Progress in Essential Oils

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Sage Oil

The main components of an oil of *Salvia officinalis* that was screened by Zani et al. (1991) for its genotoxic properties were as follows:

α-pinene (2.17%)
camphene (3.02%)
β-pinene (2.61%)
myrcene (0.39%)
limonene (0.66%)
1,8-cineole (7.73%)
α-thujone (7.33%)
β-thujone (5.23%)
camphor (17.43%)
borneol (3.31%)
α-terpineol (0.37%)
β-caryophyllene (3.30%)
α-humulene (1.79%)

As the above constituents totaled only 55.33% of the oil, the above can hardly be considered as a very exhaustive analysis. Also, the thujone levels were below those which are normally encountered in commercial sage oils.

Table I. Comparative composition (%) of sage oil and extracts

Compound	Oil	Ethanolic extract[a]	Methanolic extract	Freon II extract[b]
α-pinene	0.4	0.1	0.1	0.3
camphene	4.5	1.4	1.4	5.1
β-pinene	4.2	1.2	1.2	3.9
myrcene	0.1	0.1	0.1	0.1
α-terpinene	0.1	-	-	-
limonene	1.6	0.6	0.6	1.4
1,8-cineole	12.3	7.4	7.2	9.9
p-cymene	1.6	0.6	0.6	1.3
α-thujone	19.0	17.9	17.4	17.3
β-thujone	14.3	12.8	12.5	11.8
camphor	21.9	20.7	20.1	21.0
linalool	0.2	0.1	0.1	0.1
β-caryophyllene	0.7	0.6	0.6	0.7
α-humulene	6.6	5.2	5.1	5.6

[a] 70% aqueous EtoH
[b] trichlorofluromethane

Six years later, Milhau et al. (1997) used GC/MS to examine an oil of *S. officinalis* produced by hydrodistillation of plants cultivated in France. The components identified in this study were as follows:

α-pinene (5.9%)
camphene (9.1%)
sabinene (0.4%)
β-pinene (2.2%)
myrcene (1.6%)
p-cymene (1.5%)
1,8-cineole (20.5%)
γ-terpinene (0.2%)
α-thujone (22.8%)
β-thujone (3.7%)
camphor (2.0%)
borneol (1.9%)
terpinen-4-ol (0.3%)
α-terpineol (0.7%)
bornyl acetate (2.0%)
β-caryophyllene (2.6%)
α-humulene (2.9%)
ledol† (0.6%)

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† incorrect identification, should be viridiflorol

As part of a study of the essential oils of *Salvia* species, Mathé et al. (1997) analyzed an oil of *S. officinalis* using GC and GC/MS. The components identified in this oil were as follows:

α-thujene (0.2%)
α-pinene (1.1%)
β-pinene (2.3%)
myrcene (0.9%)
α-terpinene (0.2%)
p-cymene (0.2%)
limonene (1.3%)
1,8-cineole (3.5%)
γ-terpinene (0.5%)
terpinolene (0.4%)
α-thujone (36.0%)
β-thujone (9.7%)
camphor (9.6%)
borneol (8.4%)
terpinen-4-ol (0.5%)
α-terpineol (0.1%)
bornyl acetate (4.9%)
β-caryophyllene (0.7%)
α-humulene (4.2%)
caryophyllene oxide (0.2%)
viridiflorol (4.6%)
humulene oxide* (0.8%)
sclarene (0.9%)

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*correct isomer not identified

Sage oil produced from *S. officinalis* grown in Cuba was analyzed by GC/MS.

The constituents characterized in this oil by Pino et al. (1997) were as follows:

α-pinene (0.81%)
camphene (2.48%)
β-pinene (0.96%)
α-phellandrene (1.16%)
α-terpinene (0.12%)
limonene (1.69%)
1,8-cineole (1.81%)
(Z)-β-ocimene (0.19%)
γ-terpinene (0.29%)
p-cymene (0.35%)
terpinolene (0.22%)
α-thujone (12.95%)
β-thujone (10.89%)
menthone (0.11%)
camphor (10.36%)
linalool (0.26%)
α-fenchyl acetate (2.24%)
β-caryophyllene (5.51%)
pulegone (0.86%)
α-humulene (9.72%)
borneol (3.81%)
carvone (0.21%)

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Table II. Comparison of the main components (%) of the oils of *Salvia officinalis* grown in Bulgaria that possess different flower colors

Compound	White flower oil	Pink flower oil	Violet flower oil	Dark Violet flower oil
α-pinene	2.5	2.9-4.2	2.5	0.1-0.2
camphene	0.5	1.9-4.4	0.7-1.0	1.8-3.8
β-pinene	17.9	13.8-17.6	16.7-17.8	1.0-3.9
α-thujone	17.4	13.9-14.2	10.0-33.3	19.7-24.7
β-thujone	1.8	2.7-9.4	2.5-4.0	0.7-1.7
camphor	2.4	1.7-2.3	0.3-0.4	0.1-11.2
β-caryophyllene	17.1	5.2-7.4	7.9-9.8	7.6-11.7

caryophyllene oxide (0.96%)
humulene oxide I (2.21%)
viridiflorol (13.46%)
methyl hexadecanoate (0.26%)
methyl (Z)-9-hexadecenoate (0.06%)
manool (14.74%)
methyl (Z)-9-octadecenoate (0.11%)

An oil and three extracts of the dried leaves of *S. officinalis* grown in Poland were analyzed by Olszewska-Kaczynska and Milkowska (1997) for major components. A summary of the results of this study can be seen in Table I. It was a surprise to this reviewer that extraction studies are still being performed using Freon 11 as there is a moratorium on its use.

This same year, Kovatcheva and Zheljazkov (1997) compared the oil compositions of sage obtained from plants that had different flower colors. The main components identified in these oils are shown in Table II. Although it is not completely evident from this study, it should be concluded that there is no relationship between flower color and chemical composition (Lawrence).

Dobos et al. (1997) analyzed an oil produced from *S. officinalis* grown in Albania. The oil, which was analyzed by a combination of GC and GC/MS was found to possess the following constituents:

α-thujene (0.2%)
α-pinene (1.1%)
camphene (2.8%)
sabinene (0.3%)
β-pinene (2.3%)
myrcene (0.9%)
α-phellandrene (1.0%)
α-terpinene (0.2%)
p-cymene (0.2%)
limonene (1.3%)
1,8-cineole (3.4%)
(Z)-β-ocimene (0.5%)
(E)-β-ocimene (0.1%)
γ-terpinene (0.5%)
terpinolene (0.4%)
α-thujone (35.9%)
β-thujone (9.7%)
trans-sabinol (0.3%)
camphor (9.7%)
borneol (8.7%)
terpinen-4-ol (0.5%)
α-terpineol (0.1%)
bornyl acetate (5.0%)
thujyl acetate (0.3%)
α-copaene (trace)
β-bourbonene (trace)
jasmone* (1.0%)
β-caryophyllene (0.7%)
α-humulene (4.3%)
γ-muurolene (0.1%)
germacrene D (0.1%)
valencene (0.1%)
δ-cadinene (0.1%)
caryophyllene oxide (0.1%)
viridiflorol (4.6%)
humulene oxide* (0.7%)
sclarene (1.9%)

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*correct isomer not identified

Soliman et al. (1997) compared the composition of two oils of *S. officinalis* produced from two areas of Egypt. Using a combination of GC and GC/MS the authors found that the oils differed to some extent (See Table III).

Also in 1997, Piccaglia et al. studied the effect of flowering on the oil composition of *S. officinalis*. A comparison of the compositional differences between oil produced from vegetative and flowering plants can be seen in Table IV.

The following year, Chalchat et al. (1998) used a combination of GC (for retention indices and quantitation) and GC/MS (for component identity confirmation) to analyze the oils produced from five clones of *S. officinalis*. A summary of the results of this study can be seen in Table V.

Also in 1998, Tiziana Baratta et al. used GC/MS to analyze an oil produced from sage leaves obtained in the U.K. spice market. They found that the oil contained the following constituents:

salvene* (0.3%)
tricyclene (0.2%)
α-thujene (trace)
α-pinene (3.7%)
camphene (6.6%)
verbenene (1.6%)
sabinene (0.2%)
β-pinene (0.4%)
myrcene (0.9%)
δ-3-carene (trace)
α-terpinene (0.2%)
p-cymene (0.2%)
1,8-cineole (9.6%)
limonene (2.3%)
γ-terpinene (0.1%)
cis-linalool oxide furanoid (trace)
α-p-dimethylstyrene (0.1%)
terpinolene (0.1%)
α-thujone (24.7%)
β-thujone (6.4%)
camphor (26.4%)
cis-verbenol (0.7%)
pinocamphone (1.1%)
isopulegol (0.1%)
borneol (4.1%)
terpinen-4-ol (0.7%)
α-terpineol (0.3%)
myrtanol* (1.0%)
thymol (0.2%)
carvacrol (0.1%)
bornyl acetate (1.3%)
eugenol (0.1%)
β-caryophyllene (0.7%)
α-humulene (0.9%)
caryophyllene oxide (0.2%)
guaiol (3.3%)
humulene oxide* (0.4%)
14-hydroxy-9-epi-β-caryophyllene (0.6%)
lyral (0.1%)
α-santalol (0.3%)

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*correct isomer not identified

Kanias et al. (1998) collected eight samples of *S. officinalis* from the Eiprus area of Greece and produced oils in the laboratory using hydrodistillation. Analyses of these oils revealed that the major constituents varied as follows:

α-pinene (0.28-5.68%)
camphene (0.23-6.48%)
β-pinene (0.60-7.22%)
myrcene (0.37-2.29%)
1,8-cineole (8.42-56.30%)
α-thujone (1.80-19.90%)
β-thujone (1.11-6.35%)
camphor (4.23-45.70%)
borneol + α-terpineol (3.30-9.08%)
β-caryophyllene (2.29-11.20%)
caryophyllene oxide (0.29-2.40%)

As can be seen, some of these oils were rather atypical for sage because of their high 1,8-cineole contents.

A Sardinian oil of *S. officinalis* was analyzed by Peana et al. (1999) using both GC and GC/MS, and it was found to possess the following composition:

α-pinene (3.7%)
α-thujene (0.1%)
camphene (5.8%)
β-pinene (1.6%)
myrcene (0.7%)
limonene (2.6%)
1,8-cineole (11.8%)
γ-terpinene (0.2%)
p-cymene (0.9%)
α-thujone (23.0%)
β-thujone (3.8%)
camphor (26.8%)
bornyl acetate (1.5%)
β-caryophyllene (4.6%)
terpinen-4-ol (0.4%)
α-terpinyl acetate (0.5%)
linalool (2.0%)
α-terpineol (0.1%)
borneol (3.0%)
pinocarveol* (6.7%)
caryophyllene oxide (0.3%)

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*correct isomer not identified

Theuerl et al. (1999) compared the quantitative analysis of sage oil using conventional temperature programmed GC (which took 40 minutes) and fast temperature programmed (which took 4 minutes). The results of the comparative study can be seen in Table VI.

An oil of sage obtained on the German market, which was analyzed by Reichling et al. (1999) was found to possess the following composition:

α-pinene (4.08%)
camphene (4.94%)
β-pinene (0.68%)
myrcene (0.79%)
α-terpinene (0.21%)
p-cymene (1.29%)
1,8-cineole (12.04%)
γ-terpinene (0.20%)
terpinolene (0.23%)
β-thujone (25.54%)
α-thujone (7.21%)
camphor (19.76%)
borneol (3.12%)
terpinen-4-ol (0.30%)
α-terpineol (0.29%)
bornyl acetate (2.41%)
β-caryophyllene (5.57%)
α-humulene (5.73%)
allo-aromadendrene (0.12%)

Foray et al. (1999) reported that the main components of *S. officinalis* oil produced from plants cultivated in France were:

α-pinene (0.7%)
camphene (0.5%)
β-pinene (1.0%)
myrcene (0.3%)
limonene (0.3%)
1,8-cineole (11.7%)
α-thujone (65.5%)
β-thujone (15.4%)
camphor (2.6%)
β-caryophyllene (1.4%)
α-humulene (0.3%)

Also in 1999, Tirillini et al. used a micro-needle technique to sample the oil found in opaque and transparent

Table III. Comparative percentage composition of *Salvia officinalis* oil produced from plants grown in two areas of Egypt

Compound	Giza oil	Sinai oil
tricyclene	0.10	-
α-thujene	0.17	-
α-pinene	3.81	1.79
camphene	3.82	3.60
sabinene	3.85	-
β-pinene	3.70	2.50
myrcene	3.38	1.09
o-cymene	0.85	-
p-cymene	0.76	1.48
1,8-cineole	9.38	8.86
(Z)-β-ocimene	0.10	-
γ-terpinene	1.10	0.31
linalool	1.02	-
terpinolene	0.68	1.69
α-thujone	17.72	18.87
β-thujone	2.03	7.45
cis-pinene hydrate[a]	0.05	-
camphor	13.29	33.35
cis-β-terpineol	0.10	-
isomenthone	0.68	-
cis-pinanone[b]	0.43	-
borneol	2.37	3.65
terpinen-4-ol	-	1.08
α-terpineol	1.10	0.46
methyl chavicol	-	0.25
carvone	1.44	0.41
piperitone	-	1.07
bornyl acetate	0.08	2.61
isobornyl acetate	2.20	-
sabinene hydrate acetate*	0.68	-
thymol	0.68	-
β-caryophyllene	1.70	0.43
(E)-ethyl cinnamate	-	0.46
aromadendrene	1.10	-
α-humulene	3.05	3.04
allo-aromadendrene	0.10	0.07
germacrene B	1.44	-
γ-cadinene	0.04	-
δ-cadinene	0.60	-
spathulenol	0.85	-
caryophyllene oxide	0.60	-
globulol	3.30	3.22
bergamotol acetate	0.85	0.38

[a] probably misidentification of cis-p-menth-2-en-1-ol
[b] probably 3-pinanone, also known as isopinocamphone
* correct isomer not identified

Table IV. Comparative percentage composition of oils produced from flowering and vegetative *Salvia officinalis*

Compound	Flowering plant oil	Vegetative plant oil
cis-salvene	0.34-0.36	0.14-0.41
trans-salvene	0.09-0.11	0.02-0.11
α-thujene	0.27	0.10-0.63
α-pinene	2.41-3.21	0.56-2.92
camphene	1.41-1.72	0.63-2.79
sabinene	0.26-0.32	0.22-0.30
β-pinene	10.62-12.87	2.06-2.82
myrcene	0.72-0.83	0.78-1.14
α-terpinene	0.23-0.24	0.11-0.17
p-cymene	0.23-0.27	0.22-0.42
limonene	0.58-0.61	0.59-1.18
1,8-cineole	16.59-17.74	4.93-9.15
(Z)-β-ocimene	0.95-1.05	0.12-0.84
(E)-β-ocimene	0.22-0.24	0.02-0.15
γ-terpinene	0.43-0.45	0.31-0.44
terpinolene	0.16-0.27	0.11-0.23
linalool	0.25-0.35	0.16-0.21
α-thujone	24.55-25.86	29.66-48.93
β-thujone	5.18-5.32	5.81-9.27
camphor	1.75-3.62	3.40-10.09
borneol	2.98-4.04	1.09-1.31
terpinen-4-ol	0.41	0.33-0.37
bornyl acetate	0.16-0.64	0.20-0.27
β-caryophyllene	6.77-7.19	1.82-8.96
aromadendrene	0.15-0.31	0.07-0.33
α-humulene	5.95-6.54	2.65-13.97
allo-aromadendrene	0.11-0.13	0.04-0.33
caryophyllene oxide	0.28-0.32	0.19-0.69
viridiflorol	3.04-4.63	1.69-11.88

peltate glandular trichomes, capitate glandular trichomes and ambrate resinous droplets from mature *S. officinalis* leaves. The results of the analyses of these oil samples can be seen in Table VII.

Perry et al. (1999) examined 102 samples of *S. officinalis* oil produced from plants harvested at different times, which also reflected the different stages of development. The found that the constituents ranged as follows:

α-pinene (0.9-4.9%)
camphene (0.5-5.2%)
β-pinene (2.2-19.0%)
myrcene (0.6-1.2%)
1,8-cineole (4.6-16.4%)
(Z)-β-ocimene (0.3-0.5%)
α-thujone (15.0-53.2%)
β-thujone (2.1-12.6%)
camphor (0.9-13.6%)
borneol (0.4-6.8%)
bornyl acetate (0.1-1.5%)
α-copaene (0-0.3%)
α-gurjunene (0-0.3%)
β-caryophyllene (1.0-11.5%)
β-cubebene† (0-0.4%)
aromadendrene (0.1-1.9%)
α-humulene (2.8-11.6%)
α-amorphene (0-0.5%)
germacrene D (0.1-1.2%)
bicyclogermacrene (0-0.6%)
δ-cadinene (0-0.8%)
palustrol + spathulenol (0-0.3%)
caryophyllene oxide (0.1-2.9%)
viridiflorol (1.3-9.1%)
humulene oxide* (0.2-2.3%)
manool (0.3-5.1%)

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

Of the above compounds, the authors noted that at flowering there was a decrease in the contents of camphene, α-thujone and camphor, and a corresponding increase in the contents of β-pinene, 1-8-cineole, borneol and β-caryophyllene.

This same year, Vera et al. (1999) analyzed an oil of *S. officinalis* produced from plants grown in Reunion. In this oil they characterized the following components:

tricyclene (0.1%)
α-thujene (0.2%)
α-pinene (5.4%)
camphene (2.8%)
sabinene (0.2%)
β-pinene (1.9%)
α-phellandrene (0.8%)
δ-3-carene (trace)
α-terpinene (trace)
p-cymene (0.4%)
1,8-cineole (5.8%)
limonene (1.3%)
(E)-β-ocimene (trace)
γ-terpinene (0.3%)
terpinolene (0.2%)
α-thujone (45.5%)
linalool (trace)
β-thujone (8.4%)
isothujol (trace)
camphor (15.9%)
terpinen-4-ol (0.9%)
trans-piperitol (trace)
α-terpineol (0.6%)
myrtenol (trace)
cis-piperitol (0.2%)
trans-carveol (0.2%)
cis-carveol (trace)
neral (trace)
geraniol (trace)
linalyl acetate (trace)
bornyl acetate (0.4%)
carvacrol (trace)
α-terpinyl acetate (trace)
eugenol (trace)
geranyl acetate (0.4%)
β-caryophyllene (0.6%)
aromadendrene (0.1%)
α-humulene (1.6%)
germacrene D (trace)
γ-muurolene (0.1%)
β-selinene (trace)
viridiflorene (trace)
δ-cadinene (trace)
spathulenol (trace)
caryophyllene oxide (0.2%)
viridiflorol (1.7%)
humulene oxide* (0.3%)
β-eudesmol (trace)
α-cadinol (trace)
α-eudesmol (trace)
manool (0.5%)

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*correct isomer not identified

The enantiomeric distribution of camphor, which was found at levels of 11.8-24.9% in two French oils of *S. officinalis*, was found to be as follows (Tateo et al. 1999):

(1S)-(-)-camphor (15.1-23.4%) :
(1R)-(+)-camphor (76.6-84.9%)

In 2000, Asllani reported that there were 5,000-6,000 tonnes of dried sage leaves available in Albania, although only 1,500-1,700 tonnes were exported annually. Also, he noted that the annual production of sage oil in Albania ranged from 19-30 tonnes. In this same report, the ranges of oil composition for Albanian sage oil produced in various regions of the country were presented. A summary of the results of the numerous analyses performed by Asllani can be seen in Table VIII.

Finally, it was interesting to note that Wang et al. (1998) characterized the presence of four glucopyranosides in sage leaves. The aglycones of these glycosides were:

(1S,2R,4R)-2-hydroxy-1,8-cineole
(6R,9S)-3-oxo-α-ionol
(6R,9R)-3-oxo-α-ionol
eugenol

Table V. Comparative percentage composition of the oils of five clones of *Salvia officinalis*

Compound	Portuguese clone oils	Hungarian clone oils	Romanian clone oils	Czeck clone oils	French clone oils
tricyclene	0.1-0.2	trace-0.2	trace-0.1	0.1	0.1-0.2
α-pinene	4.8-6.6	1.9-4.91	3.4-9.0	0.8-1.3	0.8-2.9
α-thujene	-	0-trace	-	0-trace	trace-0.1
camphene	4.2-5.3	2.6-5.9	2.2-2.9	2.6-3.8	2.0-3.2
β-pinene	2.6-3.3	1.1-1.6	1.5-4.4	1.0-1.6	1.0-2.8
sabinene	0.1-0.2	0.1-0.2	0.1-0.2	0.1	0.1-0.2
α-phellandrene	trace	trace	trace	trace	trace
myrcene	0.7-1.0	0.1-1.0	trace-0.8	0.2-0.8	0.4-1.0
α-terpinene	0.1	0.1-1.0	0-0.2	0-0.1	0.1
limonene	1.1-1.7	0.6-1.5	0.4-1.4	0.4-1.4	0.5-1.5
1,8-cineole	13.4-17.0	7.1-11.9	3.6-6.0	9.5-13.3	8.6-13.4
(E)-β-ocimene	0.1-0.2	trace-0.2	0-1.3	trace-0.1	0.1-0.3
γ-terpinene	0.1-0.3	0.1-0.4	0-1.0	trace-0.3	0.1-0.5
(Z)-β-ocimene	trace	trace	0-0.3	trace	trace-0.1
p-cymene	0.1-0.3	0.1-0.2	0.3-0.4	0.1-0.2	0.1-0.2
terpinolene	0.3-0.4	0.1-0.3	0-0.3	0.1-0.3	0.1-0.7
α-thujone	1.1-1.9	19.6-25.1	18.9-26.6	0.5-0.9	20.9-31.9
β-thujone	15.0-17.7	1.5-2.9	5.0-9.2	20.6-25.9	2.5-8.9
camphor	27.0-32.2	23.8-27.9	18.2-32.9	20.8-31.8	15.8-24.0
linalool	0.3-0.4	0.5-0.8	0.3-1.4	0.8-1.2	0.2-0.8
bornyl acetate	0.8-1.9	1.4-3.9	0.6-1.4	0.6-0.9	0.4-2.8
isobornyl acetate	0-0.2	-	0-0.4	0-trace	0-trace
β-caryophyllene	2.4-4.3	1.7-6.0	0.7-1.6	4.8-8.0	1.0-4.6
terpinen-4-ol	0.1-1.1	0.4-0.5	0.2-1.2	0.1-0.4	0.2-0.4
aromadendrene	0-0.4	0-trace	0-0.4	0-0.3	0-0.3
umbellulol*	trace-1.2	0-0.2	0.1-0.4	0.1-3.2	0.1-7.3
α-humulene	0.9-1.8	6.8-12.4	0.4-10.5	1.3-5.2	0.3-7.6
thujyl alcohol	0.4-1.0	0.1-0.2	0.1-0.7	0.2-1.3	0-0.4
umbellulol*	0.4-3.9	0-0.1	0.1-3.5	0.1-6.1	trace-3.0
borneol	0.5-3.7	1.6-4.3	0.7-3.3	0.2-3.7	0.6-4.5
isoborneol	0.3-2.0	0.3-0.6	0.2-0.9	0.1-0.4	trace-0.9
myrtenol	0.1-0.6	trace-0.1	trace-0.2	0.1-0.3	0.1-0.6
trans-carveol	0.1-0.2	trace-0.1	trace-0.2	0.1	trace
p-cymen-8-ol	0-0.2	trace-0.1	0.1	trace-0.1	trace
caryophyllene oxide	0.2-0.5	0.1-0.5	0.1-0.4	0.3-0.6	0.1-0.3
ledol†	1.7-2.8	2.8-7.5	1.7-3.6	4.9-6.8	3.0-6.2
caryophyllen-8-ol	0.1-0.9	1.1-2.6	0-4.3	0.9-1.6	1.9-2.5

* correct isomer not identified
† probably a misidentification of viridiflorol

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Table VI. Percentage composition of sage oil analyzed by conventional and fast GC

Compound	Conventional GC	Fast GC
α-pinene	3.08	2.78
camphene	2.24	2.00
β-pinene	7.33	7.29
sabinene	0.43	0.36
myrcene	0.94	1.05
α-terpinene	0.18	0.19
ocimene[a]	0.93	1.10
1,8-cineole	8.92	9.25
ocimene[b]	1.28	1.40
γ-terpinene	0.30	0.42
p-cymene	0.13	0.19
terpinolene	0.22	0.34
α-thujone	30.94	30.04
β-thujone	5.45	5.37
camphor	5.57	5.57
linalool	0.34	0.33
bornyl acetate	0.72	0.59
β-caryophyllene	8.00	9.55
terpinen-4-ol	0.14	0.22
α-humulene	8.52	9.21
borneol	3.95	4.20
α-terpineol	0.16	0.26
caryophyllene oxide	5.65	6.10

[a] = (Z)-β-ocimene
[b] = (Z)-β-ocimene

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Pinus sylvestris oil

In 1986, Shatar reported that Scots pine needle oil produced from trees growing in Mongolia possessed the following composition:

α-pinene (53.0%)
camphene (13.0%)
β-pinene (0.5%)
δ-3-carene (12.0%)
myrcene (5.2%)
limonene (6.3%)

Four years later, Kreis et al. (1990) used enantiomeric separation on a chiral capillary GC column to determine that the enantiomeric ratios of α-pinene, β-pinene and limonene in Scots pine oil were found to be:

(S)-(-)-α-pinene (73-77%) : (R)-(+)-α-pinene (23-27%)
(S)-(-)-β-pinene (96-97%) : (R)-(+)-β-pinene (3-4%)
(S)-(-)-limonene (41-57%) : (R)-(+)-limonene (43.59%)

As the result of a chiral GC separation of the monoterpene hydrocarbons of Scots pine oil, Koenig et al. (1990) determined that (-)-limonene, (-)-camphene and (-)β-pinene were by far the major enantiomers in an authentic oil. The authors also examined a second commercial oil and found from the enantiomeric distribution of the above three compounds that it was adulterated with a citrus oil or citrus hydrocarbons.

The amounts and enantiomeric distribution of the monoterpene hydrocarbons of the low δ-3-carene chemotype and the high δ-3-carene chemotype of *P. sylvestris* of Finnish origin were examined were examined by Hiltunen and Laakso (1995). A summary of their results can be seen in Table IX.

Also in 1995, Stepen compared the composition of *Pinus sylvestris* oil produced in Siberia from needles harvested in July and September. He found that the oil varied as follows:

santene (1.8-3.4%)
tricyclene (1.6-3.1%)
α-pinene (29.2-36.6%)
camphene (5.3-7.0%)
β-pinene (2.2-4.2%)
myrcene (4.6-5.9%)
δ-3-carene (3.4-11.6%)
limonene (6.1-8.7%)
β-phellandrene (3.5-4.3%)
γ-terpinene (0.9-1.2%)
terpinolene (0.1-0.2%)
longifolene (0.3-0.9%)
β-caryophyllene (0.4-0.9%)
ε-muurolene (0.1-0.7%)
α-humulene (0.1-0.4%)
β-bisabolene (0.2-1.2%)
α-muurolene (0.3-1.4%)
fenchone (1.6-1.9%)
isofenchone[a] (0.5%)
α-fenchol (0.1-0.2%)
camphor (2.1-2.9%)
γ-terpineol[b] (2.0-2.4%)
terpinen-4-ol (1.2-1.6%)
isoborneol (1.8-2.2%)
borneol (0.4-0.7%)
bornyl acetate (1.1-3.2%)
α-terpinyl acetate (0.3-0.5%)

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[a] also known as 1,5,5-trimethyl-exo-2-norbornanone
[b] probably typographical error for α-terpineol

Furthermore, it was found that the oil produced in July was richer in monoterpene hydrocarbons than the oil produced in September, while the latter oil was richer in oxygenated constituents (13.1% of which were not identified).

Table VII. Percentage composition of the volatiles in the peltate and capitate glandular trichome secretions and of ambrate resinous droplets in mature leaves of *Salvia officinalis*

	Peltate glandular trichomes		Capitate glandular trichomes	Ambrate resinous droplets
Compound	**opaque**	**transparent**		
α-pinene	3.6	1.1	6.0	5.3
sabinene	-	5.3	-	-
β-pinene	16.0	2.7	25.9	22.5
1,8-cineole	14.3	46.1	32.6	28.0
α-thujone	17.4	6.3	6.6	13.0
β-thujone	-	1.5	-	-
camphor	-	1.5	0.3	-
borneol	-	1.9	0.7	-
α-terpineol	-	1.5	0.1	0.4
eugenol	-	-	trace	-
β-caryophyllene	14.3	15.1	11.1	10.2
longifolene	0.4	-	trace	-
β-gurjunene	0.4	0.7	-	-
selina-3,7(11)-diene	0.6	-	0.1	-
aromadendrene	5.2	-	0.7	1.5
α-guaiene	0.5	-	trace	-
α-humulene	7.7	3.1	1.6	1.5
allo-aromadendrene	0.4	-	0.1	-
germacrene D	-	1.9	0.1	-
γ-cadinene	0.1	-	0.3	-
eremophilene	0.3	-	-	-
cis-calamenene	0.3	-	trace	-
9,10-dehydro-isolongifolene	0.3	-	-	0.2
α-amorphene	0.9	-	0.1	0.4
ledene	10.1	7.0	6.1	10.0
birformene	7.3	4.5	7.6	7.1

The following year, Orav et al. (1996) analyzed an oil of Estonian *P. sylvestris* needle oil. Using a combination of GC and GC/MS they determined that the oil was comprised of the following constituents:

tricyclene (0.7%)
α-thujene (0.2%)
α-pinene (28.1%)
camphene (3.4%)
sabinene (1.0%)
β-pinene (2.1%)
myrcene (2.1%)
α-phellandrene (0.2%)
δ-3-carene (23.7%)
α-terpinene (0.2%)
p-cymene (0.1%)
β-phellandrene + 1,8-cineole (1.0%)
limonene (0.8%)
(E)-β-ocimene (1.5%)
γ-terpinene (0.3%)
terpinolene (2.6%)
camphor (trace)
borneol (0.3%)
terpinen-4-ol (0.4%)
α-terpineol (0.1%)
citronellol (trace)
geraniol (trace)
bornyl acetate (1.8%)
α-terpinyl acetate + δ-elemene (0.6%)
neryl acetate + α-cubebene (trace)
geranyl acetate + α-ylangene (trace)
α-copaene (0.1%)
longifolene (0.1%)
β-elemene (0.3%)
β-bourbonene (0.1%)
β-caryophyllene (2.9%)
β-copaene (0.1%)
α-humulene (0.5%)
α-guaiene† (0.1%)
ε-muurolene + β-guaiene* (0.3%)
γ-muurolene (2.0%)
germacrene B[a] (0.2%)
α-muurolene (2.8%)
α-farnesene* (0.8%)
calamenene* (0.2%)
γ-cadinene (1.2%)
δ-cadinene (4.8%)
a cadinene* (0.1%)
β-farnesene† (0.2%)
caryophyllene oxide (4.9%)
α-muurolol + T-cadinol (0.7%)
T-muurolol (1.0%)
α-cadinol (2.7%)

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* correct isomer not identified
† incorrect identity based on elution order
[a] bicyclogermacrene based on elution order

Table VIII. Percentage composition of sage oils produced in different regions of Albania

Compound	NW-1	NW-2	NE-3	N-4	M-5	M-6	S-7	SE-8
α-thujene	0.35-0.63	0.35-0.63	0.58-0.78	0.26-0.35	0.10-0.71	0.20-0.46	0.29-0.44	0.35-0.63
α-pinene	3.07-4.67	1.87-2.99	2.73-4.17	3.14-5.22	3.98-6.39	3.68-5.44	2.25-3.24	2.58-3.89
camphene	4.50-7.57	3.84-6.17	3.52-5.59	4.32-7.49	4.94-7.57	4.78-7.90	4.35-7.49	6.04-8.34
β-pinene	0.31-1.24	1.06-1.94	0.85-1.11	0.14-1.39	0.86-2.46	0.19-1.16	0.46-0.68	0.47-1.10
myrcene	0.77-1.32	0.91-1.94	1.00-1.03	1.04-1.30	0.18-1.63	1.05-1.22	1.07-1.24	0.80-1.03
α-terpinene	0.10-0.29	0.11-0.43	0.24-0.31	0.18-0.97	0.07-1.45	0.12-0.20	0.08-0.73	0.10-0.23
limonene	0.87-1.90	0.34-1.88	1.44-1.81	0.93-1.26	1.03-2.94	0.91-1.87	0.87-2.30	0.72-2.52
1,8-cineole	7.09-15.04	3.87-10.89	8.78-13.49	10.19-14.46	16.08-23.08	12.86-23.38	9.87-21.35	8.42-12.84
trans-sabinene hydrate	0.06-0.23	0.07-0.90	0.42-0.46	0.16-2.25	0.04-0.90	0.86-2.14	0.15-0.43	0.09-2.77
p-cymene	0.03-0.91	0.20-1.86	0.03-0.96	0.10-0.92	0.22-0.95	0.43-0.97	0.19-0.29	0.15-0.73
γ-terpinene	0.07-0.43	0.09-0.75	0.04-0.22	0.16-0.21	0.03-0.61	0.88-1.16	0.19-0.21	0.20-0.29
α-thujone	21.35-33.68	30.35-49.27	24.46-35.05	22.51-31.54	15.04-25.70	12.27-24.63	12.27-21.04	14.08-19.27
β-thujone	5.04-10.49	6.42-7.90	7.58-9.68	5.81-8.87	4.46-7.58	4.37-6.42	3.14-5.44	2.74-5.63
camphor	16.26-25.70	13.68-20.71	16.08-21.63	19.35-23.16	23.16-28.44	16.26-24.07	23.51-37.75	22.34-37.75
linalool	-	0-0.19	0-0.19	0.08-2.32	0-0.10	0.07-0.11	0.07-0.12	0.03-0.25
bornyl acetate	0.31-3.87	0.31-1.63	1.14-2.66	1.31-2.02	1.11-4.23	0.89-2.12	1.65-3.28	1.39-3.99
borneol	1.43-5.45	1.07-4.73	0.63-4.13	0.84-2.02	2.20-5.92	3.80-5.33	3.43-5.40	2.20-5.06
terpinen-4-ol	0.07-1.86	0.11-0.70	0.23-0.24	0.37-0.44	0.09-0.24	0.91-1.85	0.06-0.26	0.02-0.32
α-terpineol	0.11-1.93	0.11-0.25	0.03-0.47	0.12-0.34	0.11-0.85	0.09-1.94	0.03-0.20	0.04-0.62
β-caryophyllene	3.84-6.43	5.63-10.19	3.25-4.37	2.88-6.24	4.13-7.22	2.99-4.85	4.36-7.34	4.55-6.90
α-humulene	2.04-3.21	0.92-3.21	2.45-3.77	4.10-6.24	2.48-5.59	1.37-3.24	3.80-5.34	4.55-10.12

NW-1 – Northwest zone (Rec-Vojushl), NW-2 – Northwest zone (Manita-Velje), NE-3 – Northeast zone (Kukes), N-4 – North zone (Tropaje-Puke), M-5 – Middle zone (Mollas-Elbasan), M-6 = Middle zone (Berat), S-7 = South zone (Devina) and SE-8 – Southeast zone (Tepelene-Permet)

Sjödin et al. (1996) determined that the (-)-enantiomers of α-pinene, camphene, β-pinene, sabinene, limonene and β-phellandrene predominated in *P. sylvestris* needle oil of Swedish origin, whereas only the (+)-enantiomer of δ-3-carene was detected.

The headspace of *P. sylvestris* seedlings was found by Wibe et al. (1998) to contain the following relative amounts of the enantiomeric forms of seven monoterpene hydrocarbons:

(+)-α-pinene (29.0%)
(-)-α-pinene (17.6%)
(+)-camphene (0.5%)
(-)-camphene (0.8%)
(+)-β-pinene (0.4%)
(-)-β-pinene (2.2%)
(+)-sabinene (trace)
(-)-sabinene (1.8%)
(+)-δ-3-carene (45.8%)
(-)-δ-3-carene (0%)
(+)-limonene (0.3%)
(-)-limonene (0.8%)
(+)-β-phellandrene (trace)
(-)-β-phellandrene (0.8%)

Scots pine needle oil of Yugoslavian origin was determined by Ruzic et al. (1999) to contain the following constituents:

tricyclene (0.7%)
α-pinene (40.3%)
camphene (3.6%)
sabinene (0.2%)
β-pinene (15.7%)
myrcene (4.8%)
δ-3-carene (1.1%)
α-terpinene (0.2%)
p-cymene (0.2%)
limonene + β-phellandrene (23.9%)
γ-terpinene (0.2%)
terpinolene (0.6%)
borneol (0.1%)
α-terpineol (0.4%)
longipinene* (0.9%)
citronellol (0.1%)
longifolene (0.1%)
β-caryophyllene (1.2%)
germacrene D (0.4%)

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* correct isomer not identified

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Spike lavender oil

Two samples of spike lavender oil of Spanish origin were subjected to multidimensional GC/MS-chiral GC analysis from which Bernreuther and Schreier (1991) were able to determine that the enantiomeric ratio of linalool in spike lavender oil was R-(-) (48.2-51.7%) : S-(+) (48.3-51.8%). The authors noted that these oils appeared to be adulterated with racemic linalool.

According to Ravid et al. (1992), terpinen-4-ol occurs in spike lavender oil in approximately 3.3%. The enantiomeric distribution was further found to be (4S)-(+) (93%) : (4R)-(-) (7%).

In 1996, Guillen et al. analyzed an oil of spike lavender produced from plants cultivated in northeastern Spain. The components identified in this oil on using GC and GC/MS as the analytical procedures were as follows:

tricyclene (0.05%)
α-thujene (0.02%)
α-pinene (1.11%)
camphene (0.56%)
sabinene (0.47%)
β-pinene (1.48%)
myrcene (0.15%)
α-terpinene (0.33%)
terpinolene (0.69%)
1,8-cineole (31.31%)
cis-sabinene hydrate (0.61%)
cis-linalool oxide* (0.77%)
trans-linalool oxide* (0.05%)
linalool (36.94%)
camphor (13.60%)
pinocamphone (0.04%)
borneol (1.13%)
terpinen-4-ol (0.19%)
epoxylinalool* (0.07%)
1,1,3-trimethyl-2-oxobicyclo [2.2.2] octan-5-one† (0.24%)
α-terpineol (0.79%)
verbenone (0.12%)
hexyl isobutyrate (0.15%)
hexyl butyrate (0.37%)
hexenyl butyrate* (0.05%)
bornyl formate (0.11%)
hexyl 2-methylbutyrate (0.42%)
hexyl valerate (0.19%)
linalyl acetate (0.10%)
bornyl acetate (0.10%)
neryl acetate (0.02%)
hexyl tiglate (0.10%)
hexyl hexanoate (0.03%)
linalyl butyrate (0.03%)
isobornyl isovalerate (0.17%)
α-ylangene (0.02%)
β-bourbonene (0.19%)
β-cubebene (0.02%)
bergamotene* (0.13%)
bergamotene* (0.11%)
β-caryophyllene (0.47%)
β-cadinene (0.01%)
bergamotene* (0.22%)
α-humulene (0.3%)
farnesene* (0.03%)
farnesene* (0.11%)
farnesene* (0.06%)
germacrene A (0.08%)
ar-curcumene (0.01%)
β-bisabolene (0.24%)
γ-cadinene (0.12%)
caryophyllene oxide (1.59%)
farnesol* (0.03%)
T-cadinol (0.08%)
α-bisabolol oxide (0.02%)
α-bisabolol (0.23%)

* correct isomer not identified
† unusual oil constituent, probably misidentified

Table IX. Variation in the percentage composition of the chiral and non-chiral monoterpene hydrocarbons in the low and high δ-3-carene chemotypes of *Pinus sylvestris*

Compound	Low δ-3-carene chemotype (44)[a]	High δ-3-carene chemotype (84)
α-thujene	-	trace-0.3
(-)-α-pinene	10.7-62.7	5.0-37.6
(+)-α-pinene	12.0-71.0	9.4-66.7
tricyclene	0.3-4.2	0.3-3.6
myrcene	0.6-4.8	0.6-6.5
(-)-camphene	2.6-12.1	1.0-10.4
(+)-sabinene	trace-0.2	trace-0.5
(+)-camphene	0.5-1.3	0.3-2.5
(-)-sabinene	trace-0.3	0.2-1.5
(+)-β-pinene	0.4-2.6	0.2-0.4
(+)-δ-3-carene	trace-1.2	78.5-54.4
(-)-β-pinene	1.6-11.8	2.2-3.7
α-terpinene	-	trace-1.2
(Z)-β-ocimene	-	trace-0.3
(-)-limonene	0.1-2.3	0.1-2.4
(+)-limonene	0.1-2.1	0.2-1.4
(E)-β-ocimene	0.1-2.0	0.1-3.2
p-cymene	trace-2.2	0.2-5.2
(+)-β-phellandrene	0.1-0.9	0.2-1.0
γ-terpinene	-	trace-0.6
terpinolene	trace-1.5	0.1-5.1

[a] number of samples

An oil of *L. latifolia* produced in France was found by Canaud and Martineau (1996) to possess the following composition:

α-pinene (1.8%)
camphene (0.8%)
β-pinene (2.0%)
sabinene (0.6%)
myrcene (0.6%)
limonene (0.3%)
1,8-cineole (25.5%)
camphor (18.5%)
linalool (27.3%)
linalyl acetate (2.9%)
lavandulyl acetate (0.3%)
terpinen-4-ol (0.7%)
β-caryophyllene (1.6%)
lavandulol (0.3%)
α-terpineol (1.0%)
borneol (2.5%)

Using a stable isotope dilution assay and mass fragmentography, George (1996) determined that the coumarin content of spike lavender oil was 216 ppm.

Spike lavender oil produced in Samalao, Catamarca, Argentina was analyzed for its major component composition by Mizrahi et al. (1999). The oil was found to contain the following main constituents:

1,8-cineole (20.7%)
linalool (25.2%)
camphor (23.5%)
linalyl acetate (1.6%)
lavandulyl acetate (1.3%)
terpinen-4-ol (0.3%)
lavandulol (0.9%)
α-terpineol (1.6%)
borneol (7.0%)

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Roasted chicory extract

Chicory (*Cichorium intybus L.*) is a biennial or perennial herbaceous member of the Asteraceae family. It is indigenous to Europe, Egypt and Asia and has become a naturalized weed in North America. The cut herb and dried roots have been used in both traditional medicines and in natural medicines both in Europe and in Asia (Lueng and Foster 1996). The root is rich in inulin (a fructose oligomer), sucrose, fructose and glucose (Wright and van Nierkerk 1983). Bitter sesquiterpene lactones such as lactucin, 8-deoxylactucin and lactucopicrin have also been identified in the root (Leclercq et al. 1988). Chicory roots are also rich in acids with the two main acids being malic and citric (Gaber and Maier 1989). On roasting chicory roots the contents of malic and citric are reduced and formic, acetic, quinic, lactic and hydroxyacetic acids are increased. Pyroglutamic acid, which is also found in chicory root, is additionally slightly reduced on roasting (Gaber et al. 1990).

In 1994, Barlianto and Maier determined the range of acids in chicory root. They identified the following acids:

pyruvic
lactic
2-oxobutyric
2-oxovaleric
glycolic
4-oxovaleric
2-furoic
oxalic
3-hydroxypropionic
methylmalonic
benzoic
phosphoric
2-hydroxycaproic
maleic
succinic
methyl succinic
citraconic
methylglyceric

itaconic
glyceric
fumaric
glutaric
mesaconic
2,4-dihydroxybutyric
3,4-dihydroxybutyric
4-chlorophenylacetic
malic
pyroglutamic
aspartic
5-hydroxymethyl-2-furoic
3-hydroxybenzoic
erythronic
2-hydroxyglutaric
threonic
2-oxoglutaric
meso-tartaric
3-hydroxy-3-methylglutaric
2-oxoglutaric
4-hydroxybenzoic
4-hydroxyphenylacetic
glutaric
ribonic (lactone)
tartaric
succharinic
threo-isosaccharinic (lactone)
erythro-isosaccharinic (lactone)
arabonic (lactone)
2-phthalic
vanillic
(Z)-aconitic
(E)-aconitic
azeliac
2,5-dihydroxybenzoic
arabo-metasaccharinic (lactone)
ribo-metasaccharinic (lactone)
ribonic
2,4-dihydroxybenzoic
3,4-dihydroxybenzoic
3-deoxypentanoic
arabonic
citric
isocitric
4-hydrooxycinnamic
quinic
saccharinic
ribo-metasaccharinic
arabo-metasaccharinic
threo-metasaccharinic
gluconic
mannonic
3,4-dihydroxycinnamic
3-(3-indolyl)-lactic
5-hydroxyindole-2-carboxylic

In a follow-up paper, Barlianto and Maier (1995) determined which of the above acids were derived from carbohydrate degradation during roasting.

Roasted chicory root and its extract have been used for many years as a substitute for coffee. In addition, the extract of roasted chicory root has also found use as a component of flavors. In 1977, Kawabata and Deki examined the volatiles of roasted chicory roots. In this study, the following compounds were identified:

toluene
xylene
methylstyrene
acetophenone
methyl tolyl ketone
formaldehyde
acetaldehyde
propanal
butanal
valeraldehyde
furfural
furfuryl alcohol
2-acetylfuran
5-methylfurfural
2-methyl-6-isopropylfuran
furfuryl pyrrolyl ketone
2-hexanone
2-hydroxy-3-methyl-2-cyclopenten-1-one
phenylacetic acid
cinnamic acid
phenylpropionic acid
tetradecanoic acid
hexadecanoic acid
octadecanoic acid
phenol
ethylphenol
vinylphenol
2,5-dimethylpyrazine
trimethylpyrazine
2,6-diethylpyrazine
benzothiazole
2-methoxybenzothiazole
2-methylthiobenzothiazole
2-acetylpyrrole
2-acetyl-5-furfurylpyrrole

Unfortunately, the authors did not present any quantitative data; however, they stated that acetophenone was a characteristic component of roasted chicory root.

Five years later, Sannai et al. (1982) examined the steam volatile constituents of roasted chicory roots. Using a combination of modern analytical techniques, they identified the following volatiles:

furfuraldehyde (2.80%)
4-acetylpyrazole (0.15%)
benzaldehyde (trace)
5-methyl-2-furfural (0.04%)
phenylacetaldehyde (1.04%)
furfural alcohol (0.20%)
methyl phenylacetate (trace)
methylcyclopentenolone (0.15%)
benzothiazole (trace)
2-acetylpyrrole (3.77%)
2-furyl-hydroxymethyl ketone (0.63%)
2-formyl-5-methylpyrrole (0.51%)
methyl palmitate (1.85%)
dihydroactinodiolide (0.11%)
coumarin (0.20%)
benzoic acid (0.37%)
5-hydroxymethyl-2-furfural (4.27%)
methyl oleate (0.89%)
vanillin (5.48%)
phenylacetic acid (2.49%)
methyl linoleate (7.45%)
methyl linolenate (2.00%)
2-(5-hydroxymethyl)-2-formylpyrrol-1-yl) isovaleric acid lactone (0.56%)
pentadecanoic avid (0.1%)
2-(5-hydroxmethyl-2-formylpyrrol-1-yl) 4-methyl valeric acid lactone (1.4%)
7-methoxycoumarin (0.99%)
methyl 3-hydroxybenzoate (0.64%)
palmitic acid (5.80%)
oleic acid (0.60%)
linoleic acid (6.74%)
linolenic acid (2.45%)

The same authors also found that the aroma components of air-dried chicory root comprised of the following compounds:

benzothiazole (0.7%)
phenylacetic acid (0.2%)
methyl linoleate (0.1%)
pentadecanoic acid (1.8%)
palmitic acid (60.2%)
oleic acid (0.9%)
linoleic acid (31.5%)
linolenic acid (2.9%)

Baek and Cadwallader (1998) used GC/MS to compare the headspace volatiles and the steam distilled volatiles of roasted chicory. A summary of their results can be seen in Table X. In addition, trace quantities of some other components were also found as can be seen as follows:

benzaldehyde
2,4-nonadienal*
1-ethylidenephenylacetaldehyde
2,4-dimethoxybenzaldehyde
1-octen-3-one
1-(3 or 2-pyrindinyl)-ethanone
1-(1-ethyl-1H-pyrrol-2-yl)-ethanone
3-methyl-2-furfuraldehyde
furoic acid
5-(2-furanylmethyl)-2-furfuraldehyde
5-(hydroxymethyl)-2-furfuraldehyde
tetramethylpyrazine
2-methyl-5-propylpyrazine
2-vinyl-6-methylpyrazine
2-methyl-5-(1-propenyl)-pyrazine
2-methyl-3-propylpyrazine
octanoic acid
2-methoxy-4-(2-propenyl)-phenol
hexadecanoic acid
methyl oleate

Furthermore, the authors determined that the most impactful components found in the volatile concentrate of roasted chicory were:

2,3-butanedione (buttery)
2-ethyl-3,5-dimethylpyrazine (baked potato/nutty)
1-octen-3-one (mushroom-like)
3-methylbutanal (chocolate-like)

Two other compounds, one that had a roasted chicory, sweet odor and the other which was sweet chocolate-like were also found to be impactful, although they were not identified in this study. Of the compounds characterized in roasted chicory, 2-ethyl-3,5-dimethylpyrazine had the lowest threshold.

Using a Likens-Nickerson process of simultaneous hydrodistillation and extraction using diethyl ether as the extracting solvent, a volatile concentrate of dried ground roasted chicory roots (C. intybus) was produced and analyzed by Choi (1999). Because the chicory roots were roasted, many of the constituents identified during the GC/MS analysis of this volatile concentrate were pyrazinic in nature as can be seen as follows:

ethyl acetate (0.55%)
methylpyrazine (1.01%)
2,5-dimethylpyrazine (4.35%)
2,6-dimethylpyrazine (4.02%)
2-ethyl-6-methylpyrazine (0.83%)
2-ethyl-3-methyl pyrazine (4.83%)
trimethylpyrazine (1.62%)
3-ethyl-2,5-dimethylpyrazine (13.82%)
5-ethyl-2,3-dimethylpyrazine (2.46%)
furfuraldehyde (1.04%)
acetic acid (0.13%)
2-acetylfuran (0.56%)
5-methylfurfuraldehyde (0.03%)
isobutyric acid (0.33%)
dihydro-2(3H)-furanone (0.65%)
isovaleric acid (7.93%)
furfuryl alcohol (2.33%)
2-acetyl-3-methylpyrazine (0.49%)
2-furoic acid (1.10%)
tetrahydro-2(2H)-pyranone (0.78%)
hexanoic acid (2.82%)
2-acetylpyrrole (10.33%)
1H-pyrrole-2-carboxaldehyde (1.68%)
3-phenyl-2-propenal (0.55%)
2-formyl-1-methylpyrrole (1.24%)
1,4-cyclohexanediol (0.61%)
2-methyl-2-piperazine (2.00%)
propanal dimethylhydrazone (0.91%)
3-isopropyl-2,4-5-trimethyl-pyrazine (0.15%)

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Table X. Comparative chemical composition (%) of the volatiles isolated by simultaneous distillation-extraction (SDE) and dynamic headspace of roasted chicory

Compound	SDE volatiles	Headspace volatiles
2-methylbutanal	-	0.231
3-methylbutanal	-	0.088
3-methylpentanal	0.024	0.037
2-butenal*	0.013	-
hexanal	0.057	0.119
2-methyl-2-butenal*	0.002	0.016
nonanal	-	0.056
phenylacetaldehyde	-	0.179
(E,Z)-2,4-decadienal	-	0.025
1-(2-methylpropylidene)-phenylacetaldehyde	0.027	0.113
5-methyl-2-phenyl-2-hexenal*	0.056	0.151
3-buten-2-one	0.011	-
2,3-butanedione	0.331	0.050
4-methyl-2-pentanone	0.003	0.006
2,3-pentanedione	0.425	0.714
3-penten-2-one*	0.012	0.021
cyclopentanone	0.018	0.027
2,4-pentanedione	0.009	-
1-phenyl-2-propanone	0.018	-
1-(1H-pyrrol-2-yl)-ethanone	0.096	-
4-hydroxy-3-methylacetophenone	0.023	0.028
2,3-dimethylfuran	0.024	0.021
2-(2-propenyl)-furan	0.001	0.005
2-pentylfuran	0.022	0.025
2-methoxymethylfuran	0.024	0.053
dihydro-2-methyl-3(2H)-furanone	1.787	1.705
furfuryl formate	-	0.155
5-methyl-2(3H)-furanone	-	0.152
2-furfuraldehyde	9.485	26.226
1-(2-furanyl)-ethanone	1.338	3.257
2-furanmethanol acetate	-	0.974
5-methyl-2-furfuraldehyde	2.078	5.323
$2,2^1$-bisfuran	-	0.422
$2,2^1$-methylenebisfuran	-	0.133
2-acetyl-5-methylfuran	0.039	-
dihydro-2(3H)-furanone	0.067	-
2-furanmethanol	1.264	0.813
2(2-furanylmethyl)-5-methylfuran	0.055	0.171
2(5-methyl-2-furanyl)1-propanone	0.032	0.024
3,4-dimethyl-2,5-furandione	0.031	-
2,2-methylenebis-5-methylfuran	0.046	0.112
2-methyl-3-β-furylpropenal	0.017	0.052
$2,2^1$-oxybis(methylene) bisfuran	0.028	0.115
5-(5-methyl-2-furanyl)methyl-2-furfuraldehyde	0.006	-
pyrazine	0.002	0.002
methylpyrazine	0.074	0.093
2,5-dimethylpyrazine	0.187	0.158
2,6-dimethylpyrazine	0.310	0.249
ethylpyrazine	0.028	0.040
2,3-dimethylpyrazine	0.063	0.015
2-ethyl-6-methylpyrazine	0.112	0.100
2-ethyl-5-methylpyrazine	0.015	0.062
trimethylpyrazine	0.062	0.071
2-ethyl-3,6-dimethylpyrazine	0.009	0.128
2-ethyl-3,5-dimethylpyrazine	0.019	0.013
2,5-dimethyl-3-(2-methylpropyl)-pyrazine	0.061	0.086
2,5-dimethyl-3-(3-methylbutyl)-pyrazine	-	0.120
2,6-dimethyl-3-(3-methylbutyl)-pyrazine	0.073	-
N-furfurylpyrrole	0.015	0.022
N-furfuryl-2-acetylpyrrole	0.023	0.044
N-furfuryl-2-formylpyrrole	0.009	0.017
toluene	0.003	0.074
dimethyl disulphide	-	0.030
pyridine	0.005	0.017
1-methoxy-4-methylbenzene	0.009	0.006
3-methylbutryic acid	0.106	-
methyl phenylacetate	-	0.057
2,6-bis(1,1-dimethylethyl)-4-methylphenol	0.222	0.378
2-methylphenol	0.016	0.013
phenol	0.017	0.023
2,3-dimethylphenol	-	0.009
methyl hexadecanoate	0.017	-

*correct isomer not identified