile components identified in the headspace (in ppm) can be seen in Table IX.

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Table VIII. Concentration and odor activity of the twenty-seven most important components of dried parsley leaves

Compound	Concentration[a]	Odor-activity Value[b]
3-methylbutanal	0.6-1.3	1,500-3,250
2-methylbutanal	2.0-3.1	1,053-1,632
methylpropanal	2.5	3,571
dimethyl sulphide	0.9-22.5	3,000-75,000
myrcene	63-135	4,500-9,643
myristicin	1,900-2,770	63,333-92,333
p-mentha-1,3,8-triene	266-1,026	17,733-68,400
1-octen-3-one	0.010-0.016	200-320
1,5-(Z)-octadien-3-one	<0.001-0.0012	<800-1,000
2,3-butanedione	0.50-0.90	33-60
(Z)-3-hexenal	0.092-0.139	368-556
β-phellandrene	86-200	2,389-5,556
(Z)-4-heptenal	0.006-0.032	30-160
α-p-dimethylstyrene	30-90	353-1,094
2-sec-butyl-3-methoxypyrazine	0.025-0.085	8,333-28,333
propanal	6.1-19.0	610-1,900
methional	0.020-0.065	100-325
(Z)-6-decenal	0.16-2.75	471-8,088
acetaldehyde	1.4-8.0	140-800
dimethyl trisulphide	<0.001	<100
(E)-2-nonenal	0.018-0.025	72-100
p-methylaceto-phenone	8.2-50.6	342-2,108
methanethiol	0.002-0.067	10-335
3-methyl-2,4-nonanedione	0.029-0.096	967-3,200
linalool	0.22-0.42	37-70
(2E,4E)-decadienal	0.032-0.27	160-1,350
coumarin	0.011-0.036	<1-1

[a] = mg/kg dry material
[b] = concentration/threshold

Table IX. Headspace volatile components (in ppm) of parsley plants during their vegetative growth

Compound	5 weeks	9 weeks	13 weeks
α-pinene	0.9	27.6	17.8
β-pinene	2.4	18.4	4.8
myrcene	18.9	8.4	18.3
α-phellandrene	6.5	4.6	10.2
β-phellandrene	83.6	45.1	-
δ-2-carene	-	14.4	-
linalool	0.7	-	2.1
nonanal	0.7	0.3	-
p-mentha-1,3,8-triene	0.6	119.5	371.7
thymol	-	<0.1	<0.1
decanal	0.6	0.8	1.2
α-copaene	<0.1	0.3	3.1
β-caryophyllene	-	1.0	15.9
myristicin	17.2	-	-
elemol	1.5	-	-
carotol	0.5	-	-
apiole	19.7	8.7	52.5

M. M. A. El-Nikeety, A. T. M. El-Alek, M. M. I. A. El-Hady and A. Z. M. Badei, *Changes in physical properties and chemical constituents of parsley herb volatile oil during storage*. Egypt. J. Food Sci., 26-28, 35-49 (1998-2000).

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M. G. Lopez, I. R. Sanchez-Mendoza and N. Ochoa-Alejo, *Comparative study of volatile components and fatty acids of plants and in vitro cultures of parsley (Petroselinum crispum (Mill.) Nym. ex Hill*. J. Agric. Food Chem., 47, 3292-3296 (1999).