Chemical and Sensory Evaluation of Three Sage Oils

By Mans H. Boelens, Boelens Aroma Chemical Information Service, Huizen, The Netherlands and Harrie Boelens, Leiden University, The Netherlands

The genus *Salvia* belongs to the plant family Lamiaceae, which includes many aromatic plants. This genus, also called Sage, covers more than 500 species, of which *Salvia officinalis* L. (Dalmatian sage), *S. lavandulaefolia* Vahl. (Spanish sage) and *S. sclarea* L. (Clary sage) are the most important economically for the flavor and fragrance industry. Their essential oils are used in various flavor formulations and in perfume compounds for high-grade perfumery, cosmetics and functional products. Each of these oils contains hundreds of chemical compounds that are responsible for its sensory properties.

This article discusses the chemical composition of these three *Salvia* oils from various parts of the world, and describes the odor qualities of the oils and the olfactive properties of some characteristic compounds.

Botanical Origin

The genus *Salvia* contains more than 500 different species. Epling[1] wrote, in 1939, that the genus *Salvia* includes about 900 species. Onayade et al.[88] mentioned that *Salvia* is a large genus of the family Lamiaceae that comprises about 700 herbs found throughout the temperate and warmer parts of the world. More recently, Compton[2] published a review on the *Salvia* species.

A minority of these species possesses essential oils (see sidebar). Apart from the three species that are the subject of this article, the species *Salvia triloba* L. (syn. *S. fructicosa* Mill.) is also known for its essential oil. While some *Salvia* species are used for the production of essential oils, the main use for these plants is as ornamentals. In Great Britain, about 250 species and varieties are cultivated for ornamental use.

Salvia species are found in Europe and America. The birthplaces of these species are probably Middle and Southern Europe. Kustrak[97] discussed the subspecies of *Salvia officinalis* growing in former Yugoslavia. Emboden and Lewis[3] studied the chemical composition of the oils of a series of uncommon North American (Californian) *Salvia* species (see sidebar). They tentatively identified the major monoterpenoids in the oils, which were reviewed by Lawrence.[4]

Dalmatian Sage Oil

The species *Salvia officinalis* L. is also called common sage, garden sage or Dalmatian sage. Dalmatian sage oil is isolated from *Salvia officinalis* L., which grows in Mediterranean countries, especially Dalmatia (former Yugoslavia) and Albania. Smaller quantities are distilled in Bulgaria, France, Turkey and Germany.

Lawrence[104] reported in 1985 that Dalmatian sage is produced in former Yugoslavia (15 tons) and Albania (25 tons). He mentioned that the total production did not exceed 40 metric tons in 1984.

The oil is obtained by steam distillation of the partially dried leaves. The physical properties of the oil have been described in detail.[6,7,8] The main constituents of the oil are α- and β-thujone.

In 1965, Dalmatian sage oil was granted GRAS status by FEMA and approved by the FDA for food use.[9] In 1970, the Council of Europe[10] included Dalmatian sage oil in the list of substances, spices and seasonings deemed admissible for use, with a possible limitation on the more toxic active principles (thujones) in the final product. The *Food Chemicals Codex*[11] and Research Institute Fragrance Materials (RIFM)[12] have published monographs on Dalmatian sage oil.

Worldwide production of Dalmatian sage oil is less than 25,000 kg/yr. Dalmatian sage oil is used in perfumery for its

0272-2666/97/0002-0019$04.00/0—

delicate fresh herbaceous note, both in compounds for alcoholic and cosmetic perfumery and in functional perfume compositions. Dalmatian sage oil is also used in flavoring formulations for alcoholic beverages, liqueurs, canned meat and spice sauces, and it finds application in pharmaceutical preparations.[99]

Chemical Evaluation of Dalmation Sage Oil

The chemical composition of Dalmatian sage oil has been investigated[7,8] for more than 100 years. Detailed studies of the oil have been available since 1960.

Dalferth[13] wrote his PhD thesis on mono- and sesquiterpenoids of some sage essential oils. He studied the oils of *Salvia officinalis*, *S. lavandulaefolia* and *S. triloba*.

A detailed analysis of the chemical composition of Dalmatian sage oil was published in 1964 by Brieskorn and Dalferth.[14] Their results are shown in Table I.

In the same year,[15] these authors confirmed the structure of salvene (2-methyl-3-methylene-hept-5-ene) by modern spectroscopic techniques and discussed a possible biogenesis of the compound, starting from thujone.

Brieskorn and Melchior[16] reported on the quantitative change of terpenoids in the germ-bud and leaf of Dalmatian sage under various conditions. They found that in the germ-bud of sage the essential oil consists only of terpene hydrocarbons. With further growth, mono- and sesquiterpenoids appear, and they will be preferentially synthesized.

Lawrence et al.[17] reported a detailed study of Dalmatian sage oil and mentioned some new constituents. The authors identified 20 known compounds in the oil, and 26 other components were elucidated for the first time (Table I). Since this study, Lawrence[18] also identified trace amounts of 1-octen-3-ol, α-corocalene, selina-5,11-diene and ledene (Table I).

Embong et al.[19] published their studies on the composition of essential oils from herbs and spices grown in Alberta (Canada). Their results on the composition of sage oil from *S. officinalis* are shown in Table I. The authors compared the composition of a commercial oil with the isolated oil (Table I).

Lawrence[18] mentioned that it was shown that Dalmatian sage grown under prairie conditions in Canada possessed a lower volatile oil content than Dalmatian sage, and the oil was of an inferior quality to normal Dalmatian sage oil.

In 1978, Ivanic et al.[20] compared the chemical composition of oils from the Sicevska, Njegusi and Peljesac

Some Salvia Species Containing Essential Oils
(with references to published research)

Salvia officinalis L.[1-45,104]
S. officinalis L. var. *angustifolia* Ten.[95]
S. officinalis L. ssp. minor f. *auriculata*[97]
S. lavandulaefolia Vahl[46-56]
(syn. *S. officinalis* var. *hispanica* Boiss.)
S. officinalis x *S. lavandulifolia* ssp. *vellera*[94]
S. sclarea L.[60-76]
S. caespitosa Montbret et Aucher ex Benth.[93]
S. candelabrum Boiss[85]
S. canariensis L.[78,90]
S. clevelandii (Gray) x *S. leucophylla* Greene[91]
S. confertiiflora Pohl[78]
S. coccinea Juss. ex Murr.[88]
S. cryptantha Montbret et Aucher ex Benth.[92]
S. dominica L.[89]
S. dorisiana Standley[82]
S. fruticosa Mill.[87]
S. grahamii Benth.[78] (syn. *S. microphylla* H.B.K.)
S. gilliesii Benth.[80]
S. hispanica L.[83] (black chia)
S. mexicana L.[78]
S. nemorosa L.[59]
S. pisidica Boiss et Heldr.[86]
S. pomifera L. (syn. *S. calycina* Sibth et Sm.)[13,79,81]
S. scabiosifolia (Lam.)[84]
S. somaliensis Vatke[78]
S. stenophylla (Burch. ex) Benth[96]
S. syriaca L.[102]
S. tomentosa Mill.[84]
S. triloba L. (syn. *S. fructicosa* Mill.)[13,77,79]
S. verticillata L.[59]
S. willeana Holmboe[79]

North American (Californian) *Salvia* species Containing Essential Oils
(reported by Emboden and Lewis[3] and reviewed by Lawrence[4])

Salvia apiana Jepson
S. brandegei Munz.
S. californica Jepson
S. carduaceae Benth.
S. clevelandii (Gray) Greene
S. columbariae Benth.
S. dorrii (Kellog) Abrams
S. eremostacha Jepson
S. funerea M.E. Jones
S. greatai Brandeg
S. leucophylla Greene
S. mellifera Greene
S. mohavensis Greene
S. munzii Epling
S. nemorosa L.
S. pachyphylla Epling ex Munz.
S. sonomensis Greene
S. spathacea Greene
S. vaseyi (Porter) Parish

Table I. Chemical composition (%) of Dalmatian sage oils reported 1964-1978

Compound	Unknown origin 1964[14]	Unknown origin 1971[17,18]	Alberta, Canada 1977[19]	Commercial 1977[19]	Yugoslavian & commercial 1978[20]
cis-salvene	0.5	0.1	-	-	-
trans-salvene	-	t	-	-	-
tricyclene	0.3	-	-	-	-
α-thujene	0.1	-	0.5	0.8	-
α-pinene	3.5	1.5	3.6	3.4	3.3-4.3
camphene	-	3.3	3.8	7.2	0.8-3.5
β-pinene	2.8	1.4	2.1	1.4	-
myrcene	0.3	1.2	1.1	1.1	-
α-terpinene	-	0.2	-	-	-
α-phellandrene	-	-	0.1	0.1	-
p-cymene	-	0.8	0.1	0.2	1.2-1.6
limonene	0.7	2.2	2.3	2.5	0.6-1.4
(Z)-β-ocimene	-	t	-	-	-
(E)-β-ocimene	-	t	-	-	-
γ-terpinene	-	0.5	-	-	-
terpinolene	-	0.4	-	-	-
trans-allo-ocimene	-	t	-	-	-
α-p-dimethylstyrene	-	0.1	-	-	-
1,8-cineole	14.0	9.3	5.4	10.0	9.6-11.2
trans-3-hexenal	-	t	-	-	-
1-octen-3-ol	-	t	-	-	-
linalool	1.8	0.4	1.2	0.5	-
linalyl acetate	0.6	-	-	-	0.7-1.9
borneol	2.2	t	2.4	4.3	2.0-13.2
bornyl acetate	2.7	1.9	3.2	2.6	0.8-3.3
terpinen-4-ol	-	4.0	-	-	0.4-5.1
δ-terpineol	-	t	-	-	-
sabinyl acetate	-	2.2	-	-	-
sabinol	-	3.4	-	-	-
α-terpineol	-	3.4	-	-	-
p-cymene-8-ol	-	t	-	-	-
carvone	0.6	-	-	-	-
estragol	-	-	0.4	0.4	-
fenchone	-	-	0.1	0.2	-
α-thujone	28.0	29.0	20.5	19.9	28.0-40.0
β-thujone	14.5	5.5	3.2	3.7	8.5-23.4
camphor	18.0	26.0	10.3	25.6	0.4-0.9
α-cubebene	-	t	-	-	-
copaene	-	t	-	-	-
β-bourbonene	-	0.3	-	-	-
farnesene	0.5	-	-	-	-
α-gurjunene	-	0.1	-	-	-
humulene	2.9	2.2	16.4	5.5	-
isocaryophyllene	-	t	-	-	-
caryophyllene	1.7	4.4	-	-	3.3-7.2
α-maaliene	-	0.2	-	-	-
β-copaene	-	0.2	-	-	-
aromadendrene	-	t	-	-	-
allo-aromadendrene	-	0.3	-	-	-
δ-cadinene	-	0.1	-	-	-
γ-cadinene	-	0.1	-	-	-
calamenene	-	0.1	-	-	-
caryophyllene oxide	-	1.1	-	-	-

t = trace; - = absent

regions of former Yugoslavia with a commercially available Dalmatian sage oil. Rather large variations in the concentrations of α-thujone (28-40%), β-thujone (8-23%) and borneol (2-13%) were found. The concentration ranges of the identified compounds are given in Table I.

After studying the analyses of the chemical composition of the oils as shown in Table I, one may question whether sabinol and sabinyl acetate are present, or whether they are confused with other components in Dalmatian sage oil. The author assumes that sabinol and sabinyl acetate are present in the oils, but that these compounds elutriated together with camphor and bornyl acetate, respectively, on an apolar gas chromatographic column.

In 1979, Rhyu[21] published his results on the gas chromatographic characterization of sages of various geographic origins. Sages procured from Yugoslavia, Albania, Greece, Turkey and Italy were ground and steam-distilled in the laboratory. Gas chromatographic profiles obtained on the resulting volatile oils suggest that the Greek, Turkish and Italian oils are strikingly similar. Rhyu believes that these are *Salvia triloba*, and that although both the Yugoslavian and Albanian are *S. officinalis*, they display substantial differences. The Yugoslavian sage may be subclassified into those plants grown in the Dalmatian region and those grown elsewhere in Yugoslavia.

The gas chromatographic results of the analyses of the various oils from Dalmatia, Yugoslavia and Albania are shown in Table II. What appears strange in the analytical data of these oils is the rather low concentration of thujone (12-33%) and the relatively high concentration of linalool (12-35%). Perhaps linalool was confused with one of the thujones.

Burgar et al.[22] used modern spectroscopic techniques to characterize the main components in Dalmatian sage oil (Table III).

Koedam et al.[23] reported on the comparison of isolation-procedures

Table II. Chemical composition (%) of Dalmatian sage oils from Albania and former Yugoslavia (1979)[21]

	Yugoslavia		
Compound	from within Dalmatia	from outside Dalmatia	Albania
α-pinene	2.7-4.3	2.0-5.2	0.1-10.9
camphene	3.1-5.4	3.7-9.1	1.2-6.8
β-pinene	0.3-0.6	0.3-3.3	0.2-0.7
myrcene	0.3-1.0	0.1-1.0	0.5-0.8
limonene	1.0-1.9	1.2-2.8	1.5-4.3
1,8-cineole	9.3 -12.9	7.3 -13.2	5.5-10.1
thujone	19.4 -32.9	17.7 -27.0	12.7-18.2
camphor	8.1 -14.1	1.2-6.5	1.9- 3.3
linalool	11.9 -25.7	22.3 -29.5	21.5-35.0
terpineol	0.1-2.1	1.0-5.9	5.3-9.1
caryophyllene	0.1-1.0	0.3-5.5	2.5-4.1

for essential oils of rosemary and sage (Table III). They studied the influence of time and conditions of distillation on the composition of volatile oils from rosemary and sage. It was demonstrated that the oils distill almost quantitatively within one hour. The acidity of the distillation water was of minor importance; only at extremely low pH-values (2-3) could small effects on some constituents be noticed during distillation. This was explained by the fact that the epidermal oil glands burst upon contact with the boiling water and give off their oil quickly, thus preventing the formation of artifacts.

In 1982, Formacek and Kubeczka[24] reported on the chemical composition of Dalmatian sage oil in their well-known book on the analysis of essential oils by capillary gas chromatography and carbon-13 NMR spectroscopy (Table III).

In the same year, Fehr[25] published his results on the chemical composition of laboratory-distilled oil obtained from seven different samples of sage leaves (Table III).

Karl et al.[26] confirmed the presence of viridiflorol in *Salvia officinalis* by modern spectroscopic techniques.

In 1983, Cordoba Rodriguez[27] wrote her PhD thesis on the chemical composition of Spanish sage oil. She also determined the composition of 14 samples of Dalmatian sage oil (Table III).

In 1984, Pitarevic[28] studied the seasonal variation in the composition of oils isolated from *Salvia officinalis* leaves collected in the Doli-Ston district of Dubrovnik (Croatia) (Table III).

Also in 1984, Kustrak et al.[29] reported on their investigation of Dalmatian sage oil obtained from different geographical locations within former Yugoslavia (Table IV).

Table IV suggests that at least two chemotypes of Dalmatian sage exist; that is, one with a low β-thujone content (4-8%) and another with a relatively high β-thujone content (16-32%). Analogous results were obtained by Formacek & Kubeckzka[24] and by Koedam et al.[23]

In 1984, Holeman et al.[30] made a comparative study of the oils from five *Salvia* species grown in Morocco; namely,

Table III. Chemical composition (%) of Dalmatian sage oils reported 1979-1984

Compound	1979[22]	1980[23]	1982[24]	1982[25]	1983[27]	1984[28]
cis-salvene	0.5	0.7	0.64	-	0.4	-
trans-salvene	-	0.1	0.10	-	0.1	-
tricyclene	0.3	0.3	0.23	-	0.2	-
α-thujene	0.1	<0.1	0.18	-	0.3	-
α-pinene	3.5	3.2	3.70	1.7-5.9	4.8	2.3-3.6
camphene	3.7	2.7	7.37	3.1-7.5	6.2	1.7-3.2
sabinene	-	0.2	0.12	-	0.2	-
β-pinene	2.8	1.9	2.33	0.3-1.6	2.3	0.7-1.6
myrcene	0.3	1.1	1.14	0.5-0.8	1.1	0.9-1.2
α-terpinene	-	0.2	0.20	-	-	-
α-phellandrene	-	<0.1	0.06	-	0.1	-
p-cymene	-	-	-	0.2-0.7	2.0	-
limonene	0.7	0.9	3.24	1.1-2.0	3.1	0.9-1.5
β-phellandrene	-	0.1	-	-	0.9	-
(Z)-β-ocimene	-	-	0.07	-	0.2	-
γ-terpinene	-	0.3	0.39	-	0.3	0-0.4
terpinolene	-	<0.1	0.30	-	0.2	-
trans-sabinenehydrate	-	0.2	-	-	0.1	-
cis-sabinenehydrate	-	<0.1	-	-	-	-
1,8-cineole	14.0	8.4	11.34	6.9-11.2	11.1	5.8-13.2
α-thujone	28.0	31.8	25.88	17.0-21.6	26.5	12.3-27.3
β-thujone	14.5	33.2	2.69	1.7-3.7	4.3	20.6-40.1
camphor	18.0	4.1	22.80	23.1-27.3	16.8	7.1-16.4
linalool	1.8	0.4	0.48	0.5-0.7	0.5	0.3-0.5
linalyl acetate	0.6	-	-	-	0.5	0.3-0.8
borneol	2.2	1.5	3.00	3.7-4.5	2.1	1.4-3.4
bornyl acetate	2.7	0.1	1.23	1.1-2.8	1.4	0.4-1.1
terpinen-4-ol	-	0.2	-	0.2	0.3	-
α-terpineol	-	0.1	-	-	0.5	-
α-terpinyl acetate	-	0.55	-	-	0.2	-
trans-sabinol	-	<0.1	-	-	-	-
sabinyl acetate	-	-	-	-	0.3	-
farnesene	0.6	-	-	-	-	-
α-copaene	-	-	0.14	-	-	-
humulene	2.9	4.8	5.31	2.6-6.0	5.0	0.8-3.4
caryophyllene	1.7	2.2	3.29	1.0-4.0	3.3	0-0.7
δ-cadinene	-	-	0.23	-	-	-
caryophyllene oxide	-	-	0.13	-	-	-
viridiflorol	-	-	0.83	-	-	-

- = absent

Table IV. Chemical composition (%) of Dalmation sage oils from different locations in former Yugoslavia[29]

Compounds	Mainland (Mt. Velebit)	Coastal (Pouljana)	Hvar coastal (Hvar)	Hvar inland (Velo Grabije)
α-thujene	0.4-0.9	0.2-1.4	0-0.7	0-0.5
α-pinene	5.7-6.6	2.9-3.3	3.5-4.2	2.7-4.9
camphene	6.2-8.1	4.5-4.9	6.6-8.5	2.4-5.5
β-pinene	1.4-2.7	1.2-3.4	1.1-2.6	1.1-3.0
limonene	1.8-2.6	2.1-3.6	1.0-2.4	2.2-3.6
p-cymene	0.7-0.9	0.8-1.1	1.1-1.8	1.4-1.7
1,8-cineole	9.0-10.4	16.6-22.5	7.8-12.3	9.2-13.1
α-thujone	23.6-26.2	28.9-36.3	7.2-14.8	22.3-29.4
β-thujone	3.9-5.4	3.9-8.1	23.1-31.9	15.9-29.3
linalyl acetate	0-0.8	-	-	0-3.5
camphor	20.5-23.1	10.7-19.6	12.8-14.9	7.0-15.2
linalool	0.4-2.4	0.6-1.6	0-4.7	0.3-2.7
bornyl acetate	2.1-3.5	2.1-4.2	0.6-6.4	1.5-2.5
isoborneol	t-2.8	0.4-0.9	0-2.1	0.1-1.5
borneol	10.0-11.0	7.6-12.4	9.0-15.5	0-7.9

t = trace

Salvia officinalis, S. aucheri, S. verbenaca, S. phlomoides and *S. argentea*. The oils of *Salvia officinalis* were isolated in March and June; their main constituents are shown in Table V.

In 1985, Marlier et al.[31] published their GC/MS analysis of the chemical composition of an oil derived from *Salvia officinalis* grown in Peru (Table VIa).

According to Kustrak et al.,[32] a standard-quality Dalmatian sage oil should possess the chemical composition shown in Table VIa.

In 1986, Grzunov et al.[33] reported their studies of terpene alcohols in β-glucosides found in the leaves of Dalmatian *Salvia officinalis*. The results suggest that the terpene alcohols in β-D-glucosides that are present in Dalmatian sage leaves are thujol, menthol and thymol. The same alcohols were also detected in the essential oil of the plant.

Also in 1986, Farag et al.[34] published their results of biochemical studies on the essential oils of some medicinal plants, including that of *Salvia officinalis*. The most prevalent volatile compounds of thyme, rosemary and sage oils were found to be thymol, α-pinene and thujone, respectively.

Vernin and Metzger[35] reported on the qualitative chemical composition of the oils of *Salvia officinalis* L. and *Salvia lavandulaefolia* Vahl. from Albania, Dalmatia and Spain. The main constituents in the oils were also quantified and are shown in Table VIa.

Tamas et al.[36] examined the chemical composition of Dalmatian sage oil produced in Romania. Using gas chromatographic retention times for their analysis, they found figures as shown in Table VIa.

Bayrak and Akguel[37] reported on their gas chromatographic analysis of a Turkish essential oil from *Salvia officinalis* (Table VIb).

Tucker and Maciarello[38] published the chemical composition of a lab-distilled oil obtained from a cultivated broad-leaved variety of *Salvia officinalis* (Table VIb).

Lawrence[39] examined the chemical composition of sage oils produced from *Salvia officinalis* cultivated in an experimental garden in the United States (Table VIb).

Lemberkovics et al.[40] reported on the gas chromatographic determination of mono- and sesquiterpenes in commer-

Table V. Main constituents (%) of Dalmatian sage oil from Morocco[30]

Compound	Harvested March 1981	Harvested June 1983
α-pinene	5.6	8.7
β-pinene	3.7	3.8
camphene	5.6	6.4
1,8-cineole	15.3	13.8
α-thujone	2.7	2.1
β-thujone	24.9	24.7
camphor	22.6	18.3
caryophyllene	2.6	7.0
borneol	2.4	5.3
terpineol	3.0	0.6

Table VIa. Chemical composition (%) of Dalmation sage oils from various countries

Compound	Peru[31]	Dalmatia[32]	Albania[35]	Dalmatia[35]	Romania[36]
cis-salvene	-	-	+	+	-
trans-salvene	-	-	+	+	-
α-thujene	-	-	0.17	0.12	-
α-pinene	+	1.30	3.40	3.97	4.88
camphene	+	2.75	4.90	3.19	4.31
sabinene	-	2.12	0.10	0.10	-
β-pinene	+	4.80	1.10	0.97	0.34
myrcene	+	1.39	0.55	0.72	-
α-terpinene	+	0.21	0.08	0.14	-
p-cymene	+	0.57	0.80	1.12	-
α-phellandrene	-	-	-	-	0.37
limonene	+	1.68	1.46	1.25	0.56
γ-terpinene	+	0.62	0.11	0.18	-
(Z)-β-ocimene	-	-	0.04	0.02	-
(E)-β-ocimene	-	-	0.02	0.01	-
terpinolene	-	-	0.11	0.12	-
hexanol	+	-	-	-	-
3-hexenol	+	-	-	-	-
1-octen-3-ol	+	-	+	+	-
1,8-cineole	+	10.93	8.20	12.00	13.68
α-thujone	+	24.57	23.40	37.15	10.94
β-thujone	+	13.98	3.45	14.20	23.10
camphor	+	12.35	22.45	14.30	26.53
isopinocamphone	+	-	-	-	-
linalool	+	-	0.51	0.40	-
linalyl acetate	-	-	0.01	0.01	-
isobornyl acetate	-	3.39	-	-	-
borneol	+	4.42	3.00	1.50	7.49
bornyl acetate	+	0.93	3.50	0.86	-
terpinen-4-ol	+	-	0.50	0.20	-
α-terpineol	+	-	2.00	0.30	2.34
α-terpinyl acetate	-	-	0.30	0.17	-
sabinyl acetate	-	-	+	+	-
trans-sabinol	-	-	-	-	-
p-cymene-8-ol	-	-	0.13	0.05	-
humulene	+	-	6.90	3.87	-
caryophyllene	-	-	6.00	2.00	-
δ-cadinene	-	-	+	+	-
caryophyllene oxide	-	-	+	+	-
humulene oxides	-	-	0.80	0.48	-

+ = present; - = absent

Table VIb. Chemical composition (%) of Dalmatian sage oils from various countries

Compound	Turkey[37]	Commercial[38]	USA[39]	Hungary[40]	Italy[41]
cis-salvene	-	0.01	0.01-0.10	-	0.04-0.06
trans-salvene	-	0.01	-	-	0.03-0.12
α-thujene	-	0.15	0.01-0.20	-	0.04-0.20
α-pinene	3.5	3.00	1.68-5.37	5.4	0.27-3.86
camphene	4.7	3.89	1.67-5.74	6.5	1.14-5.65
sabinene	-	0.01	0.01-0.79	-	0-0.24
β-pinene	1.8	0.20	1.05-14.48	5.1	0.23-2.02
myrcene	0.8	0.07	0.27-1.09	-	0-0.73
α-terpinene	0.1	0.04	0.01-0.32	-	-
p-cymene	1.1	0.27	-	0.9	0.30-0.77
limonene	1.4	0.49	0.55-2.46	3.6	0-1.42
γ-terpinene	0.4	0.03	0.01-0.97	-	-
(Z)-β-ocimene	-	0.01	0.10-1.00	-	-
(E)-β-ocimene	-	0.01	0.01-1.67	-	-
γ-terpinene	0.4	0.01	0.01-0.97	-	-
terpinolene	-	0.03	0.01-0.34	-	-
1,8-cineole	5.0	-	2.25-18.00	9.0	4.98-13.4
α-thujone	20.6	8.60	13.94-44.05	18.3	35.90-45.8
β-thujone	15.1	4.43	2.47-9.90	6.6	4.35-9.60
camphor	22.9	44.00	1.90-21.00	15.1	15.50-21.1
linalool	1.1	0.50	0.16-0.54	0.8	-
linalyl acetate	1.0	-	-	-	-
borneol	7.9	3.00	-	3.7	0.74-3.20
bornyl acetate	2.6	1.79	0.19-1.41	0.9	0.82-2.75
thujyl acetate	-	-	-	-	0.07-0.19
terpinen-4-ol	-	0.05	0.10-0.50	-	0-0.89
α-terpineol	-	0.15	0.01-0.28	-	-
α-terpinyl acetate	0.9	0.46	-	-	-
trans-sabinol	-	-	1.30-7.66	-	-
α-copaene	-	0.05	-	-	-
β-bourbonene	-	0.09	-	-	-
α-maaliene	-	0.05	-	-	-
β-copaene	-	0.05	-	-	-
α-gurjunene	-	0.05	0.04-0.14	-	-
humulene	2.1	0.02	1.53-10.65	4.8	0-3.85
caryophyllene	4.1	0.39	1.40-10.00	3.9	0-3.78
aromadendrene	-	0.05	-	-	-
allo-aromadendrene	-	-	-	-	0-0.35
δ-cadinene	-	-	0.01-0.10	-	-
caryophyllene oxide	-	-	0.16-1.27	-	0.44-2.17
viridiflorol	-	-	0.35-9.91	-	-
manool	-	-	0.11-5.91	-	-

+ = present; - = absent

cial Hungarian essential oils (Table VIb).

Piccaglia et al.[41,45] published the chemical composition of Italian sage oil (Table VIb).

Tucker and Maciarello[42] studied the chemical composition of the essential oils of eight cultivars of Dalmatian sage from the horticultural trade in North America and compared the composition with those of commercial sage oils. Their results are shown in Tables VIIa and VIIb. The following five groups are based on the four principal (>5%) constituents of these cultivars:

- Camphor > α-thujone > 1,8-cineole > β-thujone
- Camphor > α-thujone > β-thujone > 1,8-cineole
- β-Thujone > camphor > 1,8-cineole > α-thujone
- 1,8-Cineole > camphor > α-thujone > β-thujone
- α-Thujone > camphor > β-thujone > 1,8-cineole

In 1988, Kustrak[97] wrote about the yield and chemical composition of an oil isolated from a subspecies of *S. officinalis* in former Yugoslavia. The plant material of *S. officinalis* ssp. *minor f. auriculata* yielded an oil in 1.55%, containing as main constituents: α-pinene (5.5%), camphene (6.4%), limonene (2.4%), 1,8-cineole (7.3%), α-thujonene (35.3%), β-thujonene (5.6%), camphor (18.1%), linalyl acetate (1.7%), borneol (1.7%), and α-terpineol (5.9%).

In 1992, Svoboda and Deans[44] reported on a study of the variability of rosemary and sage (*Salvia officinalis*) and their volatile oils on the British market, and their antioxidative properties. The main constituents of the essential oil obtained from samples of dried herb sage of different geographical origins are shown in Table VIII.

It will be clear from the figures in Table VIII that, in the various countries, different chemotypes of *Salvia officinalis* exist; that is, Italian, Turkish and Greek types vary significantly from those of the United Kingdom and Dalmatia.

In 1995, Pace and Piccaglia[95] analyzed by GC/MS the essential oil of a wild type of Italian sage classified as *Salvia officinalis* L. var. *angustifolia* Ten. Thirty-four components were identified in the oil. The most abundant were β-pinene (7%), 1,8-cineole (8%), α-thujone (39%), β-thujone (3%), camphor (2%), α-humulene (12.5%) and globulol (2%).

Sensory Evaluation of Dalmatian Sage Oil

Dalmatian sage oil has a fresh-herbaceous, warm-spicy, somewhat camphoraceous odor and flavor. The fresh-herbal odor characteristics are mainly due to the presence of α- and β-thujone. The camphoraceous note is emitted by camphor. The oil has a slightly woody dry-out due to the presence of sesquiterpenoids such as humulene, caryophyllene and viridiflorol.

Arctander[57] reported that Dalmatian sage oil is used for its power; partly as a topnote material, partly for its relatively good tenacity. The fadeout of the oil's odor is sweet-herbaceous and very pleasant. The oil blends well with lavandin, rosemary, citrus oils and bois de rose oil. It introduces fresh notes in fougeres, chypres, aldehydic perfume bases, colognes and spicy "men's fragrances"

Table VIIa. Chemical composition (%) of oils from cultivars of North American Dalmatian sage[42]

Compound	Albiflora	Berggarten	Compacta	Icterinaia
cis-salvene	0.10	-	-	0.08
tricyclene	-	0.70	0.19	0.36
α-pinene	0.92	7.17	4.08	5.82
camphene	2.53	10.29	5.51	7.54
β-pinene	1.31	8.38	6.12	10.92
sabinene	0.09	0.28	0.18	0.31
myrcene	0.77	2.16	3.08	0.73
α-terpinene	-	0.20	0.12	0.12
limonene	2.16	3.72	7.57	2.11
γ-terpinene	0.14	0.59	1.03	0.38
para-cymene	0.27	0.32	0.73	0.18
terpinolene	0.13	0.94	0.41	0.21
α-thujone	1.55	6.05	4.55	11.43
1-octen-3-ol	-	0.50	0.20	0.69
β-thujone	36.77	2.34	1.02	2.17
α-copaene	-	0.24	0.08	0.13
camphor	22.80	25.20	18.62	22.15
bornyl acetate	0.55	5.71	1.83	3.36
β-cubebene	-	0.23	-	-
terpinen-4-ol	-	0.52	-	0.26
caryophyllene	4.19	0.68	3.89	1.93
allo-aromadendrene	-	-	0.91	-
α-humulene	6.23	6.32	6.02	9.84
muurolene	-	1.34	-	-
borneol	1.73	6.24	5.61	0.69
δ-cadinene	-	-	0.61	0.82
caryophyllene oxide	-	-	-	0.52
viridiflorol	6.44	0.37	-	-

- = absent

Table VIIb. Chemical composition (%) of oils from cultivars of North American Dalmatian sage[42]

Compound	Purpurascens	Ribriflora	Tricolor	Woodcate Farm
cis-salvene	0.10	0.75	0.10	0.13
tricyclene	0.23	0.16	0.29	0.77
α-pinene	5.13	2.21	5.53	5.28
camphene	5.46	3.68	7.35	7.00
β-pinene	13.17	2.00	11.50	8.06
sabinene	0.51	0.32	0.44	0.74
myrcene	0.65	1.14	0.60	1.22
α-terpinene	0.12	0.23	0.10	0.38
limonene	1.40	2.42	1.96	3.37
1,8-cineole	2.28	5.29	0.74	2.40
γ-terpinene	0.34	0.64	0.32	0.84
para-cymene	0.19	0.71	0.17	0.25
terpinolene	0.06	0.35	0.15	0.98
α-thujone	17.01	27.12	14.20	10.60
1-octen-3-ol	0.41	-	0.59	-
β-thujone	2.38	6.21	2.59	2.60
α-copaene	0.45	-	0.10	0.31
camphor	14.65	18.51	19.73	17.19
bornyl acetate	0.12	0.78	1.39	4.73
β-cubebene	-	-	-	-
terpinen-4-ol	0.51	0.90	0.11	0.87
caryophyllene	2.01	5.71	2.07	1.48
allo-aromadendrene	0.42	-	-	0.42
α-humulene	16.72	0.18	18.95	9.99
muurolene	-	-	-	1.51
borneol	1.50	1.73	2.52	4.02
δ-cadinene	1.94	0.14	0.69	1.04
caryophyllene oxide	0.10	1.11	0.42	-
viridiflorol	4.39	4.72	3.50	2.36

- = absent

for after-shave lotions and toilet waters.

The same author described the odor of thujone (α/β) as powerful and penetrating, warm-herbaceous and minty-camphoraceous of moderate to poor tenacity.

Spanish Sage Oil

Spanish sage oil is produced in Spain from *Salvia lavandulaefolia* Vahl. In 1985, Lawrence[104] reported that about 5 metric tons of Spanish sage oil were produced during 1984.

The oil is used in perfumery in compounds for general purposes, but especially in technical and functional perfumes, such as those intended for soap, room sprays and household products.

The oil is obtained by steam distillation of the partially dried leaves. The physical properties of the oil have been described in detail.[6-8] The main constituents of the oil are 1,8-cineole and camphor.

In 1965, Spanish sage oil was granted GRAS status by FEMA and approved by the FDA for food use.[9] In 1974 the Council of Europe[10] included Spanish sage oil in the list of substances, spices and seasonings deemed admissible for use. The *Food Chemicals Codex*[11] and RIFM[12] have published monographs on Spanish sage oil.

Table VIII. Main constituents (%) of Dalmatian sage oils from dried herbs of various origins[44]

Compound	Italy	Turkey	UK	Dalmatia	Greece
borneol	0.9-5.9	0.6-5.0	2.8-7.0	3.3-4.0	3.2
camphene	1.7-5.1	3.3-8.8	3.9-8.7	4.0-7.2	1.8
camphor	12.5-15.3	6.2-13.6	11.6-22.0	15.2-27.4	4.1
1,8-cineole	22.1-44.8	23.0-58.4	2.7-9.0	10.4-11.7	42.0
thujones	1.2-2.4	1.8-3.5	7.0-25.3	19.8-28.8	1.4

Chemical Evaluation of Spanish Sage Oil

One of the first detailed analyses using gas chromatographic techniques was published by Brieskorn and Dalferth[14] in 1964 (Table IX).

Three years later, Cenci and Calvarano[46] reported on the chemical composition of the oils obtained from *S. lavandulaefolia* grown in southern Italy. It appears strange that the authors found neither 1,8-cineole nor camphor (Table IX).

De Gavina Mugica et al.[47] used a combination of gas chromatography and infrared spectroscopy to compare the

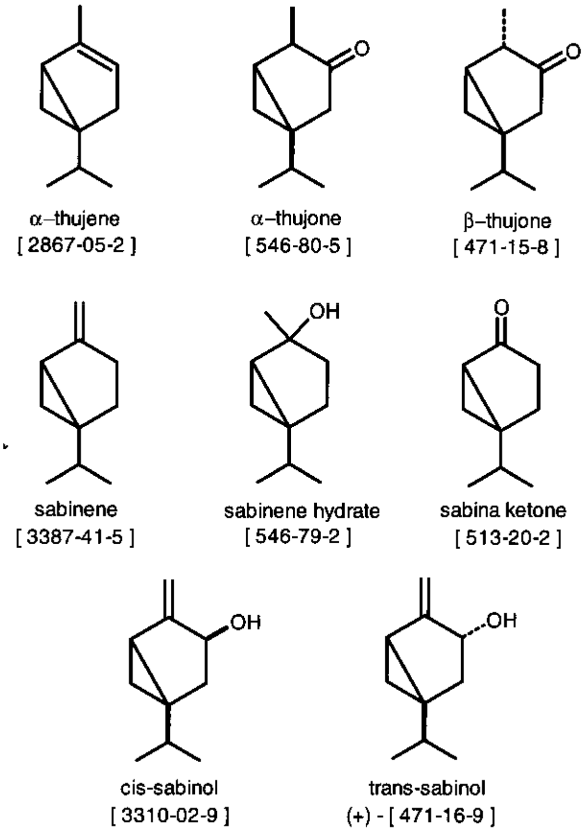

Figure 1. Structures and CAS numbers of some derivatives of thujene and sabinene

chemical composition of Spanish sage oil produced in seven provinces in Spain (Table IX).

In 1970, Lawrence et al.[48] used a combination of aluminum oxide and silver nitrate/aluminum oxide column chromatography, preparative and analytical gas chromatography, and infrared spectroscopy and found that a commercial sample of Spanish sage oil contained the compounds shown in Table IX.

A *Dragoco Report*[49] from 1979 lists the main constituents of Spanish sage oil (Table X).

Steinmetz et al.[50] reported that Spanish sage oil contained thujone and camphor, and that these compounds were responsible for the toxicity of the oil.

Pecorari et al.[51] analyzed Spanish sage oil using gas chromatographic techniques. They tentatively identified β-pinene (13.8-29.2%), 1,8-cineole (17.5-24.1%), thujone (2.1-4.2%), camphor (2.8-11.6%) and caryophyllene (4.4-90.4%).

Formacek and Kubeczka[24] used capillary gas chromatography and carbon-13 NMR spectroscopy to identify the main constituents of Spanish sage oil (Table X).

In 1983 Cordoba Rodriguez,[27] in her PhD thesis at the University of Madrid, reported on the chemical composition of Spanish sage oil. She analyzed 32 samples distilled from plants growing in different areas of Spain (Table X).

Table IX. Chemical composition (%) of Spanish sage oils reported 1964-1970

Compound	1964[14]	1967[46]	1969[47]	1970[48]
salvene	-	0-0.06	-	-
tricyclene	0.5	-	0.2-0.4	-
α-thujene	-	0.05-0.41	-	0.2
α-pinene	6.2	1.93-6.95	4.4-20.0	8.6
camphene	6.8	2.49-10.55	5.6-14.3	7.0
sabinene	-	-	-	1.3
β-pinene	6.1	4.93-12.73	8.5-18.9	4.5
myrcene	0.6	-	-	3.2
α-phellandrene	-	-	0-5.0	0.1
p-cymene	-	-	1.6-4.6	1.9
limonene	1.5	-	3-5	4.5
(Z)-β-ocimene	-	-	-	0.2
(E)-β-ocimene	-	-	-	0.4
γ-terpinene	-	-	-	0.05
terpinolene	-	-	0-0.8	0.05
cis-alloocimene	-	-	-	0.1
α-p-dimethylstyrene	-	-	-	0.3
α-pinene epoxides	-	-	0.2-0.7	-
1,8-cineole	29.0	-	18-36	23.0
trans-sabinene hydrate	-	-	-	0.5
linalool	1.1	-	0.2-2.7	2.0
camphor	34.0	-	10.8-32.7	20.1
borneol	2.2	-	-	0.1
isoborneol	1.0	-	-	-
terpinen-4-ol	-	-	-	0.5
δ-terpineol	-	-	-	0.05
α-terpineol	-	-	-	0.9
nerol	-	-	-	0.1
geraniol	-	-	-	0.4
sabinol	-	-	-	0.1
linalyl acetate	1.5	-	0-2.2	1.0
bornyl acetate	2.8	-	0-7.7	1.5
isobornyl acetate	1.3	-	0-4.9	-
α-terpinyl acetate	2.4	-	0-9.5	11.2
sabinyl acetate	-	-	-	3.0
α-cubenene	-	-	-	0.05
α-gurjunene	-	-	-	0.3
cis-α-bergamotene	-	-	-	0.3
trans-α-bergamotene	-	-	-	0.1
β-caryophyllene	0.35	-	0-3.1	0.5
aromadendrene	-	-	-	0.3
humulene	0.5	-	0-0.2	0.1
allo-aromadendrene	-	-	-	0.05
β-bisabolene	-	-	-	0.1
δ-cadinene	-	-	-	0.4
ar-curcumene	-	-	-	0.4
viridiflorol	0.35	-	0.1-0.9	-

- = absent

In 1984, Lawrence[52] used infrared spectroscopy to characterize the presence of viridiflorene, β-spathulene, viridiflorol and humulene epoxide II as trace constituents in Spanish sage oil.

Vernin and Metzger[35] used gas chromatography and mass spectrometry to study the chemical composition of Spanish sage (Table X).

Table X. Chemical composition (%) of Spanish sage oils reported 1979-1989

Compound	1979[49]	1982[24]	1983[27]	1986[35]	1989[55]
tricyclene	-	0.46	0-0.5	-	-
α-thujene	-	0.54	0.2-0.5	0.22	-
α-pinene	6.0	24.00	4.7-10.9	8.45	4.0-11.0
camphene	4.0	7.69	4.6-10.6	5.60	-
sabinene	-	0.34	0.6-2.2	1.49	0.1-3.0
β-pinene	7.0	2.23	3.3-7.3	3.86	-
myrcene	2.2	1.34	1.0-4.9	2.76	-
α-phellandrene	-	0.10	0-0.2	-	-
α-terpinene	-	0.13	0-0.1	0.01	-
p-cymene	1.5	0.84	0.4-2.1	0.97	-
limonene	-	2.65	2.4-5.0	3.62	2.0-5.0
(Z)-β-ocimene	-	0.22	0-2.2	0.99	-
(E)-β-ocimene	1.1	0.11	0-0.4	0.19	-
γ-terpinene	-	0.16	0-0.7	0.28	-
terpinolene	-	0.18	0-0.3	0.14	-
cis-alloocimene	-	-	0-0.3	-	-
α-p-dimethylstyrene	-	-	0-0.4	-	-
1,8-cineole	54.0	11.83	12.0-40.3	21.10	11.0-25.0
camphor	1.0	30.11	12.9-36.1	22.30	11.0-36.0
carvone	-	-	0-0.3	-	-
α-thujone	-	-	-	1.30	<0.5
β-thujone	-	-	-	0.01	<0.5
trans-sabinene hydrate	-	-	0.1-0.6	-	-
linalool	1.0	3.10	0.2-11.2	1.70	0.5-0.9
borneol	4.3	3.50	1.5-6.4	8.0	1.0-8.0
isoborneol	-	-	0.2-1.9	-	-
terpinen-4-ol	-	-	0.2-0.8	0.3	<2
δ-terpineol	-	-	0-0.7	-	-
α-terpineol	-	1.89	0.1-1.9	4.0	-
nerol	-	-	0-0.6	-	-
geraniol	-	-	0.1-0.7	0.37	-
p-cymen-8-ol	-	-	-	0.1	-
linalyl acetate	-	0.34	0.1-5.8	3.9	<0.5
neryl acetate	-	-	0.1	-	-
geranyl acetate	-	-	0.1-0.2	0.33	-
geranyl propionate	-	-	-	0.42	-
bornyl acetate	-	0.21	0.8-4.9	0.97	-
isobornyl acetate	-	0-0.7	-	-	
α-terpinyl acetate	-	0.23	-	1.1	-
cis-sabinyl acetate	-	-	0.1-6.6	-	-
α-cubebene	-	-	0-0.2	0.3	-
α-copaene	-	-	0-0.1	-	-
cis-α-bisabolene	0.2	-	-	-	-
α-gurjunene	-	-	0-0.2	-	-
cis-α-bergamotene	-	-	0-0.8	-	-
isocaryophyllene	-	-	0-0.8	-	-
β-caryophyllene	-	0.61	0.2-3.7	0.5	-
humulene	-	-	0-1.0	0.24	-
aromadendrene	-	-	0-0.2	-	-
allo-aromadendrene	-	-	0-0.4	-	-
ar-curcumene	-	-	0.1-0.9	-	-
β-bisabolene	-	-	0-0.2	-	-
curcumene	-	-	-	0.4	-
caryophyllene oxide	-	-	0.1	-	-
humulene oxide	-	-	-	0.2	-

- = absent

An anonymous author in a Portuguese publication reported on Spanish sage in 1989 (Table X).[55]

In 1988 Marcos Sanz et al.[54] reported on the chemical composition of the oils of four cultivars or chemotypes of *Salvia lavandulaefolia* growing across Spain (Table XI).

Jimenez Sindreu[56] of Destillaciones Bordas (Spain) analyzed Spanish sage using modern spectroscopic techniques (Table XII).

In 1995, Sanchez Gomez et al.[94] published their results on the chemical composition of the essential oils of *Salvia officinalis*, *S. lavandulaefolia* ssp. *vellera* and a new hybrid of these species (Table XII).

Sensory Evaluation of Spanish Sage Oil

Spanish sage oil has a fresh cineole- and camphor-like odor. Arctander[57] mentioned that Spanish sage oil is a pale mobile oil with a fresh-herbaceous, eucalyptol-camphor-like odor, a rather sharp pine-like topnote and little or no sweetness on drying out. The oil is used in soap perfumery and in the reconstitution of other essential oils, such as Spanish spike lavender oil. Spanish sage oil blends well with the related oils of rosemary, lavender, spike lavender, pine needle oils and citronella oils. It is generally used as a freshener in industrial perfumes, soap perfumes and detergent fragrances.

Clary Sage Oil

The species *Salvia sclarea* L. is also called clary, clary wort, muscatel sage, clear eye, see bright and eyebright.

Lawrence[104] reported that the former USSR was the largest clary sage oil producer, with a 1984 production estimate of 40 tons. Only 25% of this production was offered for export. He mentioned that other countries producing at least one ton were the USA (5 tons), Bulgaria (3 tons), France (2 tons), India (1 ton), Switzerland (1 ton) and Morocco (1 ton). Minor quantities of oil were also produced in Israel, South Africa, Hungary, former Yugoslavia and Italy. A total world production estimate for clary sage oil was 45 metric tons. Lalande[58] mentioned that the 1984 crop of French clary sage oil was around 3 tons.

The oil, concrete and absolute of clary sage are important ingredients of flavors and fragrances. The main constituents of clary sage oil are linalyl acetate and linalool; the principal component of clary sage absolute is sclareol.

In 1965, clary sage oil was granted GRAS status by FEMA and approved by the FDA for food use.[9] In 1974, the Council of Europe[10] included clary sage oil in the list of substances, spices and seasonings deemed admissible for use. The *Food Chemicals Codex*[11] and RIFM[12] have published monographs on clary sage oil.

Chemical Evaluation of Clary Sage Oil

The chemical composition of isolates from clary sage have been studied for more than a century.[7,8,60-76]

Leffingwell et al.[60] analyzed an oil of U.S. origin and compared it with commercial oils of Russian and French origins. The following constituents were identified: α- and β-pinene, camphene, myrcene, limonene, cis- and trans-ocimene, p-cymene, terpinolene, cis-3-hexen-1-ol, linalool, linalyl acetate, terpinen-4-ol, caryophyllene, α-terpineol, citronellol, nerol, geraniol, neryl acetate, geranyl acetate, trans-β-terpineol, β-gurjunene and caryophyllene oxide.

Corbier and Teisseire[61] reported on the occurrence of germacrene D in clary sage oil.

In 1978, Yoshida and Sawasaki[62] published a study on the variation of the yield and composition of clary sage oil. The maximum oil content (0.15-0.18%) was obtained at the end of the blossom period with an l-linalyl acetate content of 42.4-44.2%. In fractional distillation it was found that the l-linalyl acetate percentage (40-50%) and l-linalool percentage (20-25%) were high in initial distillation and low in after-distillation at 25-30% and 10-15%, respectively.

Table XIII shows the studies of clary sage oils by Formacek and Kubeczka.[24]

Maurer and Hauser[63] identified more than 250 compounds in clary sage oil. The main components identified were linalyl acetate (approximately 67%), linalool (approximately 16%) and several mono- and sesquiterpene hydrocarbons (approximately 13%). The authors also reported that the oil contained six new sesquiterpenoids:

(2R,5E)-2,12-epoxycaryophyll-5-ene
(2R,5E)-caryophyll-5-en-12-al
(2S,5E)-caryophyll-5-en-12-al
isospathulenol
(1R,5R)-1,5-epoxysalvial-4(14)-ene
salvial-4(14)-en-1-one

Table XI. Chemical composition (%) of oils from cultivars of *Salvia lavandulaefolia*[54]

Compound	*Lavandulaefolia*	Vellerea 1	Vellerea 2	Blancoana
α-thujene	0.01-0.5	0.1-0.7	0.01-0.3	0-0.1
tricyclene*	0.1-0.5	0.1-0.5	0.1-0.5	0.1-0.5
α-pinene*	3-27	3.5-15.5	2.3-9.6	4.9-5.8
camphene	0.9-14.0	5.3-17.2	2.4-9.8	0.6-4.5
β-pinene	2.3-27.5	2.3-6.6	2.3-20.9	35.5-48.4
sabinene	0-3.2	0-1.2	0.6-5.8	-
myrcene	0.6-15.6	1.2-7.2	1.3-5.4	4.6-11.3
α-phellandrene*	0.01-0.3	0-0.8	0.05-0.2	0.1-0.3
α-terpinene*	0.01-0.4	0-0.8	0.05-0.3	0.2-0.4
limonene	1.7-11.9	1.8-4.0	1.6-3.8	2.8-5.3
(Z)-β-ocimene	0-1.3	0-0.8	0-1.0	0-2.5
(E)-β-ocimene*	0.05-1.3	0.1-0.4	0.1-0.9	0.05-0.3
γ-terpinene*	0.05-1.3	0.1-0.5	0.2-0.9	0.05-0.4
p-cymene	0.01-2.3	0.01-1.5	0.1-0.7	0.01-0.3
terpinolene	0.01-0.4	0.1-0.4	0.2	0.1
cis-alloocimene	0.01-0.1	0-0.1	0.1-0.5	0.01-0.4
1,8-cineole	6.4-58.7	6.1-31.2	1.2-26.6	2.3-5.0
trans-sabinenehydrate	0.1-0.8	0.1-1.7	0.2-0.5	0.2-0.6
camphor	1.3-29.0	21.0-37.5	6.3-30.1	0.3-9.2
linalool	0.1-0.8	0.2-1.2	0.3-0.6	0.2-0.4
linalyl acetate	0.1-0.7	0.01-1.7	0.2-0.8	0.1-0.5
bornyl acetate	0-4.2	0.8-3.1	0.3-1.9	0.3-0.4
terpinen-4-ol	0.1-1.7	0.2-2.5	0.2-1.1	0.3-0.9
δ-terpineol	0.01-0.3	0-0.3	0	0-0.2
cis-sabinyl acetate	0.01-0.6	0.1-0.4	11.1-24.0	0.2
cis-sabinol	-	0	8.8-19.5	-
borneol*	0.2-9.0	2.0-10.0	0	0.4-1.0
α-terpineol*	0.2-0.4	0.2-0.5	0	0.1-0.2
α-terpinyl acetate*	0.1-0.5	0.1-0.5	0	0.1-0.2
geranyl acetate	0-0.2	0-0.3	0.6-1.5	0.01-0.6
nerol	0.01-0.2	0.01-0.4	0.01-0.1	0.1
geraniol	0-0.5	0-0.3	0.01-0.2	0-0.01
α-cubebene	0.01-0.3	0-0.2	0.01-0.1	0.01-1.1
α-copaene	0-0.1	-	-	0-0.01
β-caryophyllene	0.3-4.8	0.5-2.2	0.5-3.4	8.1-12.8
aromadendrene	0-0.5	0-0.1	-	0-0.2
allo-aromadendrene	0-0.2	0-0.1	-	0-0.2
α-humulene	0.2-3.2	0.1-1.4	0.4-2.8	1.7-6.2
bicyclogermacrene	0-0.2	0-0.3	0.6-1.5	0.01-0.6
δ-cadinene	0-0.9	0-0.3	0.01-0.1	0-2.8
caryophyllene oxide	0.1-3.3	0.4-1.3	0.5-1.3	2.2-3.8
viridiflorol	0-7.1	0.01-2.6	0.1-3.9	0.1-0.3
spathulenol	0-0.7	0-0.2	0.1-1.0	0.01-3.4
caryophyllenol	0-0.1	0-0.1	0-0.1	0.1

* estimated for all four cultivars

In 1983, Cordoba Rodriguez[27] wrote in her thesis about the chemical composition of nine clary sage oils from different origins (Table XIII).

Also in 1983, Verzar-Petri[64] reported on the biosynthesis and localization of essential oils in *Salvia sclarea*. The results demonstrated the successive biosynthesis from aliphatic monoterpenes, via cyclic monoterpenes, to bicyclic mono- and sesquiterpenes. The localization of the oil begins with the seedlings, in the cotyledon-trichoms, and goes into the glandular hairs of different types.

Lalande[58] wrote in 1984 about French farmers trying to improve the yield of clary sage oil by modernizing traditional distillation. Profiles of sage oils are now quite differ-

Table XII. Chemical composition (%) of Spanish sage oils reported 1990-1995

Compound	*S. lavandulaefolia* 1990-1995[56]	*S. lavandulaefolia* ssp. vellera 1995[94]	*S. officinalis* 1995[94]	Hybrid 1995[94]
tricyclene	0.2-0.3	-	-	-
α-thujene	0.2-0.3	0.18	0.06	0.28
α-pinene	6.5-8.1	4.37	2.98	5.26
camphene	4.3-6.6	5.11	2.10	7.83
sabinene	1.7-2.1	1.72	0.07	0.72
β-pinene	3.8-4.5	6.30	8.93	14.11
myrcene	4.1-5.0	2.18	0.50	2.94
α-phellandrene	0.1	-	-	-
δ-3-carene	0.1	-	-	-
α-terpinene	0.2-0.3	0.35	0.44	0.15
p-cymene	0.6-1.3	0.90	0.49	1.06
limonene	3.0-4.5	2.50	0.78	1.40
(Z)-β-ocimene	0.6-0.8	0.21	0.78	0.41
(E)-β-ocimene	0.2-0.3	0.15	0.17	0.15
γ-terpinene	0.3-0.8	-	-	-
terpinolene	0.2-0.4	0.20	0.17	0.13
1,8-cineole	19.0-21.0	43.73	15.71	18.01
trans-sabinenehydrate	0.1-0.2	-	-	-
cis-sabinenehydrate	0.2-0.4	-	-	-
linalool	1.4-2.7	0.62	0.28	0.23
fenchol	0.1-0.2	-	-	-
sabinol	1.5-2.5	-	-	-
α-thujone	-	-	22.82	3.04
β-thujone	-	-	4.32	0.56
camphor	13.5-20.0	14.63	4.99	10.80
borneol	1.1-2.3	3.56	6.69	8.28
terpinen-4-ol	0.5-0.6	0.94	0.69	0.53
α-terpineol	1.0-1.3	1.13	3.10	0.74
δ-terpineol	-	0.19	0.21	0.18
nerol	0.1-0.2	-	-	-
neral	0.1-0.2	-	-	-
geraniol	0.3-0.5	0.29	0.15	0.14
geranial	0.1-0.3	-	-	-
linalyl acetate	3.0-6.0	0.08	0.10	0.11
bornyl acetate	1.0-3.0	1.54	0.37	0.87
sabinyl acetate	1.8-6.2	-	-	-
α-terpinyl acetate	8.5-11.0	-	-	-
neryl acetate	0.1-0.2	-	-	-
geranyl acetate	0.4-0.7	-	-	-
cis-α-bergamotene	<0.1	-	-	-
β-caryophyllene	0.7-1.2	0.27	2.88	2.69
α-humulene	0.4-1.1	1.18	0.27	0.25
β-bisabolene	0.2-0.3	-	-	-
δ-cadinene	0.1-0.2	-	-	-
caryophyllene oxide	0.1-0.2	0.22	1.44	1.26
δ-cadinol	-	0.69	2.25	0.08
viridiflorol	-	0.29	10.92	6.21
α-cadinol	-	0.07	0.21	0.31
manool	-	-	3.57	1.94

- = absent

Table XIII. Chemical composition (%) of clary sage oil reported 1982-1985

Compound	1982[24]	1983[27]	1985[66]	1985[70]
α-pinene	0.25	0.1	0.05-0.2	0.05
camphene	-	-	0.01-0.1	0.05
β-pinene	0.29	0.1	0.1-0.3	0.05
sabinene	0.06	-	-	-
myrcene	0.20	0.5	0.3-1.7	0.05
limonene	0.51	0.2	0.13-0.45	-
α-phellandrene	-	-	-	0.05
β-phellandrene	0.07	-	-	-
α-terpinene	-	-	-	0.05
p-cymene	0.06	-	-	0.05
(Z)-β-ocimene	-	0.2	0.16-0.8	-
(E)-β-ocimene	-	0.4	0.16-1.2	-
γ-terpinene	-	0.4	-	-
terpinolene	-	0.1	-	-
1,8-cineole	0.08	0.1	-	1.30
cis-linalool oxide	0.40	-	-	2.00
trans-linalool oxide	0.37	-	-	1.30
camphor	0.68	-	-	-
trans-sabinenehydrate	-	0.2	-	-
linalool	18.62	13.1	8.3-23.7	19.10
isoborneol	-	0.1	-	-
terpinen-4-ol	-	0.1	-	0.05
α-terpineol	0.70	1.3	0.3-4.8	4.60
nerol	0.06	0.3	0.07-0.9	0.05
geraniol	0.16	0.8	0.2-2.7	0.05
linalyl acetate	69.93	66.7	40.3-73.2	60.20
α-terpinyl acetate	-	-	-	0.05
neryl acetate	0.26	0.1	0.5-1.5	2.10
geranyl acetate	0.49	0.6	0.34-3.0	2.60
bornyl acetate	-	0.6	-	-
α-terpinyl acetate	0.37	0.1	-	-
α-copaene	-	-	0.5-1.5	-
β-bourbonene	-	0.2	-	-
cis-α-bergamotene	-	0.3	-	-
β-caryophyllene	0.56	2.5	1.4-3.1	-
germacrene D	-	-	2.1-8.4	-
humulene	-	1.3	-	-

- = absent

ent from profiles of oils formerly produced. The linalool content has increased from 10% to 20-25%, and the content of linalyl acetate has decreased from 70% to 60%. The concentration of α-terpineol, geraniol, geranyl acetate and neryl acetate is higher, but the content of sclareol, germacrene D and caryophyllene is lower. One may question whether these variations are due to modernizing the distillation method or to the fact that part of the linalyl acetate is decomposed during isolation.

In 1985, Colsson et al.[66] published a review on French clary sage oil. They mentioned that the yield of the oil from the entire plant material was 0.15% (0.34% of the flowering parts and 0.01% of the twigs) (Table XIII).

Schmaus and Kubeczka[68] studied the influence of isolation conditions on the composition of essential oils containing linalool and linalyl acetate. A combination of solvent

Table XIV. Main constituents (%) of i solates from clary sage[65]		
Compound	Essential oil	Concrete
linalyl acetate	75.0	5.5
linalool	8.0	1.7
sclareol	1.6	70.0
germacrene D	4.0	0.5
caryophyllene	3.0	0.4

Table XV. Chemical composition (%) of three French and one Russian clary sage oils[69]

	French			
Compound	1	2	3	Russian
α-pinene	0.21	0.20	0.08	0.02
camphene	0.03	0.04	0.03	0.01
β-pinene	0.17	0.16	0.17	0.01
myrcene	0.34	0.38	0.98	0.22
limonene	0.10	0.10	0.20	0.30
1,8-cineole	0.09	0.10	0.09	0.11
(Z)-β-ocimene	0.16	0.16	0.40	0.09
(E)-β-ocimene	0.23	0.21	0.72	0.06
linalool	8.88	8.98	28.48	14.43
α-terpineol	0.20	0.27	2.64	2.17
nerol	0.05	0.06	0.56	0.42
geraniol	0.11	0.11	1.54	0.98
linalyl acetate	74.18	72.47	50.86	63.18
neryl acetate	0.13	0.17	0.75	1.08
geranyl acetate	0.30	0.40	1.42	2.07
caryophyllene	1.89	1.85	1.65	2.02
germacrene D	4.09	3.29	3.54	0.36
caryophyllene oxide	0.35	0.40	0.16	1.16
sclareol oxide	0.49	0.53	0.07	0.24
sclareol	1.21	1.97	0.79	1.80

extraction and gas phase stripping by means of a reflux trapping apparatus yielded an essential oil with a composition much more like that occurring in the living plant than that of the oil isolated by hydrodistillation. In the case of clary sage oil isolation, they found that the amount of sesquiterpenes was in good accordance with the extract. Sclareol had not been transported, due to its high molecular weight.

Ravid and Putievsky[70] reported on the chemical composition of clary sage oil (Table XIII) in their studies of essential oils of wild-growing Labiatae species in Israel. (Labiatae is an older name for the family now called Lamiaceae, which contains the *Salvia* genus.)

In 1983, Ehret[65] reported on new components from French clary sage essential oil and concrete. They identified 40 new compounds in the oil, several of which derived from curcumene, such as bifunctional monoterpenes, sesquiterpene alcohols, sesquiterpenoid mintsulfide and a diterpenic furanalcohol. The main constituents of the oil and the concrete can be seen in Table XIV.

Dore and Jaubert[69] published their gas chromatographic

Table XVI. Chemical composition (%) of clary sage oil

Compound	Fresh flower[73]	Leaf[74]	Aged oil[72/74]
α-pinene	-	-	0.03/t
camphene	-	-	t
β-pinene	-	-	t
α-terpinene	-	-	t
myrcene	1.08	-	-/2.82
limonene	0.31	-	0.20/0.48
p-cymene	t	-	0.15/0.16
(Z)-β-ocimene	0.48	-	0.37/1.07
(E)-β-ocimene	0.87	-	0.75/1.75
γ-terpinene	t	-	t
allo-ocimene	t	-	t
cis-linalool oxide (5)	0.01	-	0.59/0.81
trans-linalool oxide (5)	0.01	-	0.72/0.68
cis-5,6-epoxyocimene	-	-	t
trans-5,6-epoxyocimene	-	-	t
linalool	25.99	0.11	12.33/11.74
trans-linalool oxide acetate (5)	-	-	t
cis-linalool oxide acetate (5)	-	-	t
hotrienol	t	-	t
5-vinyl-5-methyl-tetrahydro-furan-2-one	-	t	
terpinen-4-ol	t	-	t
α-terpineol	7.85	t	t
nerol	1.67	-	0.08/t
geraniol	4.93	t	0.23/0.21
trans-carveol	-	-	t
p-cymen-8-ol	t	-	0.09
linalyl acetate	23.41	0.19	54.63/52.63
bornyl acetate	t	-	-
α-terpinyl acetate	t	-	-
neryl acetate	2.31	-	1.52
geranyl acetate	4.83	-	3.31
epoxy linalyl acetate 1	t	-	1.25
epoxy linalyl acetate 2	t	-	1.12
cis-2,6-dimethyl-2,7-octa-dien-2,6-diol	-	-	t
trans-2,6-dimethyl-2,7-octa-dien-2,6-diol	-	-	0.48
3-acetoxy-2,6-dimethyl-3,7-octadien-2-ol	-	-	2.45
2,6-dimethyl-1,7-octadien-3,6-diol	-	-	0.10
3-acetoxy-2,6-dimethyl-1,7-octadien-6-ol	-	-	0.25
camphor	-	-	-/0.88
myrtenal	-	-	t
neral	0.16	-	-
geranial	0.21	-	t
α-cubebene	t	0.12	-
δ-elemene	-	0.39	-
α-copaene	0.41	3.01	-/0.29
β-bourbonene	0.10	0.18	-/0.19
epi-β-bourbonene	t	t	t
β-cubebene	0.12	0.55	t
β-elemene	-	-	-/0.15
β-caryophyllene	1.50	11.01	t
α-humulene	t	0.25	-
germacrene D	2.13	48.39	-
β-selinene	0.83	-	-
bicyclogermacrene	-	5.51	-
viridiflorene	t	t	t
(E)-β-farnesene	t	-	-
(E,E)-α-farnesene	0.10	0.10	-
δ-cadinene	0.12	0.66	-
elemol	t	-	-
spathulenol	0.14	1.71	-/0.14
α-eudesmol	0.33	-	-
T-cadinol	-	0.23	t
isospathulenol	t	t	t
torreyol	-	0.51	-
β-eudesmol	0.89	t	t
sclareol	3.10	0.35	t
caryophyllene oxide	0.52	2.20	-/0.21
humulene oxide II	t	-	-
germacrene D oxide	t	-	-

t = trace; - = absent

analyses of three clary sage oils from France and one from Russia (Table XV).

In 1990, Lawrence[75] presented the comparative chemical composition of commercial samples of French and Russian clary sage oils, as well as United States clary sage oil produced in North Carolina (Table XVII).

One year later, Elnir et al.[76] published their studies of the chemical composition of two clary sage chemotypes and their hybrids. The composition of the Israeli and Russian *Salvia sclarea* oils during the early and late flowering stage are shown in Table XVIII.

In 1992, Balinova-Tsvetkova and Tsankova[100] reported on the influence of the stage of inflorescence development, the duration and number of extractions, and the temperature, on the extraction of fresh plants of clary sage. The extract yields varied from 0.3-1.4%, with a linalyl acetate content of 8.5-13.5% and a sclareol content of 77-80%.

Ravid et al.[101] found enantiomerically pure (R)-(–)-linalyl acetate in Russian, French, American and Israeli types of clary sage oils. The relative quantities of linalyl acetate in these oils were 43-63% in Russian, 74-78% in French, 55% in American, and 51-73% in Israeli oil.

Very recently, Dzumayev et al.[103] reported on the essential oils of *Salvia sclarea* produced from plants grown in southern Uzbekistan. The principal components of the oils were linalool (22-32%) and linalyl acetate (25-51%). It was found that the oil composition was not influenced by plant parts (except for the leaves), state of plant maturity, location of cultivation site, whether the plant was wild or cultivated, year of harvest, color of bracts or cultivation conditions.

Sclareol, the main constituent of the extract of *Salvia sclarea*, is an important raw material for the production of

Table XVII. Chemical composition (%) of clary sage oils from the U.S., France and Russia[75]

Compound	U.S. (North Carolina)	France (commercial)	Russia (commercial)
α-pinene	0.08-0.12	0.1-0.2	0.1-0.2
camphene	0.03-0.04	t	t
β-pinene	0.17-0.22	0.1-0.3	0.2-0.3
sabinene	0.01-0.04	t	t
myrcene	1.25-1.71	0.1-0.2	0.3-0.5
limonene	0.40-0.77	0.1-0.2	0.1-0.2
α-terpinene	0.01-0.02	t	t
(Z)-β-ocimene	0.42-0.70	t	t-0.2
(E)-β-ocimene	0.43-1.36	0.1-0.2	0.1-0.4
p-cymene	0.01-0.02	t	t
terpinolene	0.12-0.37	t	t-0.1
(Z,Z)-allo-ocimene	0.05	t	t
(E)-2-hexenal	t	t	t
hexanal	0.03-0.07	t	t
(Z)-3-hexenol	0.12-0.29	t-0.1	t-0.1
(E)-2-hexenol	0.11-0.19	t	t
1-octen-3-ol	0.03	t	t
cis-anhydrolinalool oxide (5)	0.01-0.02	t	t
trans-anhydrolinalool oxide (5)	0.01-0.18	t	t
cis-linalool oxide (5)	0.03-0.05	t	t
trans-linalool oxide (5)	0.03-0.04	t	t
linalool	20.29-28.63	9.0-16.0	10.4-19.3
terpinen-4-ol	0.03-0.06	t-0.1	t-0.1
α-terpineol	3.05	0.2-0.6	1.2-2.5
nerol	0.62-1.15	tr.-0.1	0.3-0.5
geraniol	1.67-3.26	0.1-0.3	0.6-1.2
linalyl acetate	44.9-53.4	49.0-73.6	45.3-61.8
α-terpinyl acetate	0.06-0.07	t	t
neryl acetate	1.00-1.67	0.2-0.3	0.4-0.6
geranyl acetate	1.93-3.24	0.3-0.5	0.8-1.2
α-cubebene	t	t	t
α-copaene	0.83-0.47	0.1-0.2	0.1-0.2
β-bourbonene	0.08-0.12	t	t
β-caryophyllene	0.86-1.31	1.4-1.6	1.1-1.8
germacrene D	2.63-3.55	1.6-2.0	0.7-2.0
caryophyllene oxide	0.21-0.27	0.3-0.5	0.5
spathulenol	0.03-0.04	t	t
mint sulphide	0.03-0.04	t	t
sclareol	0.17-0.44	0.1-0.2	0.1-0.2

t = trace

the highly valuable perfume material ambroxide. A scheme for the formation of ambroxide from sclareol via sclareolide is given in Figure 2.

Sensory Evaluation of Clary Sage Oil

The fresh plant material of *Salvia sclarea* has a strong, pungent and penetrating odor that is often disliked. This odor disappears during steam-distillation and can not be recognized as the essential oil. The penetrating odor of fresh leaves and stalks is rather substantive to skin and clothes. This odor may be due to water-soluble unsaturated aldehydes.

Table XVIII. Chemical composition (%) of clary sage oils from Israel and Russia[76]

	Israeli type		Russian type	
Compound	early	late	early	late
α-pinene	t	0.1	t	t
β-pinene	-	t	t	t
sabinene	-	t	-	-
myrcene	-	t	1.0	1.4
limonene	0.1	0.2	0.2	0.4
p-cymene	t	0.9	t	t
(Z)-β-ocimene	-	-	0.6	0.8
(E)-β-ocimene	-	-	1.1	1.4
γ-terpinene	t	0.7	-	-
terpinolene	-	-	0.3	0.4
1,8-cineole	-	t	-	-
cis-linalool oxide	-	t	-	-
trans-linalool oxide	-	t	-	-
camphor	-	-	-	t
linalool	0.9	1.7	23.6	31.0
terpinen-4-ol	-	0.2	t	t
α-terpineol	t	0.2	4.1	4.9
nerol	5.2	7.4	1.5	1.9
geraniol	24.5	15.7	4.4	5.5
neral	7.5	11.3	t	t
geranial	11.2	19.4	t	t
linalyl acetate	t	0.6	44.6	34.4
α-terpinyl acetate	t	0.1	4.1	5.0
neryl acetate	1.6	3.0	2.1	2.4
geranyl acetate	36.0	36.8	4.5	4.8
β-caryophyllene	-	t	0.4	1.0
germacrene D	10.4	1.4	4.1	3.3
caryophyllene oxide	-	t	-	-

t = trace; - = absent

Arctander[57] describes clary sage oil as a colorless to pale yellow or pale olive-colored liquid; sweet herbaceous, tenacious in odor and soft and somewhat reminiscent of ambra in its bitter-sweet undertone. Apart from the initial linalyl acetate and linalool notes, there is a very characteristic note in the odor of clary sage oil. The note remains in the dryout on a perfume blotter. Some perfumers describe it as tobacco-like, others as balsamic or tealike. It also has something in common with the odor of cistus oil and Moroccan chamomile.

Ehret[65] reported that clary sage oil is well liked in perfumery for its natural character, which blends lavender-like top notes together with an amber-like dry-out.

Maurer and Hauser[63] evaluated the organoleptic properties of the newly identified sesquiterpenoids from clary sage oil. They compared the odor of mint sulfide with that of the oxygen analog. Mint sulfide has been described as having a heavy, woody earthy odor. The oxygen analog had a weak spicy-floral note with a camphoraceous undertone. The new ketone, salvialenone, showed a full, pleasant woody note reminiscent of ambergris and vetiver, with a spicy-floral undertone. The compound was mentioned as characteristic for the odor of clary sage.

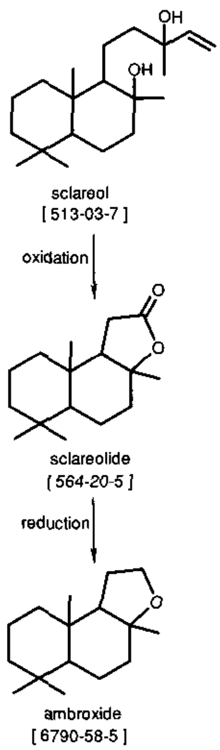

Figure 2. Formation of ambroxide from sclareol

References

Address correspondence to Mans H. Boelens, Boelens Aroma Chemical Info Service, Groen Van Prinstererlaan 21, 1272 GB Huizen, The Netherlands.

1. C Epling, A revision of Salvia subgenus calosphace, *Repert Spec Nov Regni Veg Beih* **110** 1-383 (1939)
2. J Compton, Salvia, *The Plantsman* **15** Pt IV (1994)
3. WA Emboden and H Lewis, Terpenes as taxonomic characters in Salvia section audibertia, *Brittonia* **19** 152-160
4. BM Lawrence, Aromatic flora of North America, Part I. Labiatae, *Essential Oils 1979-1980*, Carol Stream, Illinois: Allured Publishing (1981) pp 91-95
5. BM Lawrence, *Essential Oils 1988-1991*, Carol Stream, Illinois: Allured Publishing (1993) p 202
6. Essential Oils Association, Specification no. 44
7. E Guenther, *The Essential Oils*, vol III, Princeton: D Van Nostrand (1949) p 712
8. E Gildemeister and F Hoffmann, *Die Aetherische Oele*, vol VII, Berlin: Akademie Verlag (1961) p 107
9. Flavoring Extract Manufacturers' Association, Survey of flavoring ingredient usage levels, No 3001, *Fd Technol* **19**(2) part 2, 155 (1965)
10. Natural and artificial flavouring substances, partial agreement in the social and public health field, List N(1), Series 1(b), Strasbourg: Council of Europe (1970) p 27
11. *Food Chemicals Codex*, 2nd ed, Washington, DC: National Academy of Sciences (1972)
12. Fragrance raw materials monographs: Sage oil Dalmatian, *Fd Chem Cosm Tox* **12** 987-988 (1974)
13. S Dalferth, Die Mono- und Sesquiterpenoid einiger aetherische Salbeioele, PhD Thesis Univ Wuerzburg, Germany (1963)
14. CH Brieskorn and S Dalferth, Die Mono- und Sesquiterpenoide aetherische Salbeioele. *Ein Beitrage zur arzneilichen Bewertung* von Salvia officinalis, Salvia lavandulaefolia und Salvia triloba, *Deutsche Apother-Zeitung*, **104** 1388-1392 (1964)
15. CH Brieskorn and S Dalferth, Mitteilung ueber die Inhaltstoffe

von Salvia officinalis L. Ueber das Vorkommen von 2-Methyl-3-methylen-hepten-(5) im aetherischen Oel von Salvia officinalis L, *Justus Liebigs Ann Chem* **676** 171-174 (1964)

16. CH Brieskorn and J Melchior, Quantitative Aenderung der Terpenoide im Keimling und Blatt von Salvia officinalis L unter verschiedenen Bedingungen, *Arch Pharm (Weinheim)* **302** 921-931 (1969)
17. BM Lawrence et al, Les huiles essentielles et leurs constituants. Quelques nouveaux onstituants a l'etat de traces dans l'huile essentielle de Salvia officinalis L, *Parf Cosm. Sav France* 1(5) 256-259 (1971)
18. BM Lawrence, Perfum Flavor **2**(6) 36 (1977)
19. MB Embong et al, Essential oils from herb and spices grown in Alberta, Sage oil, Salvia officinalis L (Labiatae), *J Inst Can Sci Technol Aliment*, **10**(3) 201-207 (1977)
20. R Ivanic et al, Gas chromatographic examination of volatile oil from Salvia officinalis L, *Acta Pharm Jugoslav* **28** 65-69 (1978)
21. HY Rhyu, Gas chromatographic characterization of sages of various geographic origins, J Food Sci **44** 760-762 (1979)
22. MI Burgar et al, C-13 NMR Analysis of essential oil of Dalmatian sage (Salvia officinalis) *Farm Vestn (Ljubljana)* **30** 253-261 (1979)
23. A Koedam et al, Comparison of isolation procedures for essential oils VI Rosemary and sage, *Riechstoffe, Aromen, Kosmetica* **30** 271-276 (1980)
24. V Formacek and KH Kubeczka, in *Essential Oils Analysis by Capillary Gas Chromatographic and Carbon-13 NMR Spectroscopy*, Chichester: John Wiley & Sons (1982) pp 259-266
25. D Fehr, Untersuchung zur Lagerstabilitaet von Salbeiblaettern, *Pharmazeutische Ztg* **127** 111-114 (1982)
26. C Karl et al, The occurrence of viridiflorol in Salvia officinalis, *Planta Medica* **44** 188-189 (1982)
27. M de los Angelos Cordoba Rodriguez, *Contribucion al estudio del Aceite Esencial de Salvia Espanola (Salvia lavandulaefolia Vahl)*, PhD Thesis, Universidad Complutense de Madrid (1983)
28. I Pitarevic, Seasonal variation of essential oil yield and composition of Dalmatian sage, Salvia officinalis, *J Nat Prod* **47** 409-412 (1984)
29. D Kustrak et al, Yields and composition of sage oils from different regions of the Yugoslavian Adriatic coast, *J Nat Prod* **47** 520-524 (1984)
30. M Holeman et al, Etude chimique comparative des huiles essentielles de Salvia officinalis, S aucheri S verbenaca, S phlomoides et S argentea, *Fitoterapia* **LV** (3) 143-147 (1984)
31. M Marlier et al, Etude comparative de l'huile essentielle de Lepechinia meyeni (Walp.) Epling et de *Salvia officinalis* L, Paper presented at Colloque sur la Chimie des Terpenes, Grasse (Apr 24-25, 1986).
32. D Kustrak et al, Composition of essential oil and cytological investigation of sage species from the island of Vis, *Acta Pharm Jugoslav*, **36** 431-436 (1986)
33. K Grzunov et al, Terpene alcohols in β-D-glucosides in the leaves of Dalmatian Salvia officinalis, in *Progress in Essential Oil Research*, E-J Brunke, ed, Berlin: Walter de Gruyter & Co (1986) pp 267-270
34. RS Farag et al, Biochemical studies on the essential oils of some medicinal plants, *Fette, Seife, Anstrichmittel* **88**(2) 69-72 (1986)
35. G Vernin and J Metzger, Analysis of sage oils by GC/MS data bank - Salvia officinalis L and Salvia lavandulaefolia Vahl, Perfum Flavor **11**(5) 79-84 (1986)
36. M Tamas et al, Phytochemical study of Salivia folium, *Farmacia (Bucharest)* **34** 181-186 (1986)
37. A Bayrak and A Akguel, Compostition of essential oils from Turkish Salvia species, *Phytochem* **26** 846-847 (1987)
38. AO Tucker and MJ Maciarello, Plant identification, in *Proceedings of the First National Herb Growing and Marketing Conference*, JE Simon and L Grant, eds, West Lafayette, Indiana: Purdue University Press (1987) pp 126-172
39. BM Lawrence, Sage oil, *Perfum Flavor* **13**(3) 53-56 (1988)
40. E Lemberkovics, Gas chromatographic determination of mono- and sesquiterpenes in some commercial Hungarian essential oils, in *Flavors and Fragrances: A World Perspective, Proceedings of the 10th Intl Congress of Essential Oils, Fragrances and Flavors, Washington, DC*, BM Lawrence, BD Mookherjee and BJ Willis, eds, Amsterdam: Elsevier Science Publ (1988)
41. R Piccaglia et al, Effect of mineral fertilizers on the composition of Salvia officinalis oil, *J Essent Oil Res* **1** 73-83 (1989)
42. AO Tucker and MJ Maciarello, Essential oils of cultivars of Dalmatian sage (Salvia officinalis L), *J Essent Oil Res* **2** 139-144 (1990)
43. BM Lawrence, Progress in essential oils, Sage oil, *Perfum Flavor* **16**(4) 51-53 (1991)
44. KS Svoboda and SG Deans, A study of the variability of rosemary and sage and their volatile oils on the British market: their antioxidative properties, *Flav Fragr J* **7** 81-87 (1992)
45. R Piccaglia and M Martotti, Characterization of several aromatic plants grown in northern Italy, *Flav Fragr J* **8** 115-122 (1993)
46. CA Cenci and I Calvarano, Caratteristiche degli olii essenziale di alcune salvie perugine, *Essenze Deriv Agrum* **37** 141-178 (1967)
47. M de Gavina Mugica et al, L'huile essentielle de sauge Espanole (Salvia lavandulaefolia Vahl - Oleum Salviae), *Parfum Cosmet Savons* **12** 334-344 (1969)
48. BM Lawrence et al, Essential oils and their constituents. Some new constituents in the essential oil of *Salvia lavandulaefolia* Vahl, *J Chromatog* **50** 59-65 (1970)
49. Anon, Spanish spike lavender oil, *Dragoco Rept* 175-192 (1979)
50. MD Steinmetz et al, Sur la toxicite de certaines huiles essentielles du commerce essence d'hysope et essence de sauge, *Plant Medicin Phototherap* **14** 34-45 (1980)
51. P Pecorari et al, Ricerche su Piante officinali nell'Appennino Modense. Piante Coltivate IV. Indagine sui Contenuti degli olii essenziali di piante del genere Salvia, *Boll Chim Farm* **119** 584-590 (1980)
52. BM Lawrence, Progress in essential oils, Spanish sage oil, *Perfum Flavor* 9(6) 129-131 (1984)

53. ME Crespo et al, The essential oil of Salvia lavandulaefolia subspecies oxydon. A study of its vegetative cycle, *Planta Med* 367-369 (1986)
54. ME Marcos Sanz et al, Essential oils of Salvia lavandulaefolia Vahl, in *Flavors and Fragrances: A World Perspective, Proceedings of the 10th Intl Congress of Essential Oils, Fragrances and Flavors, Washington, DC*, BM Lawrence, BD Mookherjee and BJ Willis, eds, Amsterdam: Elsevier Science Publ (1988) pp. 147-160
55. Anon, Oils of Spanish sage (Salvia lavandulaefolia), ISO/TC 54 N1558, ISO, Portugal (1989)
56. R Jimenez Sindreu, The chemical composition of Spanish sage oil, Private communication, Destillaciones Bordas Chinchurreta, Seville, Spain (1990-1995)
57. S Arctander, *Perfume and Flavor Materials of Natural Origin* (1961) republished Carol Stream, Illinois: Allured Publishing (1994) pp 569-572
58. B Lalande, Lavender, lavandin and other French oils, *Perfum Flavor* **9**(2) 117-121 (1984)
59. BM Lawrence, *Essential Oils 1988-1991*, Carol Stream, Illinois: Allured Publishing (1993) p 202
60. JC Leffingwell et al, Clary sage production in southeastern United States, Paper No 3, Intl Essent Oil Congr, San Francisco (1974)
61. B Corbier and P Teisseire, Contribution to the knowledge of clary sage, *Recherches* **19** 275-278 (1974)
62. T Yoshida and T Sawasaki, On the variations of the percentage yield and the chemical composition of essential oil in clary sage (Salvia sclarea L), *Jap J Trop Agr* **21** (3/4) 145-149 (1978)
63. B Maurer and A Hauser, New sesquiterpenoids from clary sage oil (Salvia sclarea L), *Helv Chim Acta* **66**(7) 2223-2235 (1983)
64. Verzar-Petri, Biosynthesis and localisation of essential oil in Salvia sclarea, in *Proceedings 9th Intl Ess Oil Congr Singapore* (1983) pp 110-115
65. C Ehret, New components from French clary sage essential oil and concrete, in *Proceedings 9th Intl Ess Oil Congr Singapore* (1983) pp. 77-78
66. M Colsson et al, L'essence de sauge sclaree (Salvia sclarea L), *Parf Cosm Aromes* **66** 53-58 (Dec 1985)
67. R ter Heide, Concentration of odorous headspace volatiles, in *Essential Oils and Aromatic Plants*, A Baerheim Svendsen and JJC Scheffer, eds, Dordrecht, The Netherlands: Martinus Nijhoff/Dr W Junk (1985) pp 43-60
68. G Schmaus and KH Kubeczka, The influence of isolation conditions on the composition of essential oils containing linalool and linalyl acetate, in *Essential Oils and Aromatic Plants,* A Baerheim Svendsen and JJC Scheffer, eds, Dordrecht, The Netherlands: Martinus Nijhoff/Dr W Junk (1985) pp 127-134
69. JC Dore and JN Jaubert, Exemple d'etude systemique de chromatogrammes d'essences naturelles par analyse factorielle des correspondances, *Parf Cosm Aromes* **61** 79-85 (Feb-Mar 1985)
70. U Ravid and E Putievsky, Essential oils of Israeli, Wild species of Labiatae, in *Essential Oils and Aromatic Plants*, A Baerheim Svendsen and JJC Scheffer, eds, Dordrecht, The Netherlands: Martinus Nijhoff/Dr W Junk (1985) pp 155-160
71. U Ravid et al, Isolation of optically pure (–)-linalyl acetate from clary sage, Salvia dominica L, lavender and lavandin, *Flav Fragr J* **1** 121-124 (1986)
72. G Mazza, The chemical composition of bergamot, mandarin and clary sage oil, *Ess Der Agrum* **57**(1) 5-18 (1987)
73. G Mazza, Clary sage aroma: 1. Volatile compounds identification in flower tips essential oil and alcoholic infusion, *Sci Aliments* **8** 489-510 (1988)
74. G Mazza, Clary sage aroma: 2. Volatile compounds identification in leaves, oil and alcoholic infusion, *Sci Aliments* **8** 511-522 (1988)
75. BM Lawrence, Progress in essential oils, Clary sage oil, *Perfum Flavor*, **15**(1) 62-63 (1990) and **15**(4) 106-108 (1990)
76. O Elnir et al, Chemical composition of two clary sage chemotypes and their hybrids, *Flav Fragr J* **6** 153-155 (1991)
77. P Buil et al, Sur quelques huiles essentielles en provenance de Turquie, *Tivista Ital* **59** (1977).
78. F Chilava et al, Composition of the essential oils of five Salvia

species, *J Essent Oil Res* **4**(5) 447-445 (1992)

79. B Bellomaria et al, Contribution to the study of the essential oils from three species of Salvia growing wild in the eastern Mediterranean region, *J Essent Oils Res* **4**(6) 607-614 (1992)
80. A Velasco-Negueruela et al, The essential oil of Salvia gilliesii Benth, *J Essent Oil Res* **5**(3) 319-320 (1993)
81. KHC Baser, The essential oil of Salvia pomifera L, *J Essent Oil Res* **5**(3) 347-348 (1993)
82. AO Tucker and MJ Maciarello, The essential oil of Salvia dorisiana Standley, *J Essent Oil Res* **6**(1) 79-80 (1994)
83. M Ahmed et al, Leaf oil composition of Salvia hispanica L from three geographical areas, *J Essent Oil Res* **6**(3) 223-228 (1994)
84. ET Tsankova et al, Constituents of essential oils from three Salvia species, *J Essent Oil Res* **6**(4) 375-378 (1994)
85. S Canigueral et al, The leaf essential oil of Salvia candelabrum Boiss, *Flav Fragr J* **4** 135-138 (1989)
86. E Sarer, Composition of the essential oil of Salvia pisidica Boiss et Heldr, *Flav Fragr J* **4** 201-202 (1989)
87. E Putievsky et al, Genetic affinities and essential oil composition of Salvia officinalis L, S fruticosa Mill, S tomentosa Mill and their hybrids, *Flav Fragr J* **5** 121-124 (1990)
88. OA Onayade et al, Polynuclear aromatic compounds and other constituents of the herb essential oil of Salvia coccinea Juss ex Murr, *Flav Fragr J* **4** 281-290 (1991)
89. E Werker, Function of essential oil-secreting glandular hairs in aromatic plants of the Lamiaceae (eg Salvia dominica L), *Flav Fragr J* **8** 249-256 (1993)
90. S Canigueral et al, The essential oil from leaves of Salvia canariensis L, *Flav Fragr J* **9** 201-204 (1994)
91. AO Tucker et al, Volatile leaf oils of cultivars of Salvia clevelandii (Gray) Greene x S leucophylla Greene, *J Essent Oil Res* **7**(1) 101-104 (1995)
92. KHC Baser et al, Composition of the essential oil of Salvia cryptantha Montbret et Aucher ex Benth from Turkey, *J Essent Oil Res* **7**(1) 113-114 (1995)
93. KHC Baser et al, Essential oil of Salvia caespitosa Montbret et Aucher ex Benth, *J Essent Oil Res* **7**(2) 229-230 (1995)
94. PS Gomez et al, Essential oils of a new hybrid: Salvia officinalis x S lavandulaefolia ssp vellera, *J Essent Oil Res* **7**(3) 313-315 (1995)
95. L Pace and R Piccaglia, Characterization of the essential oil of a wild Italian endemic sage: Salvia officinalis L var angustifolia Ten (Labiatae), *J Essent Oil Res* **7**(4) 443-446 (1995)
96. EJ Brunke and FJ Hammerschmidt, Constituents of the essential oil of Salvia stenophylla - First identification of (+)-epi-α-bisabolol, in *Essential Oils and Aromatic Plants*, A Baerheim Svendsen and JJC Scheffer, eds, Dordrecht, The Netherlands: Martinus Nijhoff/Dr W Junk (1985) pp 145-150
97. D Kustrak, Kreuzsalbei - Salvia officinalis L supspecies minor f auriculata, *Pharm Acata Helv* **63** 254-256 (1988)
98. BJ Tyson et al, Volatilization of terpenes from Salvia mellifera, *Nature* **252** 119-120 (1974)
99. G Micali and F Lanuzza, HPLC determination of α- and β-thujone. Potentially toxic components of natural flavourings in alcoholic beverages, *Flav Fragr J* **10**(5) 329-334 (1995)
100. A Balinova-Tsvetkova and P Tsankova, On the extraction of Salvia sclarea L, *Flav Fragr J* **7** 151-154 (1992)
101. U Ravid et al, Chiral GC analysis of enantiomerically pure (R)(−)-linalyl acetate in some Lamiaceae, myrtle and petitgrain essential oils, *Flav Fragr J* **9** 275-276 (1994).
102. KHC Baser et al, Essential oil of Salvia syriaca L, *J Essent Oil Res* **8**(1) 105-106 (1996)
103. KHK Dzumayev et al, Essential oils of Salvia sclarea L produced from plants grown in southern Uzbekistan, *J Essent Oil Res* **7**(6) 597-604 (1995)
104. BM Lawrence, A review of the world production of essential oils (1984), *Perfum Flavor* **10**(5) 1-16 (1985)