



Progress in Essential Oils

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Lavender Oil

Lavender oil is produced commercially in Australia, Bulgaria, China, England, France, Moldova, Ukraine and the former Yugoslavia. At one time, France was the major producer but more recently Bulgaria and France produce 50 and 60 tonnes, respectively.

Segur-Fantino et al. (1988) reported that the major constituents of lavender oil produced within the Appellation d'Origine Control e in the commune of Barret de Lioure (DrTMme) varied as follows:

1,8-cineole (t-3.39 percent)
(Z)- β -ocimene (0.30-18.05 percent)
(E)- β -ocimene (0.20-10.24 percent)
3-octanone (t-6.03 percent)
camphor (t-0.50 percent)
linalool (10.51-71.88 percent)
linalyl acetate (2.35-59.60 percent)
terpinen-4-ol (t-12.83 percent)
lavandulol (t-4.10 percent)
lavandulyl acetate (0.24-11.99 percent)
 α -terpineol (t-0.90 percent)
t = trace (< 0.1 percent)

The authors also reported that the standard for oils produced in this area was:

1,8-cineole (0.2-0.8 percent)
(Z)- β -ocimene (5.0-9.0 percent)
(E)- β -ocimene (2.5-4.5 percent)
3-octanone (0.8-2.0 percent)
camphor (< 0.5 percent)
linalool (26.0-36.0 percent)
linalyl acetate (30.0-46.0 percent)
terpinen-4-ol (3.0-5.0 percent)
lavandulol (0.5-1.0 percent)
lavandulyl acetate (> 3.5 percent)
 α -terpineol (< 0.5 percent)

In 1996, Canaud and Martineau determined that a sample of French lavender oil contained the following constituents:

α -pinene (0.25 percent)
camphene (0.09 percent)
 β -pinene (0.08 percent)
sabinene (0.04 percent)
myrcene (0.35 percent)
limonene (0.16 percent)

1,8-cineole (0.40 percent)
(Z)- β -ocimene (7.20 percent)
(E)- β -ocimene (3.30 percent)
3-octanone (0.90 percent)
p-cymene (0.09 percent)
camphor (0.18 percent)
linalool (25.20 percent)
linalyl acetate (35.90 percent)
lavandulyl acetate (4.00 percent)
terpinen-4-ol (3.50 percent)
 β -caryophyllene (5.00 percent)
lavandulol (0.70 percent)
 α -terpineol (0.18 percent)
borneol (0.60 percent)
neryl acetate (0.60 percent)
geranyl acetate (0.16 percent)
nerol (0.18 percent)
geraniol (0.16 percent)

Lavender oil produced experimentally in Poland was found by Gora et al. (1997) to contain the following major components: linalool (29.9 percent), linalyl acetate (21.7 percent), α -terpineol (6.3 percent).

Mizrahi et al. (1999) compared the composition of French and Argentinean lavender oil. They found that the Argentinean oil was richer in linalyl acetate than the imported French oil, as can be seen in Table I.

A sample of lavender oil produced from plants gathered in Greece was analyzed by GC/MS by Daferera et al. (2000). The main constituents identified in this non-commercial oil were:

α -pinene (trace)
1,8-cineole (4.8 percent)
linalool (44.5 percent)
linalyl acetate (32.7 percent)
terpinen-4-ol (6.9 percent)
borneol (3.9 percent)

Comparative component composition of French lavender oil and Argentinean lavender oil

T-1

Compound	French Oil	Argentinean Oil	Compound	French Oil	Argentinean Oil
1,8-cineole	0.2	0.8	terpinen-4-ol	1.7	0.1
linalool	33.2	34.1	lavandulol	0.6	0.1
camphor	0.3	0.5	α -terpineol	0.6	0.2
linalyl acetate	34.4	46.8	borneol	0.9	1.7
lavandulyl acetate	2.0	0.4			

French oil = commercial oil; Argentinean oil produced in LaCubre (Córdoba)

Comparative percentage composition of two samples of Indian lavender oil

T-2

Compound	Kashmir Oil	Kodaikanal Oil	Compound	Kashmir Oil	Kodaikanal Oil
α -thujene	t	-	hexyl butyrate	0.1	-
α -pinene	0.1	-	nerol	0.3	1.2
camphene	0.3	0.2	piperitone	t	-
sabinene + 1-octen-3-ol	1.3	1.6	geraniol	-	1.7
myrcene	0.3	0.1	linalyl acetate	50.6	43.1
α -phellandrene	0.2	0.1	bornyl acetate	0.2	0.2
δ -3-carene	0.1	0.1	lavandulyl acetate	1.6	0.9
α -terpinene	t	-	α -terpinyl acetate	0.1	0.1
p-cymene	0.2	0.2	neryl acetate	0.5	1.3
limonene + 1,8-cineole	1.2	1.9	geranyl acetate	1.0	2.0
(Z)- β -ocimene	-	0.9	β -caryophyllene	1.0	1.8
(E)- β -ocimene	-	1.3	<i>trans</i> - α -bergamotene	1.0	0.1
<i>cis</i> -linalool oxide ⁺	0.5	0.2	(E)- β -farnesene	0.1	-
<i>trans</i> -linalool oxide ⁺	0.4	0.1	α -humulene	0.2	0.4
linalool	28.2	28.7	(Z)- β -farnesene	t	-
1-octen-3-yl acetate	0.9	1.4	germacrene D	0.1	0.2
p-menth-2-en-1-ol [*]	0.1	0.2	γ -muurolene	0.4	-
camphor	0.2	0.2	γ -cadinene	0.3	0.2
borneol	0.6	0.3	α -calacorene	0.1	0.2
<i>cis</i> -linalool oxide ⁺⁺	0.2	0.1	ledol	0.2	-
lavandulol	0.4	0.5	caryophyllene oxide	2.2	0.5
terpinen-4-ol	0.7	0.5	T-cadinol	-	0.1
(Z)-3-hexenyl butyrate	0.3	-	α -muurolol	0.3	0.7
α -terpineol	2.0	4.9			

t = trace (< 0.1 percent); ⁺ = furanoid form; ⁺⁺ = pyranoid form

α -terpineol (3.5 percent)
 β -caryophyllene (0.3 percent)

Mallavarapu et al. (2000) analyzed two samples of Indian lavender oil produced from plants grown in the western Himalayas (Kashmir) and in the southern hills (Kodaikanal). The analytical results obtained can be seen in Table II.

An oil of lavender produced in Serbia and Montenegro was the subject of analysis by Kulevanova et al. (2000). The components identified in this oil were:

3-octanone (0.6 percent)
 myrcene (1.5 percent)
 β -phellandrene (0.1 percent)
 1,8-cineole (0.5 percent)
 (Z)- β -ocimene (5.6 percent)
 (E)- β -ocimene (3.4 percent)
cis-linalool oxide-furanoid (0.3 percent)
 linalool (25.7 percent)
 1-octenyl acetate (2.7 percent)
 1-octen-3-yl acetate (0.4 percent)
 camphor (0.7 percent)
 borneol (0.6 percent)

Compound	Oil	Aqueous Dilution	Compound	Oil	Aqueous Dilution
camphene	0.41	-	β -caryophyllene	2.23	2.41
(Z)- β -ocimene	0.37	-	terpinen-4-ol	1.14	0.93
myrcene	0.84	5.98	cryptone	1.65	2.35
limonene	1.12	1.32	(E)- β -farnesene	0.94	0.67
1,8-cineole	2.52	3.22	lavandulol	1.37	1.19
γ -terpinene	3.19	2.70	α -terpineol	2.12	2.65
3-octanone	0.96	4.19	borneol	1.75	1.02
p-cymene	0.37	-	neryl acetate	0.77	2.77
camphor	0.44	0.55	geranyl acetate	1.85	6.04
linalool	36.86	39.10	nerol	0.45	0.76
linalyl acetate	33.00	13.68	geraniol	1.36	1.99
α -santalene	0.39	0.95	caryophyllene oxide	0.65	0.57
bornyl acetate	0.41	0.56	coumarin	0.44	-

lavandulol (2.7 percent)
 terpinen-4-ol (5.8 percent)
 α -terpineol (4.8 percent)
 linalyl acetate (23.2 percent)
 lavandulyl acetate (12.5 percent)
 neryl acetate (2.2 percent)
 β -caryophyllene (1.0 percent)
 caryophyllene oxide (0.7 percent)

t = trace (< 0.1 percent)

Because of the increasing popularity of lavender water in shampoos, lotions or nebulization sprays or spritz for personal care or as a room odorant, Plotto et al. (2001) decided to examine the composition of commercially available lavender water. Initially, the authors compared the composition of a natural lavender oil with some lab-prepared lavender water using 100 ppm of the oil diluted in water. These comparisons, which were determined by direct GC and GC/MS or by immersing SPME fibre in the water followed by GC/MS, for the oil can be found in Table III.

A sample of lavender water analyzed under the same conditions by using immersed SPME was found to contain the following constituents:

β -pinene (0.04 percent)
 sabinene (0.05 percent)
 myrcene (0.16 percent)
 limonene (0.12 percent)
 1,8-cineole (6.38 percent)
 γ -terpinene (0.07 percent)
 terpinolene (0.04 percent)
 hexanol (0.12 percent)
 3-octanol (0.21 percent)
 cis-linalool oxide⁺ (0.42 percent)

trans-linalool oxide⁺ (0.45 percent)
 camphor (2.12 percent)
 linalool (47.90 percent)
 linalyl acetate (0.07 percent)
 α -selinene (0.40 percent)
 bornyl acetate (0.48 percent)
 β -caryophyllene (0.04 percent)
 terpinen-4-ol (1.92 percent)
 (E)- β -farnesene (4.58 percent)
 lavandulol (3.01 percent)
 α -terpineol (5.98 percent)
 borneol (2.79 percent)
 neryl acetate (1.06 percent)
 geranyl acetate (0.04 percent)
 nerol (1.79 percent)
 geraniol (5.97 percent)
 caryophyllene oxide (0.20 percent)
 coumarin (2.22 percent)

⁺furanoid form

Furthermore, the authors examined the organic phase of four commercial samples of lavender water using SPME fibre immersed for 5 min. A summary of the results of this examination can be found in Table IV.

Using solid phase microextraction (SPME) and GC/MS, An et al. (2001) compared the headspace composition of a living lavender flower fragrance with the vapor above a Tasmanian oil of lavender. This study can be seen summarized in Table V. In addition, the authors examined the composition of a solvent extract (no solvent given) of lavender flowers and found it to comprise:

α -thujene (0.3 percent)
 α -pinene (0.3 percent)
 3-octanone (1.1 percent)
 myrcene (0.1 percent)
 sylvestrene⁺⁺ (1.4 percent)
 (Z)- β -ocimene (3.6 percent)
 (E)- β -ocimene (3.0 percent)

Compound	1	2	3	4
camphene	0.09	-	0.07	-
β -pinene	0.25	0.15	-	0.04
sabinene	-	-	0.06	0.05
myrcene	0.07	0.09	-	0.16
limonene	1.28	1.48	1.68	0.12
1,8-cineole	3.95	3.31	1.09	6.38
γ -terpinene	-	-	-	0.07
3-octanone	-	0.81	0.68	-
p-cymene	-	0.13	0.29	-
terpinolene	-	-	0.17	0.04
hexanol	0.07	0.10	-	0.12
3-octanol	0.31	0.32	0.14	0.21
<i>cis</i> -linalool oxide ⁺	0.76	0.54	0.46	0.42
<i>trans</i> -linalool oxide ⁺	0.61	0.59	0.38	0.45
camphor	1.15	2.15	1.00	2.12
linalool	58.86	49.10	57.64	47.90
linalyl acetate	0.11	0.11	0.19	0.07
α -santalene	0.06	-	0.14	0.40
bornyl acetate	0.20	0.25	0.64	0.48
β -caryophyllene	0.07	0.21	-	0.04
terpinen-4-ol	6.68	11.78	4.66	1.92
(E)- β -farnesene	1.92	2.41	0.35	4.58
lavandulol	2.87	3.45	1.10	3.01
α -terpineol	6.06	4.26	7.36	5.98
borneol	2.20	4.32	1.03	2.79
neryl acetate	0.20	-	-	1.06
geranyl acetate	0.08	0.10	-	0.04
nerol	1.44	1.05	1.28	1.79
geraniol	4.55	3.51	3.21	5.97
caryophyllene oxide	-	0.09	0.24	0.08

⁺ = furanoid form; sample origins: 1. California, 2. unknown, 3. Bulgaria and 4. Washington

γ -terpinene (0.3 percent)
trans-sabinene hydrate (0.4 percent)
cis-linalool oxide⁺ (0.2 percent)
 terpinolene (0.3 percent)
 linalool (41.3 percent)
 allo-ocimene⁺ (0.4 percent)
 camphor (0.1 percent)
 lavandulol (0.1 percent)
 terpinen-4-ol (10.6 percent)
 hexyl butyrate (1.1 percent)
 linalyl acetate (20.4 percent)
 lavandulyl acetate (4.3 percent)
 hexyl tiglate (0.2 percent)
 α -terpinyl acetate (0.1 percent)
 neryl acetate (0.1 percent)
 geranyl acetate (0.3 percent)
 7-epi-sesquithujene (0.1 percent)
 β -caryophyllene (6.0 percent)
 α -himachalene (0.1 percent)
 α -humulene (0.1 percent)
 (E)- β -farnesene (2.5 percent)
 germacrene D (0.8 percent)
 caryophyllene oxide (0.1 percent)

^{*} correct isomer not identified; ⁺ furanoid form; ⁺⁺ component identity in question

Trace amounts of dodecanol, isobornyl formate, α -copaene, α -cedrene, *cis*- α -bergamotene, β -selinene, bicyclogermacrene and δ -cadinene were also found in this same lavender extract.

Braun and Franz (2001) examined the enantiomeric ratios of linalool and linalyl acetate in 16 commercial samples of lavender oil. Four of the oils, which appeared to be authentic, possessed enantiomeric ratios as follows:

(3R)-(-)-linalool (95.2-97.1 percent): (3S)-(+)-linalool (2.9-4.8 percent)

(3R)-(-)-linalyl acetate (100 percent): (3S)-(+)-linalyl acetate (0 percent)

Four oils possessed pure (3R)-(-)-linalyl acetate (100 percent), while the enantiomeric ratio of (3R)-(-)-linalool to (3S)-(+)-linalool was (94.4-94.9 percent): (5.1-5.6 percent) which is a little lower than the

Compound	SPME Headspace Analysis		Compound	SPME Headspace Analysis	
	Living Flower	Tasmanian Oil		Living Flower	Tasmanian Oil
(E)-2-octene	0.2	0.7	dodecanol	0.1	-
α -thujene	0.1	0.9	isobornyl formate	-	0.1
α -pinene	0.1	3.2	linalyl acetate	16.1	20.3
3-octanone	0.4	12.1	lavandulyl acetate	0.9	1.2
myrcene	3.6	0.5	α -terpinyl acetate	-	0.1
p-cymene	0.2	3.4	neryl acetate	0.5	0.7
sylvestrene ⁺	0.9	2.6	α -copaene	-	t
(Z)- β -ocimene	5.4	1.0	geranyl acetate	1.3	1.5
(E)- β -ocimene	5.7	1.4	7-epi-sesquithujene	t	-
γ -terpinene	0.5	-	α -cedrene	-	0.1
<i>trans</i> -sabinene hydrate	0.2	-	<i>cis</i> - α -bergamotene	1.5	-
<i>cis</i> -linalool oxide (furanoid)-		2.8	β -caryophyllene	5.3	1.1
terpinolene	0.1	2.3	<i>trans</i> - α -bergamotene	0.2	-
linalool	41.2	39.6	α -himachalene	0.1	t
allo-ocimene [*]	0.5	0.1	α -humulene	t	-
camphor	-	0.9	(E)- β -farnesene	1.3	t
lavandulol	0.8	0.1	β -selinene	t	-
terpinen-4-ol	12.1	2.5	γ -cadinene	-	t
hexyl butyrate	0.5	0.6	caryophyllene oxide	0.1	0.2

^{*}correct isomer not identified; t = trace (< 0.01 percent); ⁺component identity in question

(3R)(-)-linalool. Two oils were adulterated with both synthetic linalool and linalyl acetate as their enantiomeric ratios were:

(3R)(-)-linalool (60.9-83.6 percent): (3S)(+)-linalool (16.4-39.1 percent)

(3R)(-)-linalyl acetate (64.2-64.6 percent): (3S)(+)-linalyl acetate (35.4-35.8 percent)

Three oils were adulterated with synthetic linalyl acetate as shown by their following enantiomeric ratios:

(3R)(-)-linalool (92.6-96.1 percent): (3S)(+)-linalool (3.9-7.4 percent)

(3R)(-)-linalyl acetate (89.2-94.2 percent): (3S)(+)-linalyl acetate (5.8-10.8 percent)

The two final oils possessed enantiomeric ratios of:

(3R)(-)-linalool (92.7-93.7 percent): (3S)(+)-linalool (6.3-7.3 percent)

(3R)(-)-linalyl acetate (100 percent): (3S)(+)-linalyl acetate (0 percent)

These two oils appear to be slightly adulterated with synthetic linalool.

Renaud et al. (2001) used Chiral GC analysis to show that two commercial samples of lavender oil were adulterated with synthetic linalool and linalyl acetate. These results along with their enantiomeric ratios of

the same two components in lavender cultivar oils can be seen in Table VI.

It would appear that during hydrodistillation of the lavender flower some linalyl acetate was hydrolyzed to yield racemic linalool hence the level of (3S)(+)-linalool in the cultivar oils. As a result, the enantiomeric ratio of it in these cultivar oils should be different and probably closer to 95.5 percent than reported by Renaud et al.

Using gas chromatography-pyrolysis-isotope mass spectrometry a number of commercial samples of lavender oil were examined by Bilke and Mosandl (2002) for authenticity. To ensure accuracy of the analyses, the authors used lab-prepared lavender oils, natural and synthetic samples of linalool and linalyl acetate to obtain in ²H/¹H isotope ratio standards prior to examination of the commercially available oils. As it was previously reported (Kreis et al.), if the level of (-)-(3R)-linalyl acetate and (-)-(3R)-linalool was less than 95 percent and 85 percent, respectively, then the lavender oil was not authentic. Examination of the enantiomeric ratio results for the same two components in eight commercially available lavender oils (see Table VII) reveals that samples 1-5 were obviously

Oil Type	linalool		linalyl acetate	
	R-(-)	S-(+)	R-(-)	S-(+)
commercial 1	68.1	31.9	66.4	33.6
commercial 2	70.2	29.8	66.5	33.5
'Alba'	84.8	15.2	100	0
'English'	86.6	13.3	100	0
'Grey Lady'	86.3	13.7	100	0
'Hidcote'	80.9	19.1	100	0
'Lady'	92.7	7.3	100	0
Munstead	86.6	13.4	100	0

Enantiomeric ratios of linalool and linalyl acetate in commercial samples of lavender oil

Sample No.	linalool		linalyl acetate	
	R-(-)	S-(+)	R-(-)	S-(+)
1	70.7	29.3	52.9	47.1
2	55.5	44.6	55.7	44.3
3	62.0	38.0	51.8	48.2
4	69.7	30.3	52.0	48.0
5	30.8	39.2	53.3	46.7
6	> 99.0	< 1.0	80.7	19.3
7	87.5	12.5	91.4	8.6
8	91.4	8.6	86.9	13.1

adulterated with synthetic linalool and linalyl acetate. Also, the enantiomeric ratios of samples 6-8 indicate that they contained some synthetic linalyl acetate, while the enantiomeric ratios of linalool, for samples 7 and 8 place them in the lower range for natural linalool. Thus it can be concluded that all of the commercial oils were found to be adulterated.

An oil produced from lavender flowers purchased from a market in Athens was subjected to analysis by Daferera et al. (2002) using both GC/MS and Fourier Transform Raman spectroscopy. The oil was found to contain the following constituents:

camphene (0.5 percent)
 3-octanone (0.1 percent)
 myrcene (1.6 percent)
 p-cymene (0.5 percent)
 1,8-cineole (2.4 percent)
 (Z)- β -ocimene (0.7 percent)
 α -ocimene⁺⁺ (1.1 percent)
 γ -terpinene (0.1 percent)
cis-linalool oxide⁺ (3.0 percent)
trans-linalool oxide⁺ (2.1 percent)
 linalool (25.5 percent)

3,7-dimethyl-1,5,7-octatrien-3-ol⁺⁺ (2.1 percent)
 1-octenyl acetate⁺⁺ (1.6 percent)
 p-mentha-1,3,8-triene⁺⁺ (0.6 percent)
 camphor (0.6 percent)
 borneol (3.2 percent)
 terpinen-4-ol (1.7 percent)
 cryptone⁺⁺ (1.4 percent)
 α -terpineol (5.6 percent)
 nerol (1.0 percent)
 linalyl acetate (17.7 percent)
 bornyl acetate (1.0 percent)
 lavandulyl acetate (3.9 percent)
 thymol (3.2 percent)
 carvacrol (3.2 percent)
 neryl acetate
 geranyl acetate
 β -caryophyllene
 caryophyllene oxide

⁺furanoid form; ⁺⁺tentative identification

Mori et al. (2002) determined that the main constituents of 13 commercial samples of lavender oil were as follows:

camphor (< 0.1-4.2 percent)
 linalool (17.1-33.4 percent)
 linalyl acetate (18.8-37.8 percent)

A sample of lavender oil that was analyzed by Kubeczka and Formacek (2002) using GC and ¹³C-NMR was found to possess the following composition:

α-pinene + α-thujene (1.53 percent)
camphene (0.76 percent)
β-pinene (0.68 percent)
sabinene (0.13 percent)
δ-3-carene (0.11 percent)
myrcene (0.29 percent)
limonene (2.06 percent)
β-phellandrene + 1,8-cineole [†] (4.31 percent)
(Z)-β-ocimene (1.16 percent)
(E)-β-ocimene (0.48 percent)
p-cymene (1.06 percent)
1-octen-3-yl acetate (0.75 percent)
hexyl butyrate (0.34 percent)
<i>trans</i> -linalool oxide ^{**} (0.34 percent)
1-octen-3-ol (0.44 percent)
<i>cis</i> -linalool oxide ^{**} (0.31 percent)
camphor (3.67 percent)
linalool (42.44 percent)
linalyl acetate (22.04 percent)
terpinen-4-ol (5.39 percent)
β-caryophyllene + lavandulyl acetate (2.67 percent)
lavandulol (0.76 percent)
α-terpineol (1.22 percent)
borneol (1.85 percent)
neryl acetate (0.32 percent)
geranyl acetate (0.60 percent)
nerol (0.15 percent)
geraniol (0.44 percent)

[†]major component; ^{**}furanoid form

Nine commercial samples of lavender oil produced from different lavender cultivars grown in Australia were examined using GC/MS, correlated linear retention indices and two-dimensional gas chromatography (Shellie et al. 2002). The analytical results obtained from these multiple analyses are presented in Table VIII. Based on the compositions of these oils listed in Table VIII, it is readily evident that none can be considered as being authentic oils particularly when in each oil dihydrolinalyl acetate (an impurity found in synthetic linalyl acetate) was found. It should be noted that dihydrolinalyl acetate does not occur naturally in lavender or any other oil.

Kim and Lee (2002) compared different methods to isolate the volatiles from *L. angustifolia* flowers (Hidcote cultivar). The methods examined were solid phase trapping solvent extraction (SPTE), headspace using solid phase microextraction (SPME), reduced pressure steam distillation (RPSD) and simultaneous distillation-extraction (SDE). The SPTE method was a modified headspace procedure using

a nitrogen flush over the lavender flowers with the volatiles collected on an absorbent mixture of Porpak Q (ethylvinylbenzene-divinylbenzene co-polymer). SPME was the standard technique, although various fibres were used such as thickness of polydimethylsiloxane (7 μm, 30 μm and 100 μm), polyacrylate (85 μm) and Carbowax-divinylbenzene (65 μm). RPSD was also the standard technique with the pressure kept at 100 Hg and SDE was also the standard procedure using a Likens-Nickerson apparatus and petroleum ether as the solvent. In each case, the volatiles were analyzed by GC/MS. A comparison between the volatiles obtained by SPTE and SDE can be seen in Table IX. Analysis of the volatiles obtained from three repeated RPSD runs revealed that the light boiling compounds were lost. This is not unexpected as the procedure is not recommended for isolation of essential oils. The average results of these analyses can be seen as follows:

linalool oxide* (5.27 percent)
fenchone (4.67 percent)
linalool (36.80 percent)
camphor (1.18 percent)
lavandulol (1.20 percent)
borneol (11.37 percent)
terpinen-4-ol (9.53 percent)
p-cymen-8-ol (1.30 percent)
α-terpineol (4.61 percent)
myrtenal (0.10 percent)
linalyl acetate (4.04 percent)
bornyl acetate (0.53 percent)
α-terpinyl acetate (2.08 percent)
β-caryophyllene (0.16 percent)
coumarin (7.42 percent)

*correct isomer not identified

The results of the SPME headspace analyses using various fibres is presented in Table X. Although the authors used various fibre thickness of PDMS, only the 100 μm is included in the table. As can be seen from the results, PDMS was the most versatile fibre, PA the most polar and CW-DVB intermediate although more similar to PDMS without the trapping ability for monoterpene hydrocarbons.

Schmidt (2003) analyzed numerous commercial samples of lavender oil obtained from different geographical growing regions. For example, he analyzed 30 Bulgarian oils (over a two-year period), 200 French oils (over a 15-year period), 22 Ukrainian oils (over a single year), 46 Australian oils (over a five-year period) and six Moldovan oils (over a single year). A selected example of the oils produced in each of these areas can be found in Table XI. As can be seen, although all of these oils are considered as commercial lavender oils, there are distinctive chemical differences which translate into odor differences. Consequently, the odor of these oils, not their chemical composition, is the most discerning factor for their use potential.

Compound	1	2	3	4	5	6	7	8	9
tricyclene	0.03	0.02	0.02	0.03	0.04	0.02	-	0.02	0.02
α -thujene	0.02	0.03	0.05	0.09	0.17	0.09	0.14	0.07	0.07
α -pinene	0.52	0.08	0.25	0.63	0.33	0.18	0.73	0.13	0.41
camphene	0.54	0.16	0.09	0.45	0.30	0.02	0.08	0.08	0.37
thuja-2,4(10)-diene	0.02	-	0.03	0.02	0.02	0.03	0.03	0.03	-
sabinene	0.19	-	0.06	0.24	0.04	0.04	0.39	0.06	0.13
β -pinene	0.63	0.03	0.61	0.62	0.07	0.30	1.21	0.26	0.49
1-octen-3-ol	0.82	0.26	0.59	0.59	1.14	0.03	1.08	0.09	0.24
3-octanone	0.96	2.61	3.49	0.65	0.95	1.84	0.59	2.69	0.33
myrcene	0.37	0.26	0.33	0.53	0.66	1.22	0.66	0.78	0.55
3-octanol	0.09	0.40	0.88	-	0.25	0.53	0.04	-	0.04
α -phellandrene	-	0.02	-	0.05	0.07	0.08	0.11	-	-
δ -3-carene	-	0.05	0.07	0.28	0.08	-	0.30	0.08	0.12
1,4-cineole	0.02	0.04	-	0.04	0.05	0.03	0.09	0.02	0.04
o-cymene	0.03	0.04	0.12	0.08	0.09	0.10	0.07	0.05	0.03
p-cymene	0.10	0.11	0.37	0.42	0.45	0.32	0.43	0.38	0.19
limonene	1.76	0.18	0.29	3.37	0.68	0.64	3.92	2.35	1.89
1,8-cineole	10.87	0.59	0.10	11.64	1.18	0.54	20.28	0.35	5.56
(Z)- β -ocimene	2.78	0.95	4.77	3.15	6.17	3.12	2.41	3.91	1.94
(E)- β -ocimene	1.04	0.92	0.61	0.96	0.75	2.36	0.57	1.35	0.34
γ -terpinene	0.05	0.04	0.07	0.12	0.20	0.08	0.22	0.21	0.19
<i>trans</i> -sabinene hydrate	0.20	0.05	-	0.16	0.08	0.05	0.17	0.04	0.10
<i>cis</i> -linalool oxide ⁺	1.09	0.79	0.95	0.94	0.52	0.50	1.00	0.52	0.34
terpinolene	0.18	0.03	0.05	0.14	0.19	0.22	0.07	0.02	0.25
<i>trans</i> -linalool oxide ⁺	0.99	0.64	0.74	0.77	0.38	0.35	0.92	0.39	0.26
perillene	0.04	0.02	0.04	0.08	0.04	0.08	0.05	0.05	-
linalool	42.68	57.48	34.37	33.74	38.89	23.03	40.37	25.22	26.73
α -fenchol	0.34	0.27	0.54	0.20	0.21	0.12	0.33	0.20	0.11
1-octen-3-yl acetate	0.19	0.37	2.09	0.16	4.16	1.00	0.23	2.01	0.47
<i>cis</i> -p-menth-2-en-1-ol	0.02	0.02	-	0.03	0.04	0.03	-	0.02	-
norbornyl acetate [*]	0.04	0.08	0.42	0.06	0.09	0.27	0.06	0.51	-
α -campholenal	0.06	-	-	0.06	0.04	-	0.08	0.02	0.06
<i>trans</i> -pinocarveol	0.11	0.01	0.34	0.11	0.03	-	0.16	0.04	0.05
camphor	5.08	0.34	0.35	2.57	0.36	0.09	0.58	0.09	7.10
hexyl isobutyrate	0.19	0.09	0.10	0.19	0.11	0.08	0.24	0.05	0.16
isoborneol	-	-	-	-	0.06	0.04	0.11	0.06	-
sabina ketone	0.10	0.03	0.05	0.10	0.05	0.07	-	0.02	0.02
<i>cis</i> -chysanthanol	0.02	0.02	0.06	0.04	-	0.02	-	-	0.02
thujyl alcohol	-	-	-	-	0.03	-	0.03	0.01	-
borneol	10.98	0.71	0.65	14.04	0.79	0.30	0.91	0.44	0.45
lavandulol	0.14	3.27	0.72	0.10	0.32	0.16	0.86	0.27	0.05
terpinen-4-ol	0.27	1.93	1.67	3.01	8.07	3.21	4.17	0.11	1.87
m-cymen-8-ol	0.02	0.02	0.03	0.12	0.18	0.21	0.09	0.11	0.07
p-cymen-8-ol	0.14	0.12	0.27	0.24	0.19	0.19	0.16	0.12	-
neoisomenthol	0.41	0.12	0.27	1.10	0.54	0.47	2.26	0.33	4.25
α -terpineol	0.90	1.01	1.59	1.57	3.02	6.02	1.72	3.28	0.12
hexyl butyrate	0.22	0.35	0.35	0.56	0.45	0.47	1.72	0.39	0.12
myrtenol	0.17	0.04	0.12	0.14	-	0.14	0.21	0.07	0.09
<i>cis</i> -carveol	0.09	0.02	0.04	0.13	0.09	0.07	0.11	0.05	0.02
dihydrocarveol	-	0.05	0.05	0.51	0.07	-	0.10	0.04	0.03
isobornyl formate	0.36	0.13	0.19	0.16	0.44	0.10	0.15	0.52	0.13
hexyl 2-methylbutyrate	0.07	0.03	0.08	0.26	0.06	0.04	0.30	0.07	0.05
cuminaldehyde	0.32	0.05	0.04	0.49	0.32	0.29	0.53	0.22	0.12
carvone	0.13	0.03	0.18	0.19	0.12	0.02	0.16	0.07	0.03

Compound	1	2	3	4	5	6	7	8	9
linalyl acetate	8.18	15.74	27.24	6.48	17.05	35.39	4.01	35.25	33.26
dihydrolinalyl acetate	0.11	0.05	0.13	0.21	0.14	0.07	0.16	0.13	0.02
bornyl acetate	0.09	0.04	0.04	0.14	0.32	0.04	0.08	0.12	0.03
lavandulyl acetate	0.70	3.96	2.72	1.07	1.48	6.16	0.65	6.00	2.73
carvacrol	0.11	0.03	0.15	0.18	0.17	0.13	0.16	0.13	-
hexyl tiglate	0.11	0.05	0.10	0.13	0.09	0.06	0.21	0.05	0.10
neoisopulegol	0.03	0.03	0.09	0.04	0.04	0.04	0.05	0.04	0.04
neryl acetate	0.07	0.22	0.45	0.11	0.60	1.23	0.14	0.73	0.21
α -copaene	0.02	0.03	0.03	-	0.05	0.03	-	0.03	-
daucene	0.05	-	0.02	0.03	-	-	0.05	0.01	0.10
geranyl acetate	0.19	0.39	0.62	0.35	1.15	2.37	0.32	1.31	0.48
β -bowbonene	0.04	0.04	0.04	0.08	0.04	0.02	0.07	0.03	0.09
α -cedrene	0.06	0.01	0.02	0.06	0.02	0.02	0.07	0.02	0.09
<i>cis</i> - α -bergamotene	0.03	0.03	0.09	0.02	0.05	-	0.03	0.05	0.03
β -caryophyllene	0.90	2.20	2.83	0.45	1.62	1.04	1.09	1.88	1.49
lavandulyl isobutyrate	0.06	-	-	0.04	-	0.02	0.03	0.02	0.08
<i>trans</i> - α -bergamotene	0.10	-	-	0.07	0.13	0.02	0.12	0.12	0.15
(E)- β -farnesene	0.27	1.09	0.29	1.69	0.74	0.17	0.62	0.60	1.21
germacrene D	0.54	0.60	0.37	0.22	0.16	0.24	0.46	0.35	0.94
bicyclogermacrene	0.03	0.03	0.09	0.02	0.05	-	0.03	0.05	0.04
α -bulnesene	0.05	0.02	0.02	0.05	-	-	0.07	0.01	0.10
lavandulyl isovalerate	0.48	-	-	0.55	0.03	-	0.49	0.03	0.73
γ -cadinene	0.13	0.03	0.05	0.09	0.15	-	0.13	0.04	0.39
δ -cadinene	0.03	0.13	0.24	0.03	0.12	0.08	0.04	0.13	0.38
spathulenol	0.02	0.01	0.06	-	0.04	-	0.02	-	0.02
globulol	0.02	0.02	0.05	0.03	0.02	-	0.02	0.02	-
epi-cubanol	0.02	0.01	0.03	-	-	-	0.02	-	-
α -muurolol	0.19	0.04	0.02	0.16	0.47	-	0.20	-	0.48
α -cadinol	0.02	0.02	0.42	0.05	0.03	-	0.03	0.09	0.02
bisabolol oxide B	0.04	0.01	0.04	0.08	0.02	-	0.07	0.02	0.02
α -bisabolol	0.37	-	0.03	0.70	0.02	-	0.71	-	-

*correct isomer not identified; *furanoid form

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Comparative average percentage composition of lavender volatiles produced by SPTE and SDE

T-9

Compound	SPTE	SDE	Compound	SPTE	SDE
ethylbenzene	0.34	-	borneol	1.88	3.64
m- or p-xylene	0.85	-	terpinen-4-ol	4.63	14.01
o-xylene	0.40	-	p-cymen-8-ol	0.53	-
α -thujene	0.36	-	α -terpineol	-	2.58
α -pinene	0.97	0.23	linalyl acetate	35.44	2.63
camphene	1.57	0.72	bornyl acetate	5.88	5.73
β -pinene	0.63	-	α -terpinyl acetate	-	0.56
myrcene	0.91	0.84	geranyl acetate	0.27	1.28
α -terpinene	-	0.23	β -caryophyllene	9.39	0.76
m- or o-cymene	-	0.23	coumarin	-	1.16
p-cymene	0.11	1.28	farnesene*	2.60	-
limonene	1.23	0.29	farnesene*	-	0.29
1,8-cineole	5.94	8.25	γ -cadinene	-	0.29
γ -terpinene	-	0.41	calamenene*	1.21	0.17
linalool oxide*	0.21	2.61	caryophyllene oxide	1.80	3.08
linalool	18.70	43.47	7-methoxycoumarin	-	1.32
1-octen-3-yl acetate	0.45	0.43	bis (2-ethylhexyl)	-	-
camphor	0.45	0.89	phthalate ⁺	3.00	-
lavandulol	0.25	2.62			

*correct isomer not identified; ⁺not a naturally occurring constituent but a plasticizer probably eluted off the Porpate Q

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Comparative mean percentage composition of the SPME headspace of lavender flowers using different fibres

T-10

Compound	PDMS	PA	CW-DVB	Compound	PDMS	PA	CW-DVB
α -pinene	0.51	-	-	1-octen-3-yl acetate	-	0.80	0.38
camphene	0.99	0.45	-	camphor	0.55	0.79	0.43
β -pinene	0.09	-	-	borneol	0.85	3.08	2.01
myrcene	0.90	-	-	terpinen-4-ol	1.30	5.56	4.03
m- or o-cymene	0.01	-	-	linalyl acetate	47.41	48.06	62.08
p-cymene	0.48	0.69	-	bornyl acetate	7.25	-	0.66
limonene	0.23	0.45	-	geranyl acetate	1.06	0.89	0.55
1,8-cineole	8.63	4.77	2.87	β -caryophyllene	12.45	1.58	2.47
γ -terpinene	0.05	-	-	farnesene*	2.61	-	-
linalool oxide*	0.35	0.90	0.46	calamenene*	-	1.76	2.31
linalool	3.29	26.69	19.29	7-methoxycoumarin	5.35	-	-

*correct isomer not identified; PDMS = polydimethylsiloxane, PA = polyacrylate, CW-DVB = carbowax-divinylbenzene

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Comparative average percentage composition of lavender oils produced in different geographic regions

T-11

Compound	Australia	Bulgaria	France	Moldova	Ukraine
2-butenroic acid	-	-	t	t	t
ethanol	t	-	-	-	-
acetone	0.01	0.01	0.03	0.01	t
isoamyl acetate	t	-	t	-	-
prenol ⁺	-	t	t	t	-
acetaldehyde	t	-	-	t	t
benzyl isoamyl ether	t	-	-	t	0.01
butyl acetate	t	0.01	t	t	-
hexanal	-	-	-	-	t
methyl hexyl ether	0.03	0.01	0.01	0.01	0.01
(E)-2-hexenal	-	-	-	-	t
(Z)-3-hexenol	0.07	-	t	-	t
hexanol	0.02	t	0.01	t	t
tricyclene	t	t	-	0.01	0.01
α-thujene	0.01	0.03	t	0.02	0.03
α-pinene	0.07	0.09	0.02	0.10	0.10
isobutyl isobutyrate	t	-	-	-	t
camphene	0.03	0.06	0.03	0.11	0.17
1-octen-3-ol	0.23	0.06	0.04	0.20	0.15
3-octanone	2.85	0.23	0.21	0.13	0.07
myrcene	0.27	0.33	0.10	0.45	0.40
3-octanol	0.34	0.02	0.02	0.01	t
(Z)-3-hexenyl acetate	0.01	-	-	-	t
hexyl acetate	0.09	0.24	0.08	0.11	0.15
δ-3-carene	0.02	0.03	0.01	0.17	0.21
α-terpinene	t	0.01	-	0.01	0.01
o-cymene	0.03	0.01	0.01	0.03	0.11
p-cymene	0.09	0.07	0.16	0.11	0.28
limonene	0.07	0.11	0.04	0.36	0.25
(Z)-β-ocimene	4.34	5.49	0.34	5.45	4.21
1,8-cineole	t	0.31	0.13	1.62	1.53
(E)-β-ocimene	0.56	2.24	0.13	1.31	2.41
β-phellandrene	0.03	-	t	0.03	0.05
γ-terpinene	0.02	0.06	0.01	0.01	0.02
trans-linalool oxide ⁺	0.22	0.03	0.09	0.02	0.02
terpinolene	t	0.06	-	0.01	0.01
cis-linalool oxide ⁺	0.18	0.01	0.10	0.07	0.06
terpinen-1-ol	0.01	-	0.02	0.01	t
linalool	39.06	27.11	44.35	33.96	27.46
3-octyl acetate	1.84	1.05	0.02	1.08	1.07
allo-ocimene [*]	0.04	0.04	t	0.05	0.04
linalyl formate ⁺⁺	0.02	-	t	-	-
myroxide [*]	-	t	t	-	-
hexyl isobutyrate	0.03	0.03	0.02	0.02	0.03
3,7,7-trimethyl-bicyclo[4.1.0]					
hepten-3-ol	-	-	t	-	-
sabinol [*]	0.01	t	-	t	0.01
camphor	0.14	0.11	0.30	0.23	0.32
lavandulol	0.52	0.29	0.30	0.24	0.19
undecatriene [*]	0.03	0.01	-	0.01	0.02
ocimenol [*]	0.01	-	0.02	0.01	0.01
borneol	0.69	0.35	1.03	0.65	1.04
terpinen-4-ol	2.99	4.63	1.51	2.00	2.09
p-cymenene	0.05	0.03	0.07	0.04	0.08

Compound	Australia	Bulgaria	France	Moldora	Ukraine
cryptone	0.05	0.05	0.01	0.25	0.18
α -terpineol	0.42	0.83	0.66	1.09	0.57
octyl acetate	-	0.01	0.01	0.01	0.01
geranyl butyrate	-	-	-	-	t
eucarvone	t	t	-	t	0.01
<i>cis</i> -sabinene hydrate	0.05	0.09	0.08	0.12	0.01
hexyl isovalerate	-	-	0.05	-	-
bornyl formate	0.02	0.02	0.02	0.01	0.06
linalyl acetate	36.19	42.62	41.63	38.62	43.32
thujyl acetate	0.01	-	0.02	-	0.03
<i>trans</i> - α -bergamotene	-	-	0.01	-	-
<i>trans</i> -sabinene hydrate	-	0.02	0.02	-	0.01
lavandulyl acetate	2.47	4.65	3.65	2.54	2.09
bornyl acetate	0.02	0.15	0.05	0.12	0.12
<i>p</i> -mentha-2,4-diene	-	-	-	t	-
cuminyl alcohol	t	t	t	t	t
hexyl tiglate	0.04	0.01	0.10	0.01	0.01
pinocarvyl formate*	0.01	t	0.02	t	t
<i>cis</i> -verbenyl acetate	-	t	0.05	-	t
terpinen-4-yl acetate	0.01	t	t	t	0.02
linalyl formate ⁺⁺	0.13	0.27	0.21	0.31	0.17
geranyl acetate	0.28	0.50	0.39	0.62	0.30
hexenyl hexanoate*	0.02	-	0.02	-	-
α -cubebene	t	t	0.01	t	0.01
β -bourbonene	0.02	t	0.04	0.01	0.02
zingiberene ⁺⁺	0.01	-	0.09	-	0.01
α -sesquithujene	-	0.01	0.05	0.02	0.01
lavandulyl isobutyrate	-	-	0.02	-	-
<i>cis</i> - α -bergamotene	0.04	0.02	0.02	0.03	0.04
(<i>Z,Z</i>)- α -farnesene	0.01	-	0.01	-	-
α -selinene	0.74	0.37	0.28	0.65	0.67
cadin-4-en-10-ol	t	-	0.01	t	0.01
β -caryophyllene	2.57	4.11	1.82	3.91	5.92
zingiberene ⁺⁺	0.17	0.10	0.12	0.15	0.16
germacrene D	t	t	0.01	0.01	0.01
(<i>Z</i>)- β -farnesene ⁺⁺	0.01	-	0.02	0.02	0.01
(<i>E</i>)- β -farnesene	0.40	2.43	0.62	1.62	2.04
coumarin	-	-	0.03	-	-
nerolidyl acetate*	-	-	0.01	-	0.02
epi- α -santalene	0.04	0.01	-	0.02	0.03
sesquisabinene	0.05	0.03	-	0.05	0.06
(<i>Z</i>)- β -farnesene ⁺⁺	-	0.01	-	0.02	-
α -humulene	0.04	0.05	0.03	0.05	0.08
α -muurolol	t	-	0.01	t	0.01
β -sesquiphellandrene	0.04	-	0.02	0.04	0.05
bicyclosesquiphellandrene	0.25	0.16	0.05	0.53	0.54
α -farnesene*	-	0.02	-	0.01	0.01
β -bisabolol	0.10	0.01	0.02	0.02	0.01
γ -cadinene	0.18	0.05	0.10	0.15	t
T-cadinol	0.05	0.01	t	0.06	0.08
<i>cis</i> -calamenene	t	-	0.01	t	t
caryophyllene oxide	0.13	0.08	-	0.14	0.19

*correct isomer not identified; *furanoid form; **compounds listed twice by author

Marjoram Oil

Casabianca (1996) determined that the enantiomeric distribution of linalool in a sample of marjoram oil (ex. *Origanum majorana* L.) was: (3R)-(-)-linalool (82.0 percent): (3S)-(+)-linalool (18.0 percent).

An oil produced from marjoram grown in Poland was analyzed by Gora et al. (1997) and found to possess the following major constituents:

limonene (16.7 percent)
p-cymene (11.6 percent)
linalool (15.7 percent)
linalyl acetate (14.5 percent)
 α -terpineol (6.4 percent)

Pino et al. (1997) analyzed an oil produced by water distillation from marjoram plants grown experimentally in Cuba. The constituents identified in this oil were:

α -thujene (0.33 percent)
 α -pinene (0.64 percent)
camphene (0.81 percent)
 β -pinene (4.60 percent)
myrcene (1.21 percent)
 α -phellandrene (0.11 percent)
 α -terpinene (3.32 percent)
p-cymene (4.98 percent)
limonene (2.12 percent)
(Z)- β -ocimene (1.84 percent)
(E)- β -ocimene (0.22 percent)
 γ -terpinene (8.34 percent)
trans-sabinene hydrate (2.26 percent)
cis-linalool oxide-furanoid (0.17 percent)
terpinolene (1.52 percent)
linalool (16.41 percent)
1-octen-3-yl acetate (2.08 percent)
cis-p-menth-2-en-1-ol (1.22 percent)
trans-p-menth-2-en-1-ol (0.40 percent)
camphor (3.43 percent)
terpinen-4-ol (17.67 percent)
 α -terpineol (3.19 percent)
cis-piperitol (0.22 percent)
trans-piperitol (0.11 percent)
linalyl acetate (0.25 percent)
bornyl acetate (0.49 percent)
thymol (11.55 percent)
carvacrol (0.46 percent)
 β -bourbonene (0.10 percent)
 β -caryophyllene (3.11 percent)
 α -humulene (0.27 percent)
germacrene D (1.24 percent)
bicyclgermacrene (3.27 percent)
spathulenol (1.07 percent)
caryophyllene oxide (0.70 percent)
globulol (0.09 percent)

Trace amounts (< 0.05 percent) of 1-octen-3-ol, δ -elemene, β -bisabolene, δ -cadinene and α -cadinol were also found in the same oil.

An oil of marjoram produced by water distillation from *O. majorana* cultivated in Sfax (Tunisia) was analyzed by Ben Hamida-Ben Ezzeddine et al. (1999) using both GC and GC/MS. The results of this analysis are as follows:

α -thujene (1.11 percent)
 α -pinene (0.35 percent)
sabinene (3.91 percent)
3-octanol (1.10 percent)
 α -phellandrene (0.22 percent)
 α -terpinene (5.09 percent)
p-cymene (3.84 percent)
limonene + 1,8-cineole (1.46 percent)
 β -ocimene^{*} (0.97 percent)
 γ -terpinene (9.85 percent)
trans-sabinene hydrate (2.84 percent)
terpinolene (2.17 percent)
cis-sabinene hydrate (8.58 percent)
linalool (4.38 percent)
trans-p-menth-2-en-1-ol (2.14 percent)
cis-p-menth-2-en-1-ol (1.69 percent)
borneol (0.63 percent)
terpinen-4-ol (32.84 percent)
 α -terpineol (5.64 percent)
linalyl acetate (4.08 percent)
thymol (1.36 percent)
carvacrol (0.47 percent)
 β -caryophyllene (1.37 percent)
caryophyllene oxide (0.92 percent)

^{*}correct isomer not identified

A sample of marjoram oil produced from *O. majorana* harvested in the wild in Greece was analyzed by GC/MS by Daferera et al. (2000). The main constituents found in this oil were:

α -thujene (2.8 percent)
3,b,6-trimethyl-2-norpinene^{*} (1.9 percent)
myrcene (3.8 percent)
 δ -2-carene^{*} (7.8 percent)
2-ethyl-m-xylene^{*} (5.2 percent)
m-mentha-6,8-diene^{*} (4.2 percent)
 δ -3-carene (10.4 percent)
sabinene (1.3 percent)
sabinene hydrate^{*} (6.0 percent)
linalool (3.8 percent)
borneol (2.5 percent)
terpinen-4-ol (7.8 percent)
 α -terpineol (4.2 percent)
linalyl acetate (3.4 percent)
carvacrol (0.2 percent)
thymol (14.0 percent)
 β -caryophyllene (2.6 percent)
 β -bisabolene (2.1 percent)

^{*}correct isomer not identified

Mohan Rao (2000) compared the composition of oils derived from the water distillation of fresh and dried marjoram herb obtained from Ootacamund (Tamil Nadu, India). He dried the herb either in a convection oven at 45°C or by microwave drying using

Compound	Fresh Herb Oil	Dried Herb Oils			
		conv.	175 W	385W	595W
α -pinene	0.38	0.65	0.44	-	-
β -pinene	0.52	0.61	0.35	-	-
sabinene	7.07	4.17	2.93	0.49	-
myrcene	2.29	1.18	0.93	0.34	-
p-cymene	9.57	8.34	8.03	5.93	6.67
limonene + 1,8-cineole	3.24	2.50	2.07	1.27	1.62
γ -terpinene	4.44	12.06	8.32	9.47	13.06
<i>trans</i> -sabinene hydrate	5.89	3.59	4.73	4.17	-
terpinolene	1.53	-	-	3.03	-
<i>cis</i> -sabinene hydrate	23.6	16.23	19.66	11.14	6.06
linalool	1.83	2.64	2.86	3.50	-
<i>cis</i> -p-menth-2-en-1-ol	0.80	1.98	1.91	2.76	-
terpinen-4-ol	24.25	30.16	29.17	28.58	35.51
α -terpineol	4.52	4.65	5.18	4.65	3.47
<i>cis</i> -sabinene hydrate acetate	1.77	3.52	5.00	4.67	3.87
isocaryophyllene	2.05	3.29	2.32	6.71	15.68
spathulenol	1.26	1.78	1.39	4.99	6.17
Oil Yield (percent)	1.00	0.93	0.56	0.33	0.12

175W, 385W or 595W power. Although he found that increased microwave energy caused a loss of volatiles, drying of the herb at 595W with minimum exposure time preserved the color of the herb. The results of the analyses of the various oils can be seen in Table XII. The data revealed that water distillation of either fresh or convectionally dried herb reduces the *cis*-sabinene hydrate acetate content.

An analysis of the leaf oil of marjoram appeared in the literature (Yadava and Barsainya, 2001). It was probably the most error-filled analysis that this reviewer has ever seen. It is merely included in this review for completeness.

The flower oil of *O. majorana* grown in Iran was the subject of analysis by Barazandeh (2001). The components identified in this flower oil were:

- α -thujene (0.6 percent)
- α -pinene (0.8 percent)
- camphene (< 0.1 percent)
- sabinene (12.0 percent)
- β -pinene (0.5 percent)
- myrcene (2.9 percent)
- α -phellandrene (0.2 percent)
- p-cymene (5.7 percent)
- (Z)- β -ocimene (4.1 percent)
- γ -terpinene (8.8 percent)
- trans*-sabinene hydrate (3.1 percent)
- terpinolene (2.0 percent)
- cis*-sabinene hydrate (8.7 percent)
- camphor (0.6 percent)
- α -terpineol (6.5 percent)
- cis*-piperitol (7.5 percent)
- trans*-piperitol (0.3 percent)

- linalyl acetate (26.1 percent)
- cis*-sabinene hydrate acetate (0.5 percent)
- β -caryophyllene (3.9 percent)
- α -humulene (0.2 percent)
- germacrene D (0.2 percent)
- β -bisabolene (2.8 percent)
- spathulenol (0.2 percent)

Ben Hamida-Ben Ezzeddine et al. (2001) examined the antimicrobial characteristics of Tunisian marjoram oil. The composition of the oil was the same as was reported earlier by the same author (Ben Hamida-Ben Ezzeddine et al. 1999).

Tarjan et al. (2002) showed how the analysis of marjoram oil could be performed using GC/MS and retention indices on more than one capillary GC column. Although the authors did not present any quantitative data, they reported identifying α -thujene, α -pinene, sabinene, myrcene, α -terpinene, limonene, γ -terpinene, *trans*-sabinene hydrate, terpinolene, *cis*-sabinene hydrate, linalool, terpinen-4-ol, α -terpineol, *cis*-sabinene hydrate acetate and linalyl acetate in this oil. Also, they presented the mass spectrum of *cis*-sabinene hydrate acetate.

One hundred and ninety-five single plants of 20 different accessions of *O. majorana*, which were harvested when ca. 10 percent of the plants were in bloom were dried under ambient conditions and extracted with methylene chloride and

Compound	Historical Extract	Standard Extract	Standard Oil	Compound	Historical Extract	Standard Extract	Standard Oil
α -thujene	2.2	2.1	1.4	<i>cis</i> -piperitol	-	-	0.5
α -pinene	1.2	1.0	0.7	<i>cis</i> -dihydrocarvone	-	-	0.4
sabinene	t	8.6	7.8	<i>trans</i> -dihydrocarvone	-	-	0.1
β -pinene	0.4	0.8	0.6	<i>trans</i> -piperitol	0.1	-	0.5
myrcene	0.6	1.3	1.6	<i>trans</i> -sabinene hydrate acetate	-	0.7	0.2
α -phellandrene	0.2	0.2	0.4	carvone	-	-	0.1
α -terpinene	1.1	2.5	11.4	<i>cis</i> -sabinene hydrate acetate	-	18.8	3.4
p-cymene	24.7	0.7	1.3	inalyl acetate	6.5	3.4	3.4
β -phellandrene	6.7	2.7	3.6	dihydrolinalyl acetate ⁺	0.4	-	0.1
1,8-cineole	0.1	0.4	0.4	isothujyl acetate	1.3	0.9	1.5
γ -terpinene	0.6	5.1	18.4	carvacrol	22.0	0.1	0.1
<i>trans</i> -sabinene hydrate	1.6	7.8	3.9	δ -elemene	-	0.1	0.2
terpinolene	-	0.8	3.8	α -terpinyl acetate	-	0.1	-
<i>cis</i> -sabinene hydrate	2.9	38.1	8.6	β -caryophyllene	2.1	2.6	4.2
linalool	2.7	1.7	1.8	aromadendrene	0.6	-	0.1
<i>cis</i> -p-menth-2-en-1-ol	0.3	0.4	1.5	α -humulene	0.1	0.1	0.2
<i>trans</i> -p-menth-2-en-1-ol	0.5	0.3	0.9	bicyclogermacrene	0.3	1.5	2.6
borneol	0.1	-	0.1	spathulenol	0.8	0.3	0.5
terpinen-4-ol	16.6	5.2	19.7	caryophyllene oxide	1.2	0.1	0.5
α -terpineol	4.3	3.0	2.9	viridiflorol	-	-	0.1

⁺not a naturally occurring compound; t = trace (< 0.1 percent)

analyzed using GC/MS (Novak et al. 2002). The components were:

- α -thujene (0.3-0.7 percent)
 - α -pinene (0.3-0.7 percent)
 - sabinene (5.4-7.2 percent)
 - β -pinene (0.3-0.8 percent)
 - myrcene (1.3-2.1 percent)
 - α -terpinene (t-0.2 percent)
 - p-cymene (t)
 - β -phellandrene (1.7-3.2 percent)
 - γ -terpinene (t-0.8 percent)
 - trans*-sabinene hydrate (2.8-3.5 percent)
 - cis*-sabinene hydrate (23.5-49.5 percent)
 - linalool (2.1-5.6 percent)
 - cis*-p-menth-2-en-1-ol (t-0.3 percent)
 - trans*-p-menth-2-en-1-ol (t-0.1 percent)
 - terpinen-4-ol (0.1-1.7 percent)
 - α -terpineol (2.0-3.6 percent)
 - cis*-sabinene hydrate acetate (18.4-46.2 percent)
 - linalyl acetate (3.3-7.9 percent)
 - thymol (t-0.2 percent)
 - carvacrol (t-0.2 percent)
 - β -caryophyllene (1.9-3.1 percent)
 - α -humulene (t-0.2 percent)
 - bicyclogermacrene (1.2-2.0 percent)
 - spathulenol (t-0.2)
 - caryophyllene oxide (t-0.2 percent)
- t = trace (< 0.1 percent)

In addition, the authors also compared the composition of oils produced from a historical sample of marjoram, representative of the marjoram traded in Europe, with a hydrodistilled oil and a standard solvent extract of a recently acquired commercial sample of marjoram. These results are found in Table XIII. Novak et al. agreed with an earlier opinion that there has been a change in the cultivated marjoram selection over the years from one with a phenol-rich oil to one that is rich in *cis*-sabinene hydrate acetate.

Analysis of methylene chloride extracts of 20 single *O. majorana* plants by Novak et al. (2002) revealed the existence of two groups within this chemotype. One group had *cis*-sabinene hydrate acetate levels of greater than 19 percent, while the other had levels of less than 2 percent. The average composition of the solvent extracts was as follows:

- α -thujene (0.46 percent)
- α -pinene (0.53 percent)
- sabinene (6.13 percent)
- β -pinene (0.44 percent)
- myrcene (1.54 percent)
- α -terpinene (0.13 percent)
- p-cymene (0.01 percent)
- β -phellandrene (2.33 percent)
- γ -terpinene (0.44 percent)

trans-sabinene hydrate (3.20 percent)
cis-sabinene hydrate (32.28 percent)
 linalool (2.98 percent)
 terpinen-4-ol (1.12 percent)
 α -terpineol (2.65 percent)
cis-sabinene hydrate acetate (36.01 percent)
 linalyl acetate (4.96 percent)
 β -caryophyllene (2.38 percent)
 α -humulene (0.05 percent)
 bicyclogermacrene (1.57 percent)
 spathulenol (0.13)
 caryophyllene oxide (0.11 percent)

Rodrigues et al. (2002) used micellar electrokinetic capillary chromatography to determine the composition of steam distilled marjoram oil. The compounds identified by this unusual analytical procedure were α -pinene, γ -terpinene, terpinolene, p-cymene, linalool, α -terpineol and terpinen-4-ol; however, no quantitative data was reported.

Two oils produced from *O. majorana* collected in Greece were analyzed by Daferera et al. (2002) and found to possess the following range in composition:

α -thujene (0.9-3.3 percent)
 α -pinene (0.7-2.5 percent)
 camphene (t-1.3 percent)
 sabinene (0.4-1.5 percent)
 myrcene (1.3-3.6 percent)
 α -terpinene (5.4-9.8 percent)
 p-cymene (5.8-9.8 percent)
 β -phellandrene (1.8-3.8 percent)
 γ -terpinene (9.3-18.3 percent)
cis-sabinene hydrate (1.3-1.4 percent)
 terpinolene (1.5-2.0 percent)
 linalool (2.3-5.6 percent)
 borneol (0.5-1.6 percent)
 terpinen-4-ol (9.3-9.4 percent)
 α -terpineol (2.4-2.6 percent)
 linalyl propionate* (0-1.4 percent)
 linalyl acetate (0.8-1.2 percent)
 thymol (0.1-0.8 percent)
 carvacrol (16.8-45.1 percent)
 β -caryophyllene (0.3-1.0 percent)

t = trace (< 0.1 percent); *incorrect identification based on elution order

Rodrigues et al. (2003) compared the components of steam distilled marjoram oil with that of a high pressure CO₂ extract of Brazilian-grown marjoram and a commercially available sample of marjoram. Not unexpectedly, they found that the monoterpene hydrocarbons, α -terpineol and terpinen-4-ol, contents of the oil were much larger than were found in the CO₂ extracts. Also, the *cis*-sabinene hydrate acetate was much richer in the CO₂ extracts than in the oil. The components identified in the extracts were α -pinene, β -pinene, α -terpinene, camphene (incorrectly identified), γ -terpinene, *trans*-sabinene hydrate, *cis*-sabinene hydrate, linalool, an isomer of p-menth-2-en-1-ol, terpinen-1-ol, terpinen-4-ol, α -terpineol, *cis*- and *trans*-piperitol, *cis*-sabinene hydrate acetate, linalyl acetate, α -terpinyl acetate, carvacrol, β -caryo-

phyllene, germacrene D, spathulenol and caryophyllene oxide. In contrast, the oil contained α -thujene, sabinene, myrcene, α -phellandrene, p-cymene, terpinolene, menthone and neryl acetate, and did not contain β -pinene, camphene (wrongly identified), α -terpinyl acetate and carvacrol. All other CO₂ extract constituents were found in the oil.

Edris et al. (2003) compared the effect of organic and chemical fertilization on *O. majorana* (German type) grown in Egypt over two crop cycles. The results of this study are summarized in Table XIV. As can be seen, the type of fertilization did not affect the oil composition.

Novak et al. (2003) studied the effect of genotype of *O. majorana* by environment interaction of 34 genotype and three locations. With regard to the so-called marjoram-character compounds (*cis*-sabinene hydrate and *cis*-sabinene hydrate acetate), it was found that most were extremely unstable although one hybrid form was found in which the two components were very stable irrespective of the environment in which it was grown.

Also in 2003, Daferera et al. examined the effectiveness of essential oils against plant pathogens. One of the oils they used was marjoram, the analysis of which was previously published (Daferera et al., 2002).

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Compound	June Crop		September Crop	
	Chemical Fertilization	Organic Fertilization	Chemical Fertilization	Organic Fertilization
1,8-cineole	1.0	0.9-1.5	1.4-1.9	1.8-2.3
<i>trans</i> -sabinene hydrate	3.5-4.6	3.8-4.8	5.0-7.5	4.3-4.6
linalool	2.7-4.0	2.1-2.4	0.5-5.0	1.0-1.8
<i>cis</i> -sabinene hydrate	12.7-21.5	14.5-24.1	25.1-26.7	22.4-27.1
<i>trans</i> -p-menth-2-en-1-ol	1.8-1.9	1.3-1.9	1.0-1.2	0.5-1.1
<i>cis</i> -p-menth-2-en-1-ol	0.9-1.0	0.7-1.1	0.4-0.5	0.2-0.4
terpinen-4-ol	36.5-38.5	32.6-39.5	23.6-26.9	24.9-28.4
α -terpineol	5.0	4.2-5.1	4.0-5.3	4.5-4.9
<i>trans</i> -piperitol	0.4-0.5	0.2-0.3	0.1-0.2	0.2-0.3
<i>cis</i> -piperitol	0.2-0.6	0.2-0.6	0.2	0.2
linalyl acetate	0.3-0.5	0.3-0.5	0.2-0.4	0.3-0.4
thymol	0.1-0.2	0.2	0.1-0.2	-
eugenol	0.1	0.1	-	-
caryophyllene oxide	0.7-1.6	0.9-1.0	0.6-1.7	0.5-1.8

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Benzoin Gum Oil and Extracts

Two types of benzoin gums are encountered in commerce. They are benzoin gum Siam, which is obtained from *Styrax tonkinensis* Craib. ex Hartwiss, and benzoin gum Sumatra, which is obtained from *S. benzoin* Dryander and *S. paralleloleoneurum* Perkins.

Fernandez et al. (2003) described the gum of benzoin Siam as being reddish-yellow on the surface and milky-white inside. They reported that it possessed sweet balsamic odor with a distinctly vanilla-like character. In contrast, they described the gum of benzoin Sumatra as being red to grayish-brown in color. The odor of this gum was reported to be strongly styrax-like without any vanilla-like characters.

In 1916, Holmes presented a historical perspective on benzoin gums, their origin and early commercial trade information. More recently, Coppen (1999) reported that the annual production of Siam benzoin gum was ca. 50 tonnes, while that of Sumatra benzoin was ca. 1000 tonnes. Coppen noted that Laos was the major producer of Siam benzoin with a smaller production from Vietnam, however for some years Laos has been the only producer. Sumatra benzoin is obtained only from the Tapanuli region of northern Sumatra, mainly above 1000 m south of Lake Toba.

From a compositional standpoint, Reinitzer (cited in Fernandez et al. 2003) reported that Siam benzoin gum contained:

coniferyl benzoate (65-75 percent)
 p-coumaryl benzoate (10-15 percent)
 cinnamyl cinnamate (0.5-0.6 percent)
 benzoic acid (12.0 percent)
 vanillin (0.3 percent)
 siarresinolic acid (6.0 percent)

Schroeder (1968) reported that coniferyl benzoate and p-coumaryl benzoate (reduced to p-coumaryl alcohol) were indeed constituents of Siam benzoin gum.

Saleh et al. (1980) determined the cinnamic acid and benzoic acid content of benzoin. Using a UV spectrophotometric method they found that the cinnamic acid content varied from 4.69-18.26 percent and the benzoic acid content varied from 2.35-6.10 percent.

Boelens et al. (1982) reported that a sample of Sumatra benzoin was found to contain styrene, benzyl alcohol, (E)-cinnamyl alcohol, 3-phenylpropanol, benzaldehyde, cinnamaldehyde, acetophenone, 1-phenyl-2-methyl-1,3-butadione, vanillin, acetovanillone, (3-methoxy-4-hydroxyphenyl)-2-propanone, menthone, myristic acid, benzoic acid, (E)-cinnamic acid, methyl benzoate, ethyl benzoate, allyl benzoate, benzyl benzoate, (E)-cinnamyl benzoate, methyl (E)-cinnamate, ethyl (E)-cinnamate, propyl (E)-cinnamate, benzyl (E)-cinnamate, 4-ethyl guaicol and eugenol. Furthermore, the authors noted that styrene, acetophenone, acetovanillone, menthone, allyl benzoate, methyl (E)-cinnamate, propyl (E)-cinnamate and eugenol were present only in trace levels less than 0.1 percent.

Nitta et al. (1984) reported that high grade gum-resin from *S. paralleloneuram* contained benzoic acid (3.0 percent), vanillin (0.5 percent) and cinnamic acid (20.30 percent), whereas the gum-resin from *S. benzoin* contained benzoic acid (30 percent) and no cinnamic acid. Both gum resins are used as a source of Sumatra benzoin although most is obtained from *S. benzoin*.

The volatile fraction obtained from Sumatra benzoin gum oleo-resin was analyzed by Moyler and Clery (1997) by retention indices (non-polar column) and GC/MS and was found to possess the following composition:

benzaldehyde (t)
 benzyl alcohol (41.8 percent)
 methyl benzoate (t)
 ethyl benzoate (t)
 benzoic acid (2.5 percent)
 (Z)-cinnamyl alcohol (t)
 (E)-cinnamyl alcohol (t)
 methyl cinnamate* (t)
 vanillin (1.4 percent)
 ethyl cinnamate* (0.8 percent)
 cinnamic acid* (2.7 percent)
 (Z)-nerolidol (t)
 (E)-nerolidol (0.4 percent)
 benzyl benzoate (46.6 percent)
 (E)-cinnamyl benzoate (0.1 percent)

(E)-benzyl cinnamate (0.9 percent)
 (Z)-cinnamyl (E)-cinnamate (1.5 percent)

t = trace (0.01-0.08 percent); *correct isomer not identified

The authors also stated that the volatile fraction of this benzoin resin contained an additional 83 components (1.08 percent of the oil), although none was identified.

Moyler (1998) reported that the volatile fraction of Siam benzoin contained the following constituents:

benzaldehyde (0.01 percent)
 benzyl alcohol (38.80 percent)
 methyl benzoate (0.03 percent)
 ethyl benzoate (0.10 percent)
 benzoic acid (18.40 percent)
 (Z)-cinnamyl alcohol (0.01 percent)
 (E)-cinnamyl alcohol (0.30 percent)
 methyl (E)-cinnamate (0.05 percent)
 vanillin (0.60 percent)
 ethyl (E)-cinnamate (0.80 percent)
 (E)-cinnamic acid (0.05 percent)
 (Z)-nerolidol (< 0.01 percent)
 (E)-nerolidol (0.05 percent)
 benzyl benzoate (39.30 percent)
 (E)-cinnamyl benzoate (0.02 percent)
 benzyl (E)-cinnamate (0.12 percent)
 (Z)-cinnamyl (E)-cinnamate (0.10 percent)

Compound	Siam Benzoin	Sumatra Benzoin	Compound	Siam Benzoin	Sumatra Benzoin
styrene	-	2.3	cinnamic acid	-	3.5
benzaldehyde	0.4	0.9	isoamyl benzoate	0.1	-
6-methyl-5-hepten-2-one	-	t	<i>trans</i> - α -bergamotene	-	0.2
phenylacetaldehyde	-	t	3-methyl-3-butenyl benzoate	0.3	-
1,8-cineole	0.1	0.4	β -caryophyllene	t	-
acetophenone	-	1.8	ethyl (E)-cinnamate	-	0.1
methyl benzoate	1.5	0.5	valencene	t	t
benzoic acid	12.5	1.7	ledene	t	t
ethyl benzoate	1.1	0.2	δ -guaiene	0.1	t
allyl benzoate	1.5	0.9	allyl (E)-cinnamate	-	0.5
(E)-cinnamaldehyde	-	0.7	(E)-nerolidol	-	0.4
propyl benzoate	0.2	0.1	isobutyl (E)-cinnamate	-	0.1
4-ethylguaiaicol	0.1	0.6	benzyl benzoate	80.1	76.1
isobutyl benzoate	t	-	(E)-cinnamyl benzoate	-	1.4
eugenol	1.1	0.8	benzyl (E)-cinnamate	-	3.3
dihydroeugenol	t	t	(E)-cinnamyl (E)-cinnamate	-	0.9
α -copaene	t	t			
β -elemene	t	-			

t = trace (< 0.1 percent)

Moyler reported that a further 83 constituents that were not identified comprised 1.26 percent of the volatile concentrate.

Moyler (1998) also examined the composition of a volatile concentrate of Sumatra benzoin. The components found in this extract were:

benzaldehyde (0.09 percent)
benzyl alcohol (43.4 percent)
methyl benzoate (0.06 percent)
ethyl benzoate (0.03 percent)
benzoic acid (0.11 percent)
(Z)-cinnamyl alcohol (0.01 percent)
(E)-cinnamyl alcohol (0.05 percent)
methyl (E)-cinnamate (0.02 percent)
vanillin (0.16 percent)
ethyl (E)-cinnamate (1.00 percent)
(E)-cinnamic acid (1.43 percent)
benzyl benzoate (50.7 percent)
(E)-cinnamyl benzoate (0.10 percent)
benzyl (E)-cinnamate (0.50 percent)
(Z)-cinnamyl (E)-cinnamate (1.50 percent)

A further 44 compounds accounting for 0.84 percent of the volatile concentrate were not identified.

Fernandez et al. (2003) subjected the Siam and Sumatra gum benzoin to separate hydrodistillations to yield 0.14 percent and 0.07 percent oil, respectively. Analysis of these oils using GC/MS revealed

the compositions that are presented in Table XV. In addition, the authors also examined the headspace of the crushed gums using solid phase microextraction (SPME) using a Carboxen/Polydimethylsiloxane (CAR/PDMS) and Carbowax/Divinylbenzene (CW/DVB) fibres, the former being recommended for low molecular weight compounds while the latter is recommended for polar semi-volatile compounds. The results of these comparative headspace analyses can be seen in Table XVI.

As can be seen, the SPME analyses were helpful in the identification of new compounds such as ethanol, toluene, α -pinene, β -pinene, acetic acid, propionic acid, 3-buten-2-ol, ethylbenzene, phenol, isoterpinolene, benzyl alcohol, p-cymene, benzyl formate, a linalool oxide isomer, δ -elemene, vanillin and germacrene D. However, it is obvious from the headspace data that quantitation of the constituents was fibre dependent assuming all other conditions remained the same. Using a separate static headspace-GC procedure the authors were able to determine that the toluene level of Siam and Sumatra benzoin gums was 10 ppm and less than 1 ppm, respectively. Using the same procedure, they also found that the styrene level of Siam and Sumatra benzoin gums was less than 1 ppm and 800 ppm, respectively.

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Compound	Siam Benzoin		Sumatra Benzoin	
	1	2	1	2
ethanol	0.2	1.5	0.4	0.7
acetic acid	4.1	1.1	0.8	0.9
3-buten-2-ol	0.6	-	-	-
propionic acid	0.4	0.1	-	-
toluene	66.4	1.2	0.3	-
ethylbenzene	0.2	-	-	-
styrene	5.0	-	90.4	70.1
benzaldehyde	4.4	5.9	1.3	3.2
α -pinene	4.5	-	0.2	-
phenol	-	-	0.7	2.3
6-methyl-5-hepten-2-one	-	-	-	t
phenylcetaladyde	-	-	-	0.1
isoterpinolene	-	0.1	-	-
benzyl alcohol	2.4	11.2	-	0.4
p-cymene	0.4	0.3	0.3	0.3
1,8-cineole	0.6	-	0.3	0.4
acetophenone	0.4	-	1.5	7.6
benzyl formate	0.2	0.8	-	-
linalool oxide*	t	0.3	-	t
methyl benzoate	2.0	8.7	0.3	t
benzoic acid	4.8	43.4	0.6	3.9
ethyl benzoate	1.4	12.1	-	1.3
allyl benzoate	-	t	-	t
(E)-cinnamaldehyde	-	-	-	1.0
propyl benzoate	-	0.5	-	0.2
4-ethylguaicol	-	0.5	-	0.1
isobutyl benzoate	-	0.7	-	t
eugenol	-	1.6	-	0.2
δ -elemene	0.5	-	-	-
vanillin	0.1	3.2	-	0.4
α -copaene	0.1	-	-	-
β -caryophyllene	0.3	-	-	-
germacrene D	-	0.1	-	-
benzyl benzoate	-	4.1	-	0.3

1 = carboxen/polydimethylsiloxane fibre, 2 = Carbowax/divinylbenzene fibre; t = trace (< 0.01 percent); * isomer not identified

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