Chemical and Sensory Evaluation of Lavandula Oils

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The plant family of the *Lamiaceae*, formerly called the *Labiatea*, contains many aromatic plants. Some important genera of the plants are *Lavandula*, *Mentha*, *Salvia* and *Thymus*.

The genus *Lavandula* covers about 30 species, from which *L. angustifolia* (lavender), *L. hybrida* (lavandin) and *L. latifolia* (spike lavender) are used for the production of essential oils.

The most important lavandula oils are lavender oil, lavandin oil and spike lavender oil, which are of economic value to the fragrance industry because they are used in high grade perfumery, cosmetics and functional perfume compounds.

Each of these oils contains hundreds of chemical compounds, which are responsible for the sensory properties of the oils.

In this article the chemical composition of lavandula oils from various parts of the world will be discussed. The odor qualities of the oils and the olfactive properties of some characteristic compounds will be mentioned.

Some artifacts will be shown. These artifacts include compounds at least partly formed the isolation and/or storage of the oil.

Essential oils isolated from some other *Lavandula* species are of scientific interest and will also be treated.

Botanical Origin

The botany of the genus *Lavandula* has been the subject of various publications.[1-8] Up to 30 species and many subspecies[8] or varieties have been mentioned. A scheme of the

Figure 1. Scheme of some important *Lavandula* species

Main Species	Synonym
L. angustifolia P. Miller	*L. officinalis* Chaix
	L. vera de Candolle
	L. spica L. *delphinensis*
Jordan	
	L. spica L. var. a Auct.
L. latifolia Medikus	*L. latifolia* Vill.
	L. spica L. var. b Auct.
L. hybrida Rev.	*L. x intermedia* Emeric ex Loiseleur
(*L. latifolia* x *L. angustifolia*)	
	L. fragrans latifolia
Chatenier	
	L. x brunati Briq.
	L. spicalatifolia Albert
	L. x hortensis Hy
	L. x leptostachya Pau
L. stoechas L. ssp. *stoechas*	
L. dentata L.	
L. lanata Bois.	
L. multifida L.	
L. pyrenaica Benth.	
L. viridis L'Heritier	
L. burmanni Benth.	
L. buchii Webb. & Berth.	
L. canariensis (L.) Mill.	
L. minutolii Bolle	
L. pinnata L. fil. Como	

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most important *Lavandula* species is given in Figure 1.

Tucker[5,37] determined the correct botanical name of lavandin and its cultivars and studied several subspecies.

Garcia Vallejo et al.[8] divided ten taxons of the genus *Lavandula* into the following four sections: *Lavandula*, *Dentata*, *Pterostoechas* and *Stoechas*.

Lavender Oil

General

The oil of lavender is an important oil in the fragrance industry. The oil is obtained from the plant species *Lavandula angustifolia* Miller (syn. *L. officinalis* Chaix, *L. vera* D.C.).

The main production countries are France and Bulgaria. Nicolov et al.[16] reported that Bulgaria had increased its lavender production; as a consequence, lavender is grown under a variety of ecological conditions. According to more recent figures, the production of lavender oil in Bulgaria varied from 108 tons to 155 tons between 1970 and 1980.

In 1982 Peyron[31] reported that in 1982 France produced 80 tons of lavender oil, while the production in Bulgaria was 200 tons. He also reported that less defined production figures included: Morocco, 10-15 tons; Italy, 10-15 tons; Algeria, less than 10 tons; India, 20-30 tons; China, 5 tons; and Paraguay, less than 10 tons.

Lawrence[38] reported that in 1984 the world production of lavender oil was 200 tons: Bulgaria, 100-120 tons; France, 55 tons; USSR, 35 tons; Australia, 5 tons; plus limited amounts by other countries.

More than 100 publications[9-11] have discussed the chemical composition of lavender oil. In his well known reviews on "Progress in Essential Oils," Lawrence[11] reported extensively on the chemical characterization of the oil. The more recent publications on this subject will be mentioned hereafter.

The physicochemical properties of lavender oil have been reported by various authors and authorities. These properties are shown in Table I.

Lavandulol is an important constituent of lavender oil and was identified for the first time in 1942, by Schinz and Seidel.[100] A review of the syntheses of lavandulol and analogues was published recently by Kula & Wilczynska.[101]

Chemical Evaluation

From 1969 to 1972, Karetnikova et al.[13] devoted four publications to the chemical composition of Russian lavender oil. They examined the alcohol part, the esters, the carbonyl compounds and the hydrocarbon composition. In the oil they characterized the following:

α-pinene (1.00%)	geraniol (trace-1.80%)
δ-3-carene + cis-ocimene (2.50%)	myrcene (2.00%)
	limonene (2.00%)
trans-ocimene (3.20%)	allo-ocimene (0.60%)
caryophyllene (1.00%)	3-methylbutanal (0.07%)
furfural (0.17%)	methylheptenone (0.36%)
benzaldehyde (0.26%)	hexanal (0.40%)
cuminaldehyde (0.43%)	geranial + neral (0.48%)
camphor (0.58%)	linalyl acetate (31.00%)
hexenyl butanoate (2.00%)	α-terpinyl acetate (1.00%)
lavandulyl acetate (14.00%)	geranyl acetate (1.00%)
linalool (10.00-24.50%)	terpinene-4-ol (1.80-2.90%)
α-terpineol (1.40-2.50%)	borneol (1.40-4.00%)

In addition, they identified traces of β-pinene, neryl acetate nerol and cis-3-hexen-1-ol. The authors noted that removal of the carbonyl compounds from Russian lavender oil resulted in a more valuable oil for the domestic perfumers.

Klein and Rojahn[14] characterized 4-methyl-4-vinyl-4-butanolide for the first time in both lavender and lavandin oil.

Some years later, Timmer et al.[15] isolated and identified the following ten lactones in lavender oil:

4-butanolide	4-isopropyl-4-butanolide
2-methyl-4-butanolide	4-hexyl-4-butanolide
4,4-dimethyl-4-but-2-enolide	5-pentyl-5-pentanolide
4-methyl-4-vinyl-4-butanolide	coumarin
4-methyl-4-vinyl-4-but-2-enolide	dihydrocoumarin

In 1972 Nicolov et al.[16] demonstrated a distinct relationship between the area of Bulgaria in which lavender was grown and the chemical composition of the oil. Although no direct quantitative data were presented, they showed in gas chromatograms quantitative variances of β-pinene, limonene, 1,8-cineole, 3-octanone, 1-octen-3-yl acetate, 3-octanol, linalool, linalyl acetate, bornyl acetate, terpinen-4-ol, borneol, α-terpineol, geranyl acetate and geraniol.

In the same year, Boyadzhieva and Staikov[17] reported on the oil yield per hectare of several Eastern European varieties and the yield from French clones. They found that oil from the French clones, which was produced in a lower yield, contained larger amounts of acetates (mainly linalyl acetate) and a higher average linalool content than either Russian or Bulgarian oils.

Some years later, Nicolov et al.[16] reported that Bulgarian lavender oil contained:

- α-pinene
- β-pinene
- camphene
- sabinene
- myrcene
- δ-3-carene
- limonene
- β-phellandrene

Table I. Physico-chemical characterization of lavender oil

Physical Constant	AFNOR*	Ref 9	Ref 10	Ref 45
density (20/20 C)	0.877-0.890	0.885-0.895	0.893-0.898	0.895
refractive index (n 20 C/D)	1.458-1.464	NA	1.464-1.467	1.4610
optical rotation (α 20 C/D)	-11 to +7	-3 to -9	-7.4 to -8.5	-4.25
essential oil yield	NA	1.2-2.8%	1.3-2.2%	2.3-2.66%

*AFNOR = Association Francaise de Normalisation (1986)[104,105]
NA = not available

ocimene	3-ethylbutanal
α-santalene	hexanal
β-santalene	octanal
γ-cadinene	2-hexenal
δ-cadinene	neral
caryophyllene	geranial
bergamotene	cuminaldehyde
curcumene	1,8-cineole
farnesene	linalool oxide
pentanol	caryophyllene oxide
1-octen-3-ol	camphor
2-methylbut-3-en-1-ol	3-octanone
linalool	geranyl butyrate
geraniol	linalyl butyrate
nerol	geranyl isobutyrate
borneol	linalyl isobutyrate
lavandulol	geranyl pentanoate
citronellol	linalyl pentanoate
terpinen-4-ol	geranyl hexanoate
1-octen-3-yl acetate	linalyl hexanoate
linalyl acetate	free butanoic acid
bornyl acetate	free isobutyric acid
lavandulyl acetate	free pentanoic acid
pentanal	free hexanoic acid

In 1974 Carro de la Torre[18] reported on an investigation of a lavender oil produced in Brazil. It was found that the oil contained: α-pinene, 1,8-cineole, linalool, thymol, linalyl acetate, bornyl acetate, camphor, 2-heptyl acetate, formic acid, butyric acid and hexanoic acid. The finding of a content of 45% bornyl acetate and a deficiency of linalyl acetate seems to be due to a misidentification of the esters by chemical interpretation.

Kaiser and Lamparsky[19] investigated the trace constituents of lavender oil by modern spectroscopic techniques and synthetic corroboration (see Table XXIV on page 47). They identified in the oil:

α-photosantalol A	2,6-dimethyl-6-acetoxy-octa-1,7-dien-3-one
α-photosantalol B	2,6-dimethyl-5-acetoxymethyl-hepta-1,6-dien-3-one
α-santalal	2,6-dimethyl-5-acetoxymethyl-hept-6-en-3-one
α-norsantalenone	
α-santalenic acid	

In 1979, Ahmed and Meklati[20] compared the physicochemical properties of five varieties of lavender oil produced in Algeria with several varieties of European lavender oil. They found that one of the Algerian lavender oils produced in 1977 had some characteristics that were similar to lavandin, whereas the quality of another oil was quite comparable to a fine quality French lavender oil.

Also in 1979, Prager and Miskiewicz[21] reported on the chemical composition of European lavender oils. In their study they presented chromatographic data for the products claimed to be lavender oil (18 from France, two from Bulgaria and one from Yugoslavia). The chromatographic data were in the form of percent concentrations from peak areas of capillary gas chromatographic analysis for 15 major components. The ranges found for these compounds were as follows:

α-pinene (0.0-0.6%)	cis-ocimene (0.2-0.7%)
limonene (0.2-0.7%)	monoterpene hydrocarbons (3.9-14.2%)

camphor (0.3-2.1%)	trans-ocimene (0.6-4.5%)
linalyl acetate (32.2-44.8%)	linalool (27.6-49.0%)
lavandulyl acetate (1.3-11.8%)	terpinen-4-ol + caryophyllene (3.8-11.8%)
α-terpineol (0.1-1.2%)	lavandulol (0.0-1.3%)
β-pinene (0.0-0.2%)	borneol (0.8-1.4%)
cineole (0.7-2.3%)	

They also concluded, after thorough examination of their results, that two oils that were imported as lavender oils were in fact blends of lavender oils and lavandin, while one other sample was found to be a blend of lavender oil and spike lavender oil.

In the same year, Hoffmann[22] wrote a review about the identified constituents of lavender oil and their selected syntheses. He mentioned the following groups of compounds:

14	monoterpene hydrocarbons	11	monoterpene alcohols
3	monoterpene ketones	5	monoterpene aldehydes
12	monoterpene esters	4	monoterpene oxides
9	sesquiterpene hydrocarbons	7	oxygenated sesquiterpenes
2	non-terpenoid hydrocarbons	6	non-terpenoid alcohols
22	non-terpenoid esters	13	non-terpenoid aldehydes
15	non-terpenoid ketones	11	lactones
7	miscellaneous compounds (see Table XXIV, page 47.)		

In 1980, Chen et al.[24] examined the chemical composition of a Chinese lavender oil. The authors found that the oil contained:

α-pinene	farnesene
camphene	γ-cadinene
β-pinene	β-himachalene
δ-3-carene	bisabolene
p-cymene	1,8-cineole
limonene	1-octen-3-yl acetate
terpinolene	linalool
myrcene	linalyl acetate
ocimene	lavandulol
β-phellandrene	lavandulyl acetate
caryophyllene	nerol
β-bergamotene	geraniol
borneol	geranyl acetate
α-terpineol	neryl acetate
terpinen-4-ol	bornyl acetate
β-terpineol	farnesol
camphor	

Table II. Composition of lavender oils from southeastern France[26]

Compound	Maillette (%)	Other cultivars (%)
α-pinene	0.02-0.67	0.16-1.19
limonene	0.02-0.68	0.07-0.57
1,8-cineole	0.01-0.21	0.29-1.39
cis-ocimene	1.35-2.87	5.01-10.96
trans-ocimene	0.86-1.36	2.26-5.84
3-octanone	1.75-3.04	0.94-2.41
camphor	0.54-0.89	0.03-0.73
linalool	29.35-41.62	26.86-49.86
linalyl acetate	46.71-53.80	36.77-43.03
caryophyllene	2.64-5.05	4.34-7.60
terpinen-4-ol	0.03-4.16	3.15-6.40
lavandulol	trace-0.57	0.10-1.56
lavandulyl acetate	0.27-4.24	0.63-5.93
α-terpineol	0.14-0.77	0.11-1.44

In 1981 Melegari et al.[25] reported the ranges of the main constituents of lavender oil isolated from plants raised in various locations near Moderna, Italy. The concentrations of the characterized compounds were as follows:

α-pinene (0.02-0.93%)	β-pinene (0.02-0.20%)
myrcene (0.27-1.60%)	limonene (0.05-0.62%)
1,8-cineole (0.02-1.12%)	camphor (0.18-0.80%)
linalool (29.45-49.90%)	linalyl acetate (12.40-41.80%)
caryophyllene (1.24-12.37%)	lavandulol (0.13-1.75%)
α-terpineol (1.33-7.86%)	neryl acetate (0.12-1.68%)
geranyl acetate (0.41-1.55%)	nerol (0.11-0.32%)
geraniol (0.28-1.32%)	

Also in 1981, Touche et al.[26] studied chemical composition to determine origin and quality of lavender oils produced in France. They compared the chemical composition of oils obtained from clonally reproduced lavender known as Maillette (as found in the four departments of southeastern France) with oils obtained from other French lavender cultivars. A summary of their results can be seen in Table II. The authors also pointed out that purity, quality and authenticity could be determined by the following ratios: R-1 = cis-ocimene/trans-ocimene; R-2 = trans-ocimene/3-octanone; and R-3 = linalool + linalyl acetate/ lavandulol + lavandulyl acetate.

In 1981 Giachetti et al.[27] compared the chemical composition of lavender oil produced from *Lavandula officinalis* var. *delphinensis* flowers having both intense and pale purple/blue colors. Their figures are shown in Table III.

Lawrence[11] mentioned that the difference in chemical composition of flower oils from different colored flowers is not necessarily related to the color of the flowers.

Two years later, Benecke et al.[28] reported retention indices on three stationary phases in gas chromatography (GC) of 17 major components of lavender oil. These compounds were:

α-pinene	camphene

Table III. Composition of lavender oil from *Lavandula officinalis* var. *delphinensis* flowers[27]

Compound	Intense color (%)	Pale color (%)
α-pinene	0.33	0.36
camphene	0.23	0.18
limonene + 1,8-cineole	1.59	1.69
cis-ocimene	2.02	3.91
trans-ocimene + terpinene	1.00	7.09
camphor	0.26	0.16
linalool	60.86	41.82
linalyl acetate	7.88	8.26
caryophyllene + lavandulyl acetate	6.58	15.85
α-terpineol + borneol	7.29	7.48
geraniol	3.72	5.55

β-pinene	p-cymene
limonene	linalool
linalyl acetate	terpinen-4-ol
camphor	caryophyllene
lavandulyl acetate	lavandulol
cis-ocimene	α-terpineol
trans-ocimene	borneol
1,8-cineole	

Tajuddin et al.[30] reported that lavender oil produced in the Kashmir valley (India) contained the following compounds:

α-pinene (0.20%)	linalool (10.00%)
camphene (0.42%)	terpinen-4-ol (2.29%)
p-cymene (0.27%)	α-terpineol (7.58%)
farnesene (0.07%)	cumene (1.02%)
citronellol (10.00%)	limonene (11.00%)
bornyl acetate (0.45%)	caryophyllene (2.12%)
lavandulyl acetate (0.13%)	linalyl acetate (45.30%)
β-pinene (1.29%)	limonene epoxide (0.57%)
myrcene (0.47%)	borneol (0.23%)
1,8-cineole (1.82%)	

Lawrence[11] mentioned that from these results it can be seen that this sample of Indian lavender oil is quite abnormal compared to the standard commercial oils.

In 1983 Kaiser and Lamparsky[32] published their first communication on the examination of new carbonyl compounds in the high-boiling fraction of French lavender oil. Analysis of the isolated carbonyl fraction was achieved by liquid and gas chromatography, and a combination of GC-mass spectrometry. The following carbonyl compounds were identified:

α-norsantalenone	13-hydroxy-α-santalan-12-one
nortricyclo-eka-santalal	teresantalal
α-santalal	norcadin-5-en-4-one (+ isomer)
tricyclo-eka-santalal	cadina-4,10(15)-dien-3-one
α-santalan-12-one	γ-cadinen-15-al
α-santal-13-en-12-one	

In a second communication, the same authors reported on a number of other oxygenated sesquiterpene compounds from the same high-boiling fraction of lavender oil. The following compounds were identified:

kobusone	2-methyl-6-(4-methylphenyl)-hept-1-en-3-one
12-norcaryophyllen-2-one	2-methyl-6-(4'-methylphenyl)-heptan-3-one
caryophylla-2(12)-6-dien-5-one	4-(4'-methylphenyl)-pentanal
caryophylla-2(12),5-dien-7-one	11-norbourbonan-1-one
caryophylla-2(12),5-dine-13-al	(2Z,6E)-farnesal
cedrenal	(2E,6E)-farnesal
15-norcedran-8-one	β-ionone
4,7-dimethyl-1-tetralone	methyl jasmonate
4-isopropyl-6-methyl-1-tetralone	6,10,14-trimethylpentadecan-2-one
6-methyl-5-(3'-methylphenyl)-heptan-2-one	

One year later Kaiser and Lamparsky[32] published a third communication on the occurrence of a new series of lavender oil constituents which can be seen as Diels Alder adducts of unsaturated hydrocarbons and unsaturated carbonyl compounds. They identified about 40 of these compounds derived from the following "dienes": trans-ocimene, myrcene, 1,3,5-undecatriene, farnesene and methylcyclopentadiene; and from the following unsaturated carbonyls: crotonaldehyde, methyl vinyl ketone, 1-penten-3-one, 1-hexen-3-one, 1-octen-3-one. For the identified compounds see Table XXIV, page 47.

In 1984 Lalande[34] reported that French lavender oil possessed the following major components:

cis-ocimene(7.5%)	lavandulol (0.7%)
3-octanone (0.9%)	linalyl acetate (34.0%)
borneol (0.5%)	limonene + 1,8-cineole (0.5%)
α-terpineol (0.5%)	camphor (0.3%)
caryophyllene (6.0%)	terpinen-4-ol (5.0%)
trans-ocimene (4.0%)	lavandulyl acetate (3.5%)
linalool (29.0%)	

In 1984, Agnel and Teisseire[35] discussed the purity of French lavender oil after studying its composition and adulteration. They mentioned that over 150 constituents had been previously identified in lavender oil. The authors included gas chromatograms that displayed up to 40 identified peaks, and showed that the occurrence of dehydrolinalool, dihydrolinalool, dehydrolinalyl acetate and dihydrolinalyl acetate indicated that the oil had been adulterated with synthetic linalool and/or linalyl acetate.

Also in 1984, Thies[36] reported that high-pressure liquid chromatography could be used to fractionate lavender oil.

Ognyanov[33] reported that the major components of the four regular brands of Bulgarian lavender oil are as shown in Table IV.

Tucker et al.[37] examined the chemical composition of lavender oil from cultivars grown in the United States. Although the authors examined twelve different cultivars, the oils can be subdivided into six categories according to their chemical composition, the so-called chemotypes. Examples are linalool type (>30%), linalyl acetate type (>30%) and lavandulyl acetate type (>25%). Lawrence[11] mentioned that none of the oils possessed a composition similar to that of commercial lavender oils.

In 1985, Don et al.[39] used a combination of GC and mass spectrometry (GC/MS) and peak enrichment to confirm up to 70 constituents in Chinese lavender oil. Several of these compounds, namely ten aliphatics, were identified for the first time in lavender oil.

Also in 1985 it was reported by Naef[40] that lavender oil contained two unsaturated hydrocarbons; namely, 1,3,5-undecatriene and 1,3,5,8-undecatetraene.

One year later, Ravid et al.[41] proved that lavender oil contained (3R)-(−)-linalyl acetate of an optical purity of 93%.

In 1986, Cu[42] reported that the major components of lavender oil produced in Yunnan, Henan and Xinjiang (China) were:

limonene + 1,8-cineole (0.99-2.23%)	camphor (1.06-3.51%)
	linalyl acetate (28.80-35.90%)
linalool (23.80-35.64%)	lavandulyl acetate (1.60-6.94%)

Darmati et al.[43] studied the composition of some domestic lavender oils in Yugoslavia. They also discussed the correction of the quality.

In 1987, Shchedrina et al.[44] made a gas chromatographic analysis of Russian lavender oil and linalyl acetate.

The next year, Zhixi and Hua[91] reported that the plant material *Lavandula angustifolia* Mill. was introduced in Xingjiang in northwest of China in 1952, with a cultivation area of hundreds of hectares. The linalyl acetate content in the oil is about 40%, while the camphor, cineole and borneol content is relatively low.

In 1989, Barnard et al.[45] reported on a two-stage production of lavender oil. First, the flowering tops were extracted with 1,1,2-trichloro-1,2,2-trifluoroethane to yield a concrete and, second, this concrete was steam distilled. GC/MS analysis showed that the oil produced in this way was richer in sesquiterpenes than a steam distilled oil. Seventy-three compounds, representing 81.8% of the total essential oil, were identified. The remaining 18.2% was comprised mainly of compounds with molecular weights greater than 220. The characterized compounds are shown in Table VIII, page 31. It appears strange that they found neither lavandulol nor lavandulyl acetate in the oil.

In 1990, Nikolaevskii et al.[46] studied the effect of lavender oil on the course of experimental atherosclerosis in rabbits.

Also in 1990, Mosandl and Schubert[47] published their results of the enantiomeric stereo-differentiation of linalyl acetate in lavender oil. By using optical active stationary phases in GC, they established that linalyl acetate in genuine lavender oil has 100% (R)-(−)-configuration.

Rabotyagov and Akimov[48] examined the chemical composition of oils obtained from colchine treated lavender plants that were either tetraploids or sesquidiploids. The major components in the oil were:

δ-3-carene (1.3%)	terpinen-4-ol (0.1%)
linalyl acetate (31.1%)	linalool (37.2%)
camphor (1.4%)	geraniol (0.3%)
limonene (3.5%)	isoborneol (3.2%)
nerol (0.2%)	

In 1991, Jean et al.[49] compared the major compounds of lavender oil produced by hydrodiffusion with those of an oil produced by microwave extraction using hexane as solvent. Their results are reported in Table V.

Touche et al.[50] reported on a statistical interpretation of the results obtained from the analyses of more than 900 samples of lavender oil designated Lavande Fine Haute Provence. In addition to comparing the physicochemical properties of oils of the clonally reproduced lavender Maillette and seed-raised lavender, they compared the major components of oils produced between 1983 and 1989.

In 1991, Segur-Fantino et al.[51] examined the extent of polymorphism in a lavender population raised in France. This study was performed to determine whether it was possible to establish correlations between some morphological characteristics (such as color of flowers, number of

Table IV. Major components of four Bulgarian lavender oils[33]

Compound	Hemus %	Kazanlik %	Karlovo %	Svejen %
ocimenes	7.2	6.8	7.7	7.7
1,8-cineole	3.0	2.1	2.5	2.6
linalool	33.7	30.4	30.1	33.7
linalyl acetate	37.5	36.8	35.2	37.6
terpinen-4-ol	4.5	5.2	4.6	5.8

Table V. Major compounds of lavender oil produced by hydrodiffusion and lavender oil produced by microwave extraction in hexane[49]

Compound	Hydrodiffusion oil %	Microwave extract %
linalyl acetate	27.3	29.8
linalool	26.5	34.6
lavandulyl acetate	8.2	5.0
(Z)-β-ocimene	8.0	4.7
(E)-β-ocimene	2.9	4.4
β-caryophyllene	7.1	1.6
terpinen-4-ol	2.7	8.8
lavandulol	1.1	0.6
camphor	trace	-
coumarin	1.0	0.3

glandular hairs on the calyx, number of flowers per spike, number of vericils) and oil content and chemical composition. They found that genotypes could be differentiated by means of their relative density, the length of calyx trichomes and traces of anthocyanin in the ramified hairs on the calyx. In addition, the number of glandular hairs on the calyx was found to correlate with oil content. It is of interest to note that because the population studied had a high degree of genetic diversity, the composition of oils produced from selected genotypes was found to vary widely. For instance, linalool content varied from 9-69% and linalyl acetate content from 1-60%. The authors also examined, from a compositional, physicochemical and aroma standpoint, the differences in chemical composition of different floral parts of a clone. These results are shown in Table VI.

Table VI. Composition of different floral parts of a lavender clone[51]

Compound	Flower spike %	Corolla %	Calyx %
(Z)-β-ocimene	1.78	3.79	1.37
(E)-β-ocimene	0.72	trace	0.63
3-octanone	0.80	0.14	0.17
camphor	0.30	1.72	0.21
1,8-cineole	0.73	0.89	0.21
linalool	31.06	20.74	34.16
linalyl acetate	45.17	29.95	47.21
terpinen-4-ol	0.21	0.12	0.22
lavandulyl acetate	2.41	3.54	2.15
lavandulol	0.39	6.88	0.44
α-terpineol	0.09	0.61	trace

Some years ago, in an excellent study, Naef and Morris[52] compared the chemical composition of lavender oil with oils of lavandin and spike lavender, using modern gas chromatographic and spectroscopic techniques. The compounds identified in the oil are shown in Table VIII. In addition, the authors determined several odor aspects of lavender oil with reference to the odor of particular constituents.

Also in 1992, Kreis and Mosandl[53] used enantiomeric multidimensional chromatography employing a combination of a polar column and a chiral column to simultaneously stereodifferentiate between cis- and trans-linalool oxide (furanoid), camphor, 3-octanol, 1-octen-3-ol, lavandulol, terpine-4-ol, linalool and linalyl acetate in lavender oil. The enantiomeric distribution of the components of eleven authentic French lavender oils was determined. The enantiomeric excess concentration of the components was: (2R,5S)-cis-linalool oxide (>75%), (2R,5R)-trans-linalool oxide (>75%), (R)-lavandulol (>90%), (S)-terpinen-4-ol (>90%), (R)-linalool (>90%), and (R)-linalyl acetate (>95%).

According to the before-mentioned publications, the main constituents of lavender oils from various countries can be summarized as in Table VII. From these figures one can see a tendency in the variation of the concentrations of the ocimenes and linalyl acetate; namely, if the content of the ocimenes is relatively higher, that of linalyl acetate is lower and vice versa.

Table VII. Main constituents of lavender oils from various countries

Country	E/Z ocimenes %	Linalool %	Linalyl acetate %	Lavandulol & acetate %	Others %	Ref
Bulgaria	7.2	33.7	37.5	ND	3.0 1,8-cineole	33
idem	6.8	30.4	36.8	ND	2.1 idem	33
idem	7.7	30.1	35.2	ND	2.5 idem	33
idem	7.7	33.7	37.6	ND	2.6 idem	33
China	ND	23.8-35.6	28.8-35.9	1.6-1.7	1-4 camphor	42
France	3.0-10.4	27.6-49.0	32.2-44.8	1.3-13.0	1-2 camphor	22
idem	2.2- 4.2	29.4-41.6	46.7-53.8	0.3-4.8	1-4 4-terpinenol	26
idem	7.3-16.8	26.9-49.9	37.8-43.0	0.7-8.0	3-6 idem	28
idem	11.5	29.0	34.0	4.0	5 idem	34
idem	10.9	26.5	27.3	9.3	3 idem	49
idem	9.1	29.8	34.6	5.6	9 idem	49
idem	1.2	20.9	25.1	ND	2 idem	45
idem	14.5	17.8	21.8	8.5	6 idem	52
India	ND	10.0	45.3	0.1	10 citronellol	30
Italy	ND	29.5-49.9	12.4-41.8	0.1-1.8	1-8 terpineol	30
Russia	5.0	10 -24.5	31.0	14.0	1-4 borneol	13
	ND	37.2	31.1	ND	3 (iso)borneol	48
Spain	3.5	30.7	29.4	6.6	3 terpineols	

(ND = not determined)

Sensory Evaluation of Lavender Oil

The sensory evaluation of essential oils is a rather subjective matter, due to inter- and intra-individual differences. A general odor description of lavender oil is: herbal, floral, fresh; the topnote having green, hay-like and fruity aspects, and on dry-out being sweet and slightly woody.

The most extensive qualitative odor evaluation has been made by Naef and Morris.[52] First, they mentioned a number of constituents which are responsible for certain odor characteristics of the oil:

- ***Lower aliphatic esters:*** fruity, fatty and diffusive topnotes.
- ***Functionalized C_8 compounds:*** green, herbal, fatty, sweet, warm and floral notes.
- ***The ocimenes:*** fresh, aromatic and spicy notes.
- ***Undecatriene and undecate-***

Table VIII. Chemical composition of French lavender oil

Compound	Ref 45 %	Ref 52 %
tricyclene	-	0.01
α-pinene	0.07	0.34
sabinene	0.02	0.05
myrcene	0.39	1.27
δ-3-carene	0.01	0.13
p-cymene	0.14	0.29
cis-β-ocimene	0.59	8.23
γ-terpinene	-	0.38
allo-ocimene	-	0.03
α-thujene	0.03	0.22
camphene	0.09	0.22
β-pinene	0.09	0.18
α-phellandrene	-	0.07
α-terpinene	-	0.11
limonene	0.22	0.42
trans-β-ocimene	0.57	6.24
terpinolene	0.05	0.15
Total monoterpene hydrocarbons	**2.27**	**18.34**
1,3E,5Z-undecatiene	-	0.11
β-bergamotene	-	0.12
β-caryophyllene	3.00	8.00
β-farnesene	1.08	1.98
α-humulene	-	0.25
γ-cadinene	0.85	0.25
γ-bisabolene	t	-
α-calacorene	0.12	-
1,3E,5Z,8Z-undecatiene	-	0.01
α-santalene	0.76	1.11
α-bergamotene	t	0.15
β-santalene	-	0.02
germacrene D	0.23	0.88
β-bisabolene	0.10	-
α-farnesene	t	-
Total sesquiterpene hydrocarbons	**6.15**	**12.76**
methoxyhexane	-	0.09
1,8-cineole	2.58	0.91
cis-linalool oxide-5	1.54	0.16
cis-linalool oxide-6	0.29	t
rosefuran	-	0.01
1.2-limonene epoxide	0.71	-
prenol	-	t
1-octen-3-ol	0.54	0.48
linalool	20.90	17.81
borneol	1.70	1.06
lavandulol	-	1.17
1-p-cymen-8-ol	0.09	0.17
nerol	0.21	0.23
camphene hydrate	0.10	-
p-mentha-1,5-dien-7-ol	t	-
ocimene oxide	-	t
trans-linalool oxide-5	0.78	0.16
trans-linalool oxide-6	0.13	t
caryophyllene oxide	2.11	0.33
epoxy-α-santalene	-	t
hexanol	-	0.02
octanol-3	0.07	0.18
hotrienol	-	t
sabinene hydrate	-	0.11
terpinen-4-ol	2.03	6.43
α-terpineol	0.70	1.00
geraniol	0.26	0.43
cis-carveol	-	0.05
dihydro-p-cymen-8-ol	0.03	-
Total monoterpene alcohols	**26.02**	**28.46**
α-photosantalol	-	0.10
α-cadinol	t	-
pentanal	-	t
2-hexenal	-	t
nonanal	-	t
cuminaldehyde	-	0.13
acetone	-	0.08
3-octanone	0.08	1.39
camphenilone	-	t
6-methyl-5-hepten-2-one	0.04	-
carvone	0.06	t
6-methyl-3,5-hepta-6,10,14-trimethyl-dien-2-one	t	-
butyl acetate	-	0.06
butyl isobutanoate	-	0.02
hexyl acetate	0.66	0.55
hexyl propionate	-	0.02
hexyl butanoate	0.02	0.38
3-octenyl-1 acetate	-	2.49
hexenyl butyrate	0.80	-
octylpropanoate	0.26	-
Z-3-hexenyl nonanoate	0.02	-
linalyl acetate	25.06	21.84
lavandulyl acetate	-	7.30
neryl acetate	2.23	0.53
epoxylinalyl acetate	-	0.02
neryl propanoate	0.14	-
cubenol	-	t
cadinol-T	-	0.31
hexanal	-	t
octanal	-	t
tricyclo-eka-santalal	-	0.05
cinnamaldehyde	0.32	-
2-hexanone	0.02	-
camphor	2.90	0.45
cryptone	-	0.18
piperitone	t	-
pentadecanone	0.02	-
butyl propanoate	-	0.01
butyl butanoate	0.06	0.25
3-octyl acetate	0.02	0.18
hexyl isobutanoate	-	0.08
butyl tiglate	-	0.11
hexyl tiglate	-	0.10
hexyl hexanoate	0.03	-
Z-3-hexenyl octanoate	0.56	-
Z-3-hexenyl decanoate	0.14	-
bornyl acetate	0.24	0.55
butyl benzoate	-	t
geranyl acetate	0.13	0.96
linalyl hexanoate	-	0.11
Total monoterpene esters	**27.80**	**31.31**
thymol	-	t
anethole	4.62	-
eugenol	t	-
dimethyl sulfide	-	t
estragole	t	-
aceteugenol	0.05	-

t = trace

traene: fresh, green galbanum odors.

- ***Functionalized santalenes***: soft, warm woody characteristics.
- ***Butyl benzoate:*** balsamic note.
- ***Cryptone:*** warm, herbal and cuminic note.

Second, the authors gave a list of so-called group discriminators with their percentage in the oil: lower esters (1.0%), 3-octyl derivatives (4.7%), ocimenes (14.5%), undecatri(tetra)enes (0.1%), santalene derivatives (2.3%), butyl benzoate (0.01%) and cryptone (0.2%).

According to several publications,[8,9,11] the odor characteristics of lavender oil are described with reference to its constituents as follows:

- ***Fresh, green:*** cis-3-hexenol and derivatives.
- ***Herbal, green:*** undecatriene and undecatetraene.
- ***Herbal, earthy:*** 1-octen-3-ol and derivatives.
- ***Fruity, fatty:*** butyl and hexyl esters.
- ***Fresh, floral:*** linalool (esters), lavandulol (esters).
- ***Herbaceous:*** monoterpenyl carbonyls.
- ***Sweet aromatic:*** benzenoid derivatives
- ***Warm, woody:*** santalene derivatives, sesquiterpene compounds.
- ***General modifiers:*** substituted pyridines.

The odor character of lavandulol was described by Arctander[102] as being oily, herbal, warm-rosy, somewhat reminiscent of geraniol and a spike-like note.

Lavandin Oils

General

The botanical species of lavandin is an interspecific hybrid between lavender and spike lavender and is defined—according to ISO 32/8—as *Lavandula angustifolia* P. Miller X *Lavandula latifolia* (L.) Medikus.[105] The lavandin plant is often called *Lavandula hybrida*. However, according to Tucker,[5] the correct name for lavandin is *Lavandula x intermedia* Emeric ex Loiseleur.

Peyron[31] reported that 900-1,000 tons of lavandin oil were produced in France in 1982, while 30-50 tons were produced in the USSR and Yugoslavia.

In 1979 Moutet[89] presented some ideas about the future of Lavandin Abrialis and Grosso oils. She stated that 55% of the lavandin crop for 1980 would be devoted to the Grosso variety.

Lawrence[38] mentioned that the world production of lavandin oil in 1984 was 750 tons with France producing more than 90% of the oil. Also according to Lawrence,[54] the oil of lavandin has the reputation of being among the top ten most important essential oils used in the fragrance industry. He mentioned that from the chemical standpoint, lavandin oil has been the subject of considerable study over the years.

Chemical Evaluation

As early as 1945, Naves[55] reported the presence of α-pinene, camphene, limonene, camphor, borneol, linalool and linalyl acetate in lavandin oil.

In 1955, Igolen[92] in 1955 studied lavandin oil and identified six carbonyl compounds: hexanal, octanal, cuminaldehyde, 3-octanone, camphor and coumarin.

In 1960, Stadtler[93] reported on the isolation of the carbonyl compounds from lavandin oil by Girard T reagent. He identified ten compounds: cuminaldehyde, phellandral, 3-octanone, 6-methyl-5-hepten-2-one, 6-methyl-3,5-heptadien-2-one, camphor, nopinone, sabina ketone, cryptone and carvone.

Some years later, in 1966, Peyron and Benezet[12] isolated and identified the following:

3-octanone	3-octanol
hexyl acetate	1-octen-3-ol
hexanol	epoxydihydrolinalool
ocimene	hexyl butyrate
3-octyl acetate	linalool
1-octen-3-yl acetate	linalyl acetate
alloocimene	

One year later Steltenkamp and Casazza[56] reported a detailed quantitative and qualitative analysis of oil of lavandin, which is shown in Table IX.

In 1973, Mookherjee and Trenkle[58] published the results of their investigation on lavandin oil. They isolated the carbonyl fraction by treating the oil with Girard T reagent and identified:

hexanal	heptanal
(E)-2-hexenal	octanal

(E,E)-2,4-heptadienal
nonanal
α-campholenal
decanal
myrtenal
cuminaldehyde
phellandral
perillaldehyde
p-mentha-1,4-dien-7-al
(E,E)-2,4-decadienal
6-methyl-2-heptanone
3-octanone
6-methyl-5-hepten-2-one
6-methyl-3,5-heptadien-2-one
camphor
nopinone
sabina ketone
cryptone
p-methylacetophenone
1-(2H)-naphthalenone
3,4-dihydro-4,6-octadien-2-one-6-hydroxy-6-methyl acetate
2,7-octadienal-6-hydroxy-2,6-dimethyl acetate
2-heptenal-7-hydroxy-5-isoprenyl-2-methyl acetate
lavandulol
p-cymen-8-ol
γ-methyl-γ-vinyl-butyrolactone
coumarin
7-methoxy-coumarin
1-octen-3-ol
6,7-epoxy-3,7-dimethyloctyl acetate
2,6-dimethyl-3,7-octadiene-2,6-diol-6-acetate
2,6-dimethyl-1,7-octadiene-3,6-diol-6-acetate

In 1977, Kaiser and Lamparsky[19] examined the trace constituents of lavandin oil. They used a combination of modern spectroscopic techniques for structure elucidation followed by synthetic corrobation. The following compounds were identified:

α-photosantalol A
α-norsantalenone
2,6-dimethyl-6-acetoxy-octa-1,7-dien-3-one
2,6-dimethyl-6-acetoxy-oct-7-en-3-one

Also in 1977, it was reported[60] that the 1,8-cineole content of samples of Abrialis and Super lavandin oil was determined by a number of independent laboratories to be 8.7-9.2% in lavandin Abrialis oil and 2.7-3.0% in lavandin Super oil.

Two years later Prager and Miskiewicz[21] presented chromatographic data for 19 samples of lavandin oil, all imported into the US from France. The chromatographic data were in percent concentrations of

Table IX. Chemical composition of lavandin oils

Compound	Ref 56 %	Ref 61 Abrialis %	Ref 61 Super %	Ref 61 Grosso %	Ref 62 Abrialis %
tricyclene	0.03	-	-	-	-
α-pinene	0.40	0.52	0.28	0.60	0.50
camphene	0.30	0.46	0.26	0.35	0.50
β-pinene	0.30	0.49	0.15	0.45	0.40
myrcene	0.30	0.55	0.47	0.65	0.60
sabinene	0.10	0.17	0.06	0.15	0.20
δ-3-carene	0.02	0.02	0.02	0.08	-
limonene	0.70	0.68	0.73	0.67	0.60
cis-ocimene	2.60	2.30	1.35	1.15	2.20
trans-ocimene	3.00	3.00	2.00	0.50	1.00
γ-terpinene	-	-	-	-	0.40
terpinolene	0.20	0.26	0.12	0.25	-
p-cymene	0.04	0.32	0.69	0.35	0.50
α-santalene	0.20	-	-	-	-
caryophyllene	0.70	2.35	1.75	1.47	2.60
trans-β-farnesene	0.30	-	-	-	-
germacrene D		-	-	-	-0.50
1,8-cineole	7.60	8.17	3.15	5.20	6.90
hexanol	-	-	-	-	0.30
1-octen-3-ol	0.30	0.34	0.26	0.50	0.10
3-octanol	-	-	-	-	0.25
linalool	35.00	33.50	30.98	32.25	32.00
lavandulol	0.60	0.96	0.87	1.50	1.00
borneol	2.90	2.59	2.27	2.00	2.10
α-terpineol	0.50	0.48	0.52	1.00	0.50
terpinen-4-ol	?	0.50	0.46	2.77	0.60
trans-linalool oxide	0.20	0.21	0.28	0.25	-
cis-linalool oxide	0.10	0.10	0.08	0.98	-
acetone	0.01	-	-	-	-
3-octanone	1.00	0.97	0.43	0.60	3.00
camphor	8.90	9.54	5.42	6.95	9.00
butyl acetate	0.03	-	-	-	-
hexyl butanoate	0.40	0.35	0.66	0.40	0.40
hexyl isobutanoate	0.09	0.13	0.15	0.20	0.25
hexyl 3-methylbutanoate	-	-	-	-	0.50
1-octen-3-yl acetate	0.30	0.48	0.49	0.45	-
linalyl acetate	27.00	27.10	39.50	31.90	23.60
lavandulyl acetate	1.00	1.76	1.55	1.95	1.20
lavandulyl butanoate	0.20	-	-	-	-
lavandulyl isobutanoate	-	-	-	-	0.60
lavandulyl 2-methylbutanoate	0.70	-	-	-	-
neryl acetate	0.70	-	-	-	-
geranyl acetate	0.30	0.21	0.37	0.30	0.40
hexyl tiglate	0.30	-	-	-	-
caryophyllene oxide	0.30	-	-	-	-
isocaryophyllene oxide	0.04	-	-	-	-
coumarin	0.03	-	-	-	-

peak areas of capillary GC for 11 major components. The ranges found for these compounds were as follows:

α-pinene 0.0-1.2%	α-terpineol 0.0-0.9%
β-pinene 0.0-0.7%	camphene 0.0-0.6%
1,8-cineole 5.8-11.1%	limonene 0.5-1.4%
trans-ocimene 0.6-4.6%	cis-ocimene 1.0-1.2%
linalool 30.6-37.1%	camphor 5.5-11.7%
terpinen-4-ol + caryophyllene 2.0-3.9%	linalyl acetate 21.7-32.1%
	lavandulol 0.3-0.8%
lavandulyl acetate 1.3-1.9%	borneol 1.7-3.3%

In the same year, co-workers at Dragoco[77] reported that the major constituents of lavandin oil were the following compounds:

α-pinene (0.9%)	camphene (0.6%)
β-pinene (0.7%)	myrcene (0.6%)
limonene (0.8%)	1,8-cineole (9.0%)
trans-ocimene (1.5%)	3-octanol (0.4%)
camphor (9.4%)	linalool (32.0%)
linalyl acetate (22.0%)	bornyl acetate (1.9%)
caryophyllene (4.4%)	cis-α-bisobolene (0.6%)

Meklati and Ahmed[91] prefractionated Algerian lavandin oils using high-pressure liquid chromatography prior to gas chromatographic identification. They qualitatively identified fifty-five compounds in the oil.

In 1979 Zola and LeVanda[61] published their results on a comparison of the chemical composition of the oils of the three most common varieties of lavandin: Abrialis, Super and Grosso. Their detailed figures are shown in Table IX. The authors demonstrated that it was possible to differentiate between the three types. Oil of the Abrialis variety contained 3.97% trans-ocimene + 3-octanone; 0.5% terpinen-4-ol; 33.5% linalool and 27.1% linalyl acetate. Oil of the Super variety had 2.43% trans-ocimene + 3-octanone; 0.46% terpinen-4-ol; 30.98% linalool and 39.50% linalyl acetate. Oil of the Grosso variety contained 0.6% trans-ocimene + 3-octanone; 2.77% terpinen-4-ol; 32.25% linalool and 31.9% linalyl acetate. In this way it was shown that Grosso oil can be differentiated by the low percentage of trans-ocimene + octanone and a relatively high percentage of terpinen-4-ol, whereas the Super oil can be characterized by the higher proportion of linalyl acetate.

In the same year, 1979, Hoffmann[22] wrote a review of the chemical composition of lavandin oil. In this review he surveyed the literature between 1937 and 1977.

In 1980, Lawrence[62] examined the chemical composition of lavandin Abrialis oil using modern analytical techniques. The identified compounds are shown in Table IX.

In 1981, Melegari et al.[25] compared the essential oils of four lavandin cultivars grown in the vicinity of Moderna, Italy, at different altitudes. A summary of their results is shown in Table X, from which it can be seen that essential oil content was strongly influenced by the location and elevation, especially when considering that the lavandin cultivars were all clonally reproduced.

Three years later, in 1984, Lalande[34] reported the provisional French specifications for the oils of the varieties lavandin Grosso and lavandin Abrialis (see Table XI).

Also in 1984, Tucker et al.[37] examined the chemical composition of lavandin cultivars grown under the same conditions in the United States. Although the authors examined six different cultivars, only one of which (Grosso) is known to be grown commercially, the oil compositions could be classified into three groups.

One year later Szabolcs et al.[86] used retention values on four different packed gas chromatographic columns to characterize the presence of the following compounds in a sample of lavandin Grosso oil of French origin:

α-pinene	β-pinene
camphene	p-cymene

Table X. Composition of four lavandin cultivars grown at different altitudes near Moderna, Italy[25]

Compound	Abrialis %	Super %	Maime %	R.C. %
α-pinene	0.19-0.84	0.05-0.58	0.10-0.58	0.38-1.34
β-pinene	0.10-1.14	0.05-0.37	0.08-0.37	0.14-1.10
myrcene	0.48-2.37	0.40-2.43	0.21-1.53	0.50-1.81
limonene	0.30-1.00	0.27-1.67	0.31-1.25	0.36-2.59
1,8-cineole	4.50-12.02	1.86-10.88	1.82-11.05	3.85-26.04
camphor	7.85-13.34	5.03-14.79	8.10-13.85	11.16-18.50
linalool	30.31-45.10	23.55-47.88	33.52-60.13	43.50-70.60
linalyl acetate	14.10-36.17	32.53-52.20	13.67-30.42	-
caryophyllene	0.82-2.38	0.67-1.05	1.65-3.50	2.15-6.61
lavandulol	0.58-1.08	0.20-1.04	0.23-0.80	0.50-1.81
α-terpineol	2.33-4.60	2.51-6.31	2.33-4.56	2.04-4.82
neryl acetate	0.10-0.32	0.13-0.43	0.06-0.20	-
geranyl acetate	0.58-1.86	0.51-1.90	0.39-1.06	0.05-1.02
nerol	0.05-0.23	0.05-0.59	0.02-0.15	-
geraniol	0.17-0.75	0.28-1.31	0.14-0.39	-

Table XI. French specifications for the oils of lavandin Abrialis and lavandin Grosso[34]

Compound	Abrialis oil %	Grosso oil %
1,8-cineole	6-11	4-7
cis-ocimene	1.5-4	ND
trans-ocimene	3-7	ND
linalool	30-38	25-35
camphor	7-11	6-8
borneol	2-4	1.5-3
lavandulol	0.5-1.5	0.3-0.5
terpinen-4-ol	<1.0	2-4
linalyl acetate	20-30	28-38
lavandulyl acetate	1-2	1.5-3

ND = not determined

cis-ocimene	borneol
limonene	terpine-4-ol
1,8-cineole	α-terpineol
trans-ocimene	linalyl acetate
linalool	lavandulyl acetate
camphor	caryophyllene
lavandulol	

In 1987 Gaydou and Randriamiharosoa[64] used chiral active stationary phases in GC for the separation of linalool enantiomers. They found that lavandin oil contains almost exclusively (3R)-(+)-linalool.

One year later Ramaswani et al.[65] confirmed the presence of α-santalene in lavandin oil.

Also in 1988, Karuza-Stojakovic and Blazevic[66] reported on an accurate measurement of 1,8-cineole in lavandin oil. They found that the 1,8-cineole content was 7.18%.

In 1989, Galletti et al.[67] in 1989 examined an oil of lavandin Abrialis by GC/MS and the ion trap detection method. The authors showed that an oil as complex as lavandin could readily be analyzed using this technique. They also reported that some discrepancies in compound identification were dependent on the sample amount.

The same year, Lammertink et al.[68] reported on their results from growing and distilling lavandin in New Zealand. A comparison of the major components found in the oils of three lavandin cultivars is given in Table XII.

In 1990 Mosandl and Schubert[47] reported that lavandin oil contained 100% (R)-(−)-linalyl acetate.

One year later, Chambon et al.[69] compared the chemical composition of oils obtained from one-year-old lavandin Grosso plants produced from normal rooted cuttings with oils obtained from plants produced from tissue culture. A summary of their results is shown in Table XIII.

Also in 1991, Pellerin[70] compared the composition of steam-distilled lavandin Grosso oil with a carbon dioxide extracted oil and an absolute from the same lavandin cultivar (see Table XIV).

In 1992, Naef and Morris,[52] in a thorough study, compared the chemical composition of lavender, lavandin and spike lavender oils. Using modern gas chromatographic and spectroscopic techniques they also compared the oils obtained from lavandin Abrialis and from lavandin Grosso. The results of this detailed analysis are shown in Table XV.

One year later, Piccaglia and Marotti[87] reported on the characterization of several aromatic plants grown in northern Italy. Lavandin oil was obtained from plants grown at Casolavalsenio (Ravenna). In this oil the researchers detected 73 compounds and identified 60. Their results are shown in Table XVI. The authors also mentioned the main compounds and yields of the oils of the three cultivars grown in Italy (see Table XVII).

Sensory Evaluation

A general odor description of lavandin oil is fresh, herbal, floral, slightly spicy; depending on the cineole

Table XII. Composition of oils of lavandin cultivars grown in New Zealand

Compound	Grosso %	Grosso-CS %	Abrialis %
monoterpene hydrocarbons	1.6	1.6	1.5
1,8-cineole	6.2	6.5	10.4
linalool	34.1	34.1	39.6
camphor	7.8	7.9	11.5
borneol	3.1	3.4	3.1
terpinen-4-ol	3.1	3.6	0.4
linalyl acetate	33.0	33.8	22.1
lavandulyl acetate	2.4	2.1	1.1

Table XIII. Composition of lavandin Grosso plants produced from tissue culture and from normal rooted cuttings[69]

Compound	Oil of tissue culture %	Oil of rooted cuttings %
limonene	0.88	0.77
1,8-cineole	7.20	5.29
camphor	7.67	8.85
linalool	33.09	31.44
linalyl acetate	26.38	22.42
terpinen-4-ol	3.86	3.85
borneol	2.77	2.93
lavandulol	0.41	0.48
lavandulyl acetate	1.90	2.85

Table XIV. Composition of lavandin Grosso oil from steam distillation, oil from CO_2 extraction and an absolute from the same lavandin cultivar

Compound	Steam-distilled oil %	CO_2-extract %	Absolute %
α- and β-pinene	1.0	-	-
myrcene	1.1	-	-
1,8-cineole	7.2	3.2	-
(Z)-β-ocimene	1.1	0.5	-
(E)-β-ocimene	0.6	-	-
linalool	42.5	17.5	10.1
camphor	7.8	4.5	1.7
terpinen-4-ol	-	1.5	1.1
borneol	2.7	1.6	1.5
α-terpineol	3.9	-	-
linalyl acetate	21.0	33.5	28.4
lavandulyl acetate	2.5	1.9	1.8
geranyl acetate	1.4	-	-
coumarin	-	5.3	7.7
β-caryophyllene + α-humulene	1.3	3.4	2.4
herniarin	-	1.6	2.6

Table XV. Chemical composition of lavandin oils[52]

Compound	Grosso %	Abrialis %	Compound	Grosso %	Abrialis %
tricyclene	0.01	0.01	α-thujene	0.12	0.07
α-pinene	0.61	0.89	camphene	0.33	0.55
sabinene	0.14	0.38	β-pinene	0.44	0.87
myrcene	1.50	1.24	α-phellandrene	0.07	0.07
δ-3-carene	*0.05*	*0.13*	*α-terpinene*	*0.05*	*0.09*
p-cymene	0.16	0.22	limonene	0.93	1.50
cis-β-ocimene	1.05	2.63	trans-β-ocimene	0.52	4.22
γ-terpinene	0.40	0.26	terpinolene	0.26	0.48
1,3E,5Z-undecatriene	t	t			
β-bergamotene	t	0.39	α-santalene	0.21	0.67
β-caryophyllene	2.73	6.03	β-santalene	-	t
β-farnesene	1.12	1.09	α-humulene	0.17	0.43
germacrene D	1.06	1.20	γ-cadinene	0.25	0.30
bisabolene	0.10	0.05			
1,8-cineole	10.22	10.28			
cis-linalool oxide-5	0.16	0.11	trans-linalool oxide-5	0.16	0.11
trans-linalool oxide-6	tr	0.25	caryophyllene oxide	0.12	0.11
hexanol	0.02	0.05	octanol-3	-	t
1-octen-3-ol	0.12	0.33	plinol (isomer 2)	0.19	-
linalool	*22.53*	*19.59*	*hotrienol*	*-*	*t*
borneol	2.89	3.65	sabinene hydrate	0.18	0.24
lavandulol	0.84	0.55	terpinen-4-ol	3.34	1.23
1-p-cymen-8-ol	0.02	0.05	α-terpineol	1.18	0.98
γ-terpineol	0.43	-			
nerol	0.05	t	geraniol	0.23	0.10
cubenol	t	t	cadinol-T	0.20	0.21
β-bisabolol	0.40	0.24	methoxyhexane	0.05	0.06
2-hexenal	-	t	octanal	t	t
cuminaldehyde	0.02	tr			
acetone	*t*	*0.02*	*5-methylheptan-3-one*	*0.14*	*-*
fenchone	0.01	0.01	isofenchone	0.08	0.09
3-octanone	0.04	0.14	camphor	12.16	12.20
camphenilone	-	tr	cryptone	-	0.05
			5,5,6-trimethyl-bicyclo [2.2.1]heptan-2-one	-	0.13
butyl isobutanoate	0.01	t	butyl butanoate	0.04	0.03
hexyl acetate	0.17	0.24	3-octyl acetate	-	t
hexyl propionate	0.02	0.06	hexyl isobutanoate	0.04	0.14
hexyl butanoate	0.28	0.30	butyl tiglate	0.10	0.15
3-octenyl-1 acetate	0.26	0.49	hexyl tiglate	0.13	0.19
octyl acetate	t	-	hexyl 2-methybutanoate	0.05	0.12
linalyl acetate	26.18	18.58	bornyl acetate	0.24	-
lavandulyl acetate	2.27	2.64	neryl acetate	0.13	0.20
geranyl acetate	1.19	1.22	epoxylinalyl acetate	0.03	0.09
linalyl hexanoate	t	-	lavandulyl butanoate	0.02	t

t = trace

content the odor is more or less minty. The Grosso type oil has a harsh, terpenic note.

Naef and Morris[52] made an evaluation of the odor aspects of lavandin oil. They mentioned that the oil has a camphoraceous and fresh connotation due to the presence of the well-known constituents 1,8-cineole (10%), camphor (12%) and borneol (3%); however, fenchone, iso-fenchone and 5,5,6-trimethyl-bicyclo[2.2.1]heptan-2-one also participate in those odor characteristics. For more details see the odor evaluation of lavender oil earlier in this article. The odor characteristics of lavandin oil can be described in relation to its constituents as follows:

- ***Fruity, fatty:*** aliphatic esters.
- ***Harsh, terpeny:*** monoterpene hydrocarbons.
- ***Fresh, eucalyptus:*** 1,8-cineole.
- ***Camphoraceous:*** camphor.
- ***Fresh, floral:*** linalool (acetate).
- ***Herbaceous:*** monoterpenyl carbonyls.
- ***Sweet aromatic:*** benzenoid derivatives.
- ***Warm woody:*** sesquiterpene derivatives.

Table XVI. Chemical composition of Italian lavandin oil[87]

Compound	Range (%)	Compound	Range (%)
3-hexen-1-ol	0.05-0.06	isoborneol	trace
hexanol	0.05-0.09	borneol + lavandulol	1.75-2.36
α-pinene	0.09-0.37	camphene	0.09-0.25
terpinen-4-ol	0.12-2.59	sabinene	0.04-0.16
α-terpineol + hexyl butanoate	1.29-1.80	β-pinene	0.11-0.47
oct-1-en-3-ol	trace	citronellol + nerol	0.14-0.23
3-octanol	0.04-0.69	myrcene	0.87-1.02
carvone	0.05-0.14	oct-3-en-1-ol	trace
linalyl acetate	20.54-30.16	α-phellandrene	trace
geraniol	trace	δ-3-carene	trace-0.06
perillaldehyde + geranial	trace	hexyl acetate	0.25-0.74
geranial	trace	p-cymene	trace
isobornyl acetate	trace	limonene + β-phellandrene	0.58-0.95
lavandulyl acetate	1.95-2.05	hexyl tiglate	0.20-0.27
1,8-cineole	2.08-8.54	neryl acetate	0.17-0.37
cis-ocimene	1.08-2.90	geranyl acetate	0.66-0.93
trans-ocimene	0.40-5.46	undecane	0.10-0.17
γ-terpinene	trace-0.09	tridecane	0.09-0.13
cis-linalool oxide	0.04-0.16	caryophyllene +	
trans-linalool oxide	0.20-0.25	α-farnesene	0.84-1.44
terpinolene	0.17-0.30	β-farnesene +	
linalool	28.05-30.09	α-humulene	0.90-1.72
thujone	trace	β-cubebene	0.62-0.89
oct-1-en-3-yl acetate	0.50-0.68	β-chamigrene +	
nonanone	trace	β-bisabolene	0.41-0.72
hexyl isobutanoate	0.05-0.13	γ-cadinene	trace
camphor	3.84-8.11	α-cubebene	trace
citronellal	trace	caryophyllene oxide	trace

Table XVII. Main compounds and yields of the oils of three lavandin cultivars grown in northern Italy

Compound	Abrialis %	Grosso %	Super A %
1,8-cineole	8.6	5.2	2.0
camphor	8.2	5.9	3.8
linalool	30.4	28.4	29.3
linalyl acetate	20.8	27.6	30.4
"rhodinol fraction"	1.5	1.7	2.2
Yield	1.71	1.15	1.0

Spike Lavender Oil

General

Spike lavender oil is produced from the plants of *Lavandula latifolia* Medikus, also called *L. spica* Vill. The plant material is native to Mediterranean countries, particularly Spain. In 1985 Lawrence[38] mentioned that at one time more than 200 tons of spike lavender oil were produced in Spain. He estimated that in 1984 the production did not exceed 35 tons. Lawrence[71] also wrote that surprisingly enough, even though it is an important oil in the fragrance industry, spike lavender oil failed to receive scientific attention comparable to that focused on other oils of similar economic stature, and this condition prevailed until 1975.

Chemical Evaluation

In 1969, Wobben et al.[72] used modern chromatographic and spectroscopic techniques on Spanish spike lavender oil to confirm the presence of the following:

α-pinene	cryptone
camphene	camphor
β-pinene	nopinone
myrcene	p-methyl-acetophenone
sabinene	carvone
limonene	linalool
p-cymene	terpinen-4-ol
caryophyllene	borneol
1,8-cineole	α-terpineol
linalyl acetate	eugenol
cuminaldehyde	caryophyllene oxide
3-octanone	coumarin
methyl heptenone	

In 1970 Mizrahi and Rojo[73] demonstrated that differential IR-spectroscopy could be used to distinguish between lavender, lavandin and spike lavender.

Herisset et al.[74] studied UV-, IR- and Raman-spectroscopy to differentiate between

Table XVIII. Composition of spike lavender oils from Siena and Pietramala, Italy[75]

	Siena %	Pietramala %
α-pinene	1.0	3.7
camphene	0.7	0.8
β-pinene	1.2	1.5
1,8-cineole	37.4	35.1
p-cymene	0.9	0.9
camphor	23.5	9.8
linalool	24.8	36.3
linalyl acetate	0.6	1.3
borneol + α-terpineol	4.3	4.4

Table XIX. Chemical composition of Spanish spike lavender oils

Compound	Ref 77 %	Ref 80 %	Ref 83 %	Ref 84 %
α-thujene	0.00-0.17	-	0.01-0.05	-
α-pinene	1.69-4.23	4.21	1.63-2.01	0.1
camphene	0.36-1.78	0.23	0.55-0.69	0.1
β-pinene	1.75-3.56	0.84	1.64-2.47	0.1
myrcene	0.39-0.67	0.15	0.04-0.57	-
sabinene	0.00-0.55	0.86	0.49-0.71	trace
α-phellandrene	0.02-0.12	-	0.12-0.13	-
α-terpinene	0.04-0.10	-	0.07-0.29	-
limonene	1.00-2.16	-	1.02-1.11	1.0
cis-ocimene	0.00-0.01	-	0.05-0.20	-
trans-ocimene	0.15-0.29	-	0.20-0.60	-
γ-terpinene	-	-	0.26-0.45	-
terpinolene	0.13-0.25	-	0.22-0.23	-
p-cymene	0.26-0.98	0.91	0.18-0.27	0.4
caryophyllene	0.31-1.74	1.39	1.36-1.53	0.2
α-humulene	0.00-0.46	-	0.27-0.43	trace
trans-β-farnesene	-	0.30	-	0.2
α-bisabolene	0.38-1.61	1.90	1.79-2.07	-
β-bisabolene	0.01-0.20	0.40	-	trace
γ-cadinene	-	0.80	0.10-0.30	-
δ-cadinene	-	-	0.20-0.50	trace
1,8-cineole	25.40-34.34	33.65	25.49-27.25	36.3
hexanol	0.01-0.07	-	0.10-0.20	-
octanol-3	0.00-0.01	-	0.05-0.10	-
linalool	37.21-43.75	26.34	40.60-43.18	30.3
lavandulol	0.15-1.50	-	0.36-0.65	-
borneol	1.46-2.54	4.89	0.79-0.88	2.8
isoborneol	0.00-0.39	-	0.13-0.26	0.3
α-terpineol	0.52-1.96	1.71	0.99-1.06	2.6
terpinen-4-ol	0.19-0.45	-	0.50-0.60	0.7
citronellol	0.00-0.37	-	-	-
nerol	0.01-0.08	-	0.02-0.04	0.7
geraniol	0.03-0.19	0.20	0.09-0.12	0.9
cis-carveol	0.00-0.05	0.35	-	0.1
trans-pinocarveol	-	0.37	-	-
p-cymen-8-ol	-	0.37	-	1.0
myrtenol	-	0.23	-	0.8
cumin alcohol	-	0.23	-	0.2
6-methyl-5-hepten-2-one	0.02-0.07	-	-	-
3-octanone	0.04-0.07	-	0.10-0.20	-
α-thujone	0.02-0.08	-	-	trace
β-thujone	0.02-0.05	-	-	trace
camphor	5.94-14.26	5.31	12.49-13.07	8.0
carvone	0.12-0.50	-	-	0.1
butyl acetate	-	-	0.05-0.10	-
hexyl acetate	-	-	0.05-0.10	-
1-octen-3-yl acetate	-	-	0.10-0.20	-
linalyl acetate	0.00-1.04	-	0.83-1.45	-
bornyl acetate	0.00-0.69	-	0.23-0.33	trace
lavandulyl acetate	0.00-0.30	-	-	-
neryl acetate	0.10-0.40	-	-	-
geranyl acetate	0.00-0.07	-	-	trace
hexyl tiglate	0.07-0.79	-	-	-
linalool oxides (5)	0.19-0.48	0.53	0.30-0.66	0.5
caryophyllene oxide	0.06-0.22	0.53	0.03-0.04	0.2
coumarin	0.00-0.20	9.04	0.07-0.10	2.4
dihydrocoumarin	0.00-0.20	-	0.02-0.03	-
eugenol	0.00-0.08	-	0.01-0.10	-

the lavandula oils. They used 1,8-cineole and limonene, camphor, linalool and linalyl acetate as differentiation criteria and could readily distinguish all three oils.

In 1971, Franchi[75] investigated two Italian oils, from Siena and Pietramala, by GC. His results are shown in Table XVIII. Small amounts of neryl and geranyl acetate were also found. Comparison of the chemical composition of the two oils shows that one oil has high camphor content (23.5%) and relatively low linalool content (24.8%); the other oil has just the opposite: 9.8% and 36.3%, respectively.

In 1972, Kubelka et al.[90] used a GC/MS technique to identify the following components for the first time in spike lavender oil:

ocimene
hexyl acetate
β-farnesene
nerol
γ-cadinene
γ-terpinene (tentative)
longifolene (tentative)
lavandulol (tentative)

In 1974, De Gavina Mugica and Torner Ochoa[76] investigated nine different spike oils from Guadalajara, Spain, by means of GC and IR-spectroscopy. They found that the oils had the following chemical composition:

α-pinene (0.0-1.6%)
β-pinene + sabinene (0.2-2.2%)
limonene + 1,8-cineole (22.1-34.0%)
trans-linalool oxide (0.1-6.8%)
linalool (11.0-53.9%)
terpinen-4-ol (0.0-0.4%)
α-terpineol + borneol (0.9-2.5%)
camphene (0.4-0.9%)
myrcene (0.0-0.7%)
p-cymene (0.2-1.1%)
cis-linalool oxide (0.1-8.5%)
camphor (5.0-15.0%)
geraniol (0.0-1.2%)

Moreover, in the same oils they tentatively identified the following compounds:

α-phellandrene
hexanol
3-octanone
methyl heptenone
γ-terpinene
thujone
octanol
lavandulol
linalyl acetate
bornyl acetate
isobornyl acetate
carvone
cuminaldehyde
α-terpinyl acetate
geranyl acetate

Prager and Miskiewicz,[21] from the US Custom laboratories in 1979, reported on the chemical composition of a number of imported spike lavender oils. They analyzed the oils with GC/MS and identified the following 14 major compounds:

α-pinene (1.8-6.8%)
β-pinene (1.3-3.4%)
1,8-cineole (20.5-31.1%)
camphor (9.6-16.5%)
linalyl acetate (0.7-1.8%)
terpinen-4-ol + caryophyllene (0.2-2.2%)
α-terpineol (0.7-1.9%)
camphene (0.5-2.1%)
limonene (1.1-2.7%)
trans-ocimene (0.0-0.4%)
linalool (29.8-46.4%)
lavandulol (0.2-0.6%)
borneol (0.4-6.9%)

The authors stated that it was easy to differentiate between spike lavender oil and lavender and lavandin oils, because spike lavender oil contained larger amounts of α- and β-pinene, camphene, limonene, 1,8-cineole and camphor. In addition, according to their findings, spike lavender oil contained less linalyl acetate and caryophyllene, little ocimene and no lavandulyl acetate.

In 1979 Kuster[77] reported on detailed analyses of some Spanish spike lavender oils. The chemical composition of these oils is shown in Table XIX.

Carrasco et al.[78] published in 1980 the chemical composition of the oils of cultivated spike lavender obtained from plants one to six years old. From these

Table XX. Chemical composition of spike lavender oil obtained from plants of various ages[78]

Compound	Wild-growing plants %	Cultivated plants (age in years) 1 %	2 %	3 %	4 %	5 %	6 %
α-thujene	0.03	0.03	0.17	0.02	t	t	0.02
α-pinene	1.60	2.82	2.10	1.80	1.60	1.50	1.40
camphene	0.61	0.51	0.41	0.48	0.30	0.35	0.30
β-pinene	1.90	3.20	2.70	2.30	2.10	2.00	1.70
sabinene	0.80	1.61	1.41	1.04	1.07	0.98	0.95
myrcene	0.60	0.99	0.89	0.73	0.77	0.64	0.60
α-phellandrene	0.10	0.12	0.05	0.09	0.09	0.10	0.07
α-terpinene	0.04	0.05	0.03	0.04	0.04	t	0.04
limonene	1.00	1.16	0.96	0.95	0.74	0.86	0.77
γ-terpinene	0.60	0.70	0.53	0.58	0.70	0.44	0.66
p-cymene	0.10	0.06	0.07	0.07	0.11	0.07	0.09
terpinolene	0.20	0.22	0.19	0.25	0.21	0.22	0.13
Total monoterpenes	**7.58**	**11.47**	**9.51**	**8.35**	**7.73**	**7.16**	**6.73**
caryophyllene	1.30	1.03	1.13	1.60	1.91	1.83	1.69
1,8-cineole	31.70	42.40	35.10	34.40	32.90	33.10	29.00
camphor	15.10	14.70	14.40	16.60	14.80	15.30	15.20
cryptone	1.60	2.34	2.52	0.73	1.56	0.22	1.58
linalool	33.20	19.50	31.60	31.80	32.90	33.85	34.20
terpinen-4-ol	0.50	0.53	0.37	0.42	0.47	0.57	0.44
α-terpineol	1.30	2.39	1.73	1.40	2.16	1.65	1.39
borneol	0.80	0.78	0.55	0.70	0.69	0.59	0.79
Terpene alcohols	**35.80**	**23.20**	**34.05**	**34.32**	**36.22**	**36.66**	**36.82**
bornyl acetate	0.25	0.30	0.25	0.18	0.22	0.26	0.25

t = trace

results it may be concluded that the 1,8-cineole content decreases over time (from 42 to 29%), and that there is a tendency for the linalool content to increase (from 19 to 34%) over the six years. Their results are shown in Table XX, which also shows the authors' findings on the chemical composition of an oil obtained from wild spike lavender.

Also in 1980, de Rijke et al.[79] reported that an oil of Spanish spike lavender was found to contain pinic acid, pinonaldehyde, α-campholenic aldehyde, α-campholenic acid, oxodihydrocampholenic acid and α-campholenic acid.

In 1982, Formacek and Kubeczka[29] used a combination of C_{13}NMR and capillary GC to characterize in a sample of spike lavender oil the following 16 compounds:

- α-pinene (0.89%)
- camphene (0.32%)
- β-pinene (0.01%)
- sabinene (0.22%)
- limonene (1.01%)
- p-cymene (0.35%)
- α-phellandrene (trace)
- β-phellandrene (trace)
- 1,8-cineole (28.26%)
- camphor (12.93%)
- linalool (47.85%)
- terpinen-4-ol (0.67%)
- α-terpineol (0.66%)
- borneol (1.23%)
- isoborneol (0.28%)
- geraniol (0.16%)

One year later, in 1983, de Pascual Teresa et al.[80] reported on an analysis of spike lavender oil. They used a combination of fractional distillation, liquid and gas chromatography and modern spectroscopic techniques to examine the chemical composition of a lab-distilled oil of *Lavandula latifolia* that was obtained from plant material collected in Zamorra, Spain. The identified compounds are shown in Table XIX.

Also in 1983, ter Heide et al.[81] reported their detailed results on the analysis of Spanish spike lavender oil. The results represented a compilation of the various analyses performed on a spike lavender oil over the last 15 years. For the identification of more than 200 components of the oil, the authors used all modern spectroscopic techniques. In addition, certain compounds, for which reference spectra could not be found, were synthesized and structurally elucidated. The characterized compounds are shown in Table XXIV, page 47.

In 1985, Proenca da Cunha et al.[82] in 1985 published their results on the examination of the chemical composition of spike lavender oil produced from plant material

Table XXI. Chemical composition of spike lavender oil

Compound	Ref 52 %	Boelens %	Compound	Ref 52 %	Boelens %
tricyclene	t	0.05	α-thujene	-	0.03
α-pinene	4.77	1.93	camphene	1.08	0.78
sabinene	0.37	0.52	β-pinene	4.10	2.03
myrcene	0.80	0.39	α-phellandrene	t	0.03
δ-3-carene	0.05	0.13	α-terpinene	0.05	0.09
p-cymene	1.39	0.46	limonene	3.18	1.00
cis-β-ocimene	0.47	0.05	trans-β-ocimene	0.08	0.10
γ-terpinene	0.15	0.03	terpinolene	0.07	0.21
β-bergamotene	t	-	β-caryophyllene	2.17	1.06
β-farnesene	0.31	0.20	α-humulene	0.16	0.10
germacrene D	0.20	0.10	γ-cadinene	0.18	0.10
1,8-cineole	22.90	28.08			
cis-linalool oxide-5	0.11	0.22	trans-linalool oxide-5	-	0.21
cis-linalool oxide-6	t	-	trans-linalool oxide-6	0.18	-
caryophyllene oxide	0.29	0.10			
hexanol	0.01	0.08	octanol-3	-	-
1-octen-3-ol	0.09	0.05	plinol (isomer 1)	0.37	-
plinol (isomer 2)	0.36	-	plinol (isomer 3)	t	-
linalool	27.06	39.95	borneol	1.69	1.24
lavandulol	0.5?	0.12	terpinen-4-ol	0.36	0.51
1-p-cymen-8-ol	0.09	0.12	α-terpineol	2.67	0.89
γ-terpineol	0.53	-	myrtenol	0.07	0.10
nerol	0.69	0.30	geraniol	0.35	0.10
cadinol-T	0.06	-	β-bisabolol	0.02	-
2-hexenal	t	-	octanal	-	0.15
acetone	0.11	-	3-octanone	0.05	-
fenchone	0.01	0.05	isofenchone	??	??
3-octanone	0.04	0.08	camphor	16.25	13.25
cryptone	0.07	0.05			
5,5,6-trimethylbicyclo [2.2.1]-heptan-2-one	0.47	-			
hexyl isobutanoate	t	0.10	hexyl butanoate	0.02	-
hexyl isovalerate	0.06	-			
3-octenyl-1 acetate	t	-	hexyl tiglate	t	-
linalyl acetate	1.06	0.57	bornyl acetate	0.08	-
lavandulyl acetate	-	0.10	neryl acetate	0.88	0.05
geranyl acetate	1.22	0.10			
coumarin	-	0.20	dihydrocoumarin	-	0.05

t = trace

collected in Coimbra, Portugal. Using a combination of GC/MS the authors identified the following components:

α-pinene (1.7%)	camphene (0.5%)
β-pinene (1.5%)	myrcene (1.4%)
1,8-cineole (23.5%)	p-cymene (0.6%)
camphor (20.0%)	linalool (32.4%)
terpinen-4-ol (1.6%)	borneol (4.6%)
geraniol (1.8%)	

Also, trace amounts of limonene, terpinolen, epoxylinalool, linalyl acetate, caryophyllene, β-farnesene, nerol and neryl acetate were identified in the oil.

The same authors also examined the composition of spike lavender oil produced from plants in Alto do Vieira, Leiria, Portugal. They characterized the following major constituents:

α-pinene (0.9%)	terpinen-4-ol (0.8%)
myrcene (1.3%)	geraniol (2.2%)
linalool (33.0%)	β-pinene (0.8%)
borneol (4.8%)	camphor (21.5%)
camphene (0.3%)	α-terpineol (1.4%)
1,8-cineole (24.1%)	

One year later, in 1986, Boelens[83] published a review of spike lavender oil of Spanish origin. He summarized some analyses from three separate seasons. His results are shown in Table XIX. For the current article, the author (Boelens) recently analyzed spike lavender oil to compare his data with the analysis of Naef and Morris.[52] These figures are given in Table XXI.

In 1989, de Pascual Teresa et al.[84] used a combination of modern analytical techniques to compare the chemical composition of a lab-distilled spike lavender oil with that of a commercial oil. Their results can be seen in Table XIX.

In 1990, Mosandl and Schubert[47] examined a sample of spike lavender oil to determine the optical enantiomer of linalyl acetate. Using a chiral-active stationary phase in GC they proved that in this sample the linalyl acetate was 100% (R)(–)-form.

Two years later, Naef and Morris[52] published their results from an extensive study about the chemical composition of lavandula oils, including spike lavender oil. The identified compounds are shown in Table XXI. In addition, these authors investigated the sensory quality of the oils in detail, as shown below under "Sensory Evaluation."

In 1993, Rieck et al.[88] reported on the enantiomeric distribution of α-curcumene, α-bisabolene and β-bisabolene. They confirmed the presence of (–)-α-bisabolene in spike lavender oil.

Sensory Evaluation

A general odor description of spike lavender oil is fresh, herbal, minty, camphoraceous, floral; also having hay-like and spicy aspects.

The odor characteristics of spike lavender oil have been described in detail.[83]

The olfactive body of spike lavender oil is determined by linalool, 1,8-cineole and camphor, together making up about 80% of the oil. The balance is made by the olfactively less interesting mono- and sesquiterpene hydrocarbons, totaling 10-15%. There remains about 5-10% for the odoristic finishing touch. The odor aspects of spike lavender oil with reference to its constituents are shown below.

- ***Fresh, green:*** probably due to hex(en)yl derivatives.
- ***Fruity:*** probably due to lower aliphatic esters.
- ***Harsh, terpeny:*** probably due to monoterpene hydrocarbons.
- ***Fresh, eucalyptol:*** probably due to 1,8-cineole.
- ***Camphoraceous:*** probably due to camphor (borneol).
- ***Fresh floral:*** probably due to linalool (lavandulol) + acetate.
- ***Modifier floral:*** probably due to alkylsubstituted pyrazines.
- ***Herbaceous:*** probably due to cryptone, verbenone.
- ***Sweet aromatic (hay-like):*** probably due to (dihydro)-coumarin.
- ***Spicy:*** probably due to eugenol (derivatives).
- ***Woody, powdery:*** probably due to sesquiterpene oxygen derivatives.

Oils of Lavandula Hybrids

In 1994, Peracino et al.[103] reported on the isolation and chemical composition of the essential oils from several *Lavandula* hybrids growing in the northwest Italian Alps. The data obtained were statistically processed in order to partition the natural hybrids according to their oil composition. The results showed the presence of five distinct groups of plants characterized by high linalool, linalyl acetate, cis-linalool oxide, 1,8-cineole, camphor and germacrene D contents in their oils.

The *Lavandula* hybrids were growing at various altitudes in the following places: Tanaro, Gesso, Stura di Demonte, Maira, Chisone and Susa. The chemical composition of the oils isolated from plants growing in the different places is shown in Table XXII.

The authors mentioned that the results of their investigation showed a high variability in oil composition among the spontaneous *Lavandula* hybrids from northwest Italy. The hybrids having high percentages of linalool and linalyl acetate were found to be similar in composition to the typical oil composition of *Lavandula angustifolia* (lavender), and to that of some selected hybrids such as Abrialis and Super (lavandin).

On the other hand, some hybrids were similar, although to a smaller extent, to *Lavandula latifolia* (spike lavender) because of their percentages of camphor and 1,8-cineole.

The other hybrids showed oil compositions which were intermediate between *L. angustifolia* and *L. latifolia*.

According to the authors, the high percentages of germacrene D, cis-linalool oxide and trans-linalool oxide found in the oils of some hybrids are new for the specific literature on this topic, and should be taken into consideration in order to distinguish natural hybrids from cultivated Abrialis and Grosso hybrids.

Oils of Various Lavandula Species

In 1989, Garcia Vallejo et al.[8] reported on their extensive studies about essential oils of the genus *Lavandula* L. in Spain. They mentioned that ten taxons of this genus grow wild in Spain. The authors analyzed the oils distilled from 207 samples and reported the following:

- *L. angustifolia* ssp. *pyranaica*, 38% linalool, 20% borneol, 8% camphor.
- *L. latifolia*, 34% linalool, 31% 1,8-cineole, 11% camphor.
- *L. dentata*, 55% 1,8-cineole, 12% β-pinene.
- *L. multifida*, 25% carvacrol, 23% bisabolene.
- *L. stoechas*, ssp. *stoechas*, 42% fenchone, 23% camphor.
- *L. stoechas* ssp. *sampaioana*, 20% fenchone, 38% camphor.
- *L. stoechas* ssp. *pedunculata*, 17% 1,8-cineole, 20% fenchone, 24% camphor.
- *L. luisieri*, 22% 1,8-cineole, 25% unknown esters.
- *L. viridis*, 42% 1,8-cineole, 13% camphor.

The authors also collected samples and studied the essential oils of the following hybrids: *L. angustifolia* ssp.

Table XXII. Composition of Lavandula hybrids oils from northwest Italian Alps[103]

Compound	Tanaro %	Gesso %	Demonte <900m	Demonte >900m	Maira/Chisone/ Susa %
camphene	t-0.1	t	t	t	t-0.7
β-pinene	t	t	t-0.3	t	t
sabinene	t	t	t-0.1	t	t
myrcene	0.7-1.1	t-0.7	t-1.0	t-0.8	t-0.8
α-phellandrene	t-0.1	t-0.2	t-0.3	t	t
limonene	t-0.2	t-0.4	t-0.2	t	t-0.2
β-phellandrene	0.1-0.4	t-0.2	t-0.2	t-0.3	t
(Z)-β-ocimene	0.2-0.4	t-0.5	t-0.4	t-0.3	t-0.4
γ-terpinene	0.2-0.4	t-0.5	t-0.2	t-0.4	t
(E)-β-ocimene	0.5-0.7	t-0.4	t-0.8	0.4-1.0	t-0.6
p-cymene	t-0.4	t-0.8	t-0.1	t-0.5	t-0.5
octan-3-ol	0.2-1.3	t-1.1	t-8.2	0.6-4.5	1.4-4.0
oct-1-en-3-ol	0.2-0.5	t-0.5	t-0.3	t-0.8	t-0.6
linalool	29.6-53.1	25-46.9	9-31.6	24-37	14.0-33.5
terpinen-4-ol	0.1-1.9	t-2.6	t-0.9	1.0-1.6	0.6-2.3
lavandulol	0.3-0.8	t-0.7	t-0.6	0.5-1.9	0.5-1.5
α-terpineol	t-3.0	t-0.3	t-0.6	t-0.6	t-1.0
borneol	2.9-3.8	1.1-2.9	1-4.1	2.1-2.7	1.9-3.0
isoborneol	0.1-0.7	t-2.0	0.5-1.7	t-2.6	0.1-3.4
geraniol	t-0.7	t-2.8	0.4-0.9	0.9-1.3	1.0-2.5
nerol	t-0.6	t-1.3	t-1.9	t-1.3	0.9-1.8
oct-1-en-3-one	t-1.1	t-0.6	t-0.7	t-0.4	t-0.6
camphor	0.7-2.1	1.9-2.3	1.7-3.3	17-35.8	1.1-4.9
linalyl acetate	15.5-29.1	2.3-21.7	5.8-22	9.5-22	7.5-20.2
bornyl acetate	t-3.0	t-2.7	t-1.3	t-3.2	t-2.7
lavandulyl acetate	0.1-4.3	t-4.5	t-1.1	1.3-3.0	0.9-4.8
neryl acetate	0.1-1.1	t-2.0	t-0.5	t-1.9	0.5-1.5
geranyl acetate	1.1-2.3	t-1.7	0.5-2.3	1.4-1.7	0.4-1.9
cis-linalool oxide	4.2-9.5	1.5-18.9	2.0-8.4	9.7-12.3	6.2-14.8
trans-linalool oxide	3.7-8.9	1.7-17.0	t-7.3	8.9-11.5	1.0-12.1
1,8-cineole	t-0.5	t-0.8	3.8-19	0.5-2.1	1.3-6.1
β-caryophyllene	5.6-9.7	3.6-8.7	0.9-2.2	3.4-7.2	0.8-2.9
germacrene D	t-0.2	t-6.8	4.7-6.3	1.1-12.7	5.6-16.4
caryophyllene oxide	0.9-1.8	2.3-8.8	1.3-2.4	2.9-3.6	2.8-4.5

t = trace

pyrenaica x *latifolia, L. lanata* x *latifolia, L. luisieri* x *stoechas* ssp. *stoechas, L. luisieri* x *stoechas* ssp. *pecunculata* and *L. luisieri* x *viridis*. Their essential oils showed compositions intermediate between those of their ancestors.

One of the most interesting wild species of *Lavandula* is *L. stoechas*. Numerous subspecies and varieties of this species have been established. Garcia Vallejo et al.[8] mentioned that in antiquity and in the Middle Ages, *L. stoechas* was the most distilled species in Spain, but now it is no longer distilled. The oil of *L. stoechas* ssp. *stoechas* is known in Spain as "cantueso" oil. The authors analyzed 19 oils of *L. stoechas* ssp. *stoechas* distilled from individual samples collected in nine provinces. The results of these analyses are shown in Table XXIII.

The author of the present article (Boelens) also analyzed an oil isolated from *Lavandula stoechas* ssp. *stoechas* growing in Andalucia (Spain) using modern gas chromatographic and spectroscopic techniques. The characterized compounds are shown in Table XXIII.

Recently Tucker et al.[85] published their results on the chemical composition of the essential oils of *Lavandula* x *hybrida* Balb. ex Ging., a distinct hybrid from *L. heterophylla* Poir. Thirty compounds were identified and quantified in the oils. The major constituents were α-pinene (6%), β-pinene (8%), 1,8-cineole (33.5%), linalool (7%), camphor (12.5%) and α-terpineol (4%).

Artifacts in Lavandula Oils

Artifacts are compounds which are not originally present in the plant material. These compounds are formed during isolation and/or storage.

The decomposition of linalool and linalyl acetate during acidic steam distillation is known in the literature[94-96] and probably also occurs during (weak acidic) steam distillation of *Lavandula* plant material. Acyclic and monocyclic terpene hydrocarbons are at least partly formed from linalyl acetate[94] during acidic oil isolation.

Acidic allylic rearrangement of linalyl acetate can contribute to the formation of neryl and geranyl acetate, whereas the hydration of a terpinyl ion (formed as an intermediate) may give α-terpineol.

It is also known in the literature[97] that linalool can be transformed via the epoxide into linalooloxides. This reaction can occur during storage of linalool in the presence of oxygen (air). During these oxidations, cis- and trans-isomers of furanoid and pyranoid linalooloxides are formed.

The oxidation of caryophyllene to the epoxide is also easily performed in the presence of air, even at room temperature.

Heating of linalool may give rise to the formation of plinols (4 isomers).

Mookherjee et al.[98] made a comparative analysis of the headspace volatiles of living and picked flowers. They determined that substituted pyrazines occurred in the headspace of living flowers, whereas the headspace of picked flowers contained no pyrazines at all.

The formation of alkyl-substituted pyridines has been studied by Surburg.[99] He reported that it may be possible that substituted pyridines are formed as a result of the isolation process.

Table XXIII. Chemical composition *L. stoechas* ssp. *stoechas* oils

Compound	Ref 8 min. %	Ref 8 max. %	Ref 8 average %	Boelens %
tricyclene	-	-	-	0.13
α-thujene	-	-	-	0.01
α-pinene	0.2	8.6	1.8	7.25
α-fenchene	-	-	-	0.11
camphene	0.1	3.6	1.3	1.89
β-pinene	t	0.3	0.1	0.06
myrcene	-	0.3	0.1	0.20
α-phellandrene	-	-	-	0.06
δ-3-carene	-	-	-	0.09
α-terpinene	-	-	-	0.02
p-cymene	-	-	-	0.30
limonene	0.4	3.1	1.3	2.21
β-phellandrene	-	-	-	0.01
cis-ocimene	-	-	-	0.56
trans-ocimene	-	-	-	0.08
γ-terpinene	-	-	-	0.03
terpinolene	-	-	-	0.26
caryophyllene	0.1	5.5	1.6	0.08
caryophyllene oxide	t	0.8	0.3	0.05
cis-linalool oxide-5	-	-	-	0.22
trans-linalool oxide-5	-	-	-	0.13
1,8-cineole	0.3	52.7	9.4	1.28
oct-1-en-3-ol	0.1	1.1	0.4	0.01
linalool	0.1	3.7	0.9	3.64
α-fenchol	0.2	3.3	0.7	0.66
borneol	0.0	1.2	0.3	0.61
terpinen-4-ol	t	0.5	0.2	0.16
α-terpineol	t	0.7	0.4	0.25
trans-verbenol	t	1.2	0.4	0.10
myrtenol	t	3.1	1.1	0.30
p-cymen-8-ol	0.2	1.8	0.4	0.09
nerol	-	-	-	0.02
geraniol	-	-	-	0.06
viridiflorol	t	2.7	1.2	0.08
dihydrocaryophyllenol*	1.3	0.5	-	-
α-cadinol	0.0	0.3	0.1	0.01
myrtenal	t	0.8	0.4	-
octanone-3	-	-	-	0.05
fenchone	23.6	68.2	42.1	21.40
camphor	1.5	51.6	23.0	49.72
verbenone	0.0	0.9	0.1	0.02
linalyl acetate	-	-	-	0.90
verbenyl acetate*	0.0	0.8	0.1	-
myrtenyl acetate*	t	5.3	2.6	0.02
bornyl acetate	-	-	-	0.74
lavandulyl acetate	-	-	-	0.32

* tentative identification
t = trace

Table XXIV. Compounds identified in *Lavandula* oils

DB-1	DB-5	CBWX	Compound [Ref]
Aliphatic and aromatic hydrocarbons:			
-	-	-	isoprene [81]
700	700	700	heptane [22]
-	-	-	1,3E,5Z-undecatriene [52]
-	-	-	1,3E,5Z,8Z-undecatetraene [52]
-	-	1233	1-dodecene [81]
749	771	1023	toluene [81]
Monoterpene hydrocarbons:			
919	929	1020	tricyclene [22,52]
925	931	1030	α-thujene [52,83]
932	941	1021	α-pinene [22,52,81]
940	954	1073	α-fenchene [52]
947	957	1076	camphene [22,52,81]
950	964	1100	pinadiene [83]
967	980	1121	sabinene [22,52,81]
972	986	1111	β-pinene [22,52,81]
984	993	1159	myrcene [22,52,81]
998	1011	1165	α-phellandrene [78]
1006	1017	1142	δ-3-carene [22]
1008	1023	1189	α-terpinene [22]
1014	1031	1270	p-cymene [22,52,81]
1023	1036	1193	limonene [22,52,81]
1025	1040	1229	(Z)-ocimene [22,52,81]
1022	1043	1202	β-phellandrene [78,83]
1038	1051	1251	(E)-ocimene [22,52,81]
1049	1065	1245	γ-terpinene [81]
-	-	-	cis-alloocimene [22]
-	-	-	trans-alloocimene [22,52]
1074	1096	1287	terpinolene [22,52,81]
1076	1096	1432	α,para-dimethylstyrene [81]
Sesquiterpene hydrocarbons:			
1376	1396	1492	α-copaene [81]
-	-	-	β-bergamotene [52,81]
1414	-	1536	cis-α-bergamotene [52,81]
1420	1446	1594	caryophyllene [22,52,81]
1435	-	1574	trans-α-bergamotene [22,52,81]
1421	-	1583	α-santalene [22,52]
1458	-	1660	β-santalene [22,52]
1477	-	1703	β-selinene [81]
-	-	-	α-bisabolene [77,88]
1502	-	1726	β-bisabolene [77]
1448	-	1657	cis-β-farnesene [81,83]
1477	-	1668	trans-β-farnesene [22,81,83]
1449	1480	1668	α-humulene [52,77]
1388	-	1562	β-cubebene [81]
1400	-	1501	α-gurjunene [81]
1477	1507	1681	germacrene D [52]
-	-	1734	α-cadinene [22]
1506	-	1750	γ-cadinene [81]
1516	1543	1752	δ-cadinene [22,81]
1415	1436	1587	α-cedrene [81]
1470	-	1774	ar-curcumene [22]
1402	-	1574	longifolene [90]
1646	-	-	1,6-dimethyl-4-isopropyl-naphthalene [81]
Aliphatic alcohols:			
500	-	919	ethanol [81]
-	-	-	propanol-2 [81]
649	677	1137	butanol [81]
596	-	1006	butanol-2 [81]
618	642	1072	2-methylpropanol-1 [81]
752	775	1249	pentanol [81]
721	746	1196	3-methylbutanol-1 [81]
688	710	1149	1-penten-3-ol [81]
-	-	-	2-methylbut-3-en-2-ol [81]
756	1311	??	3-methylbut-2-en-1-ol [52,81]
-	-	-	3-methylbut-3-en-2-ol [22]
852	871	1346	hexanol [22,52,81]
835	862	1378	(Z)-3-hexen-1-ol [52,81]
954	982	1445	heptanol [81]
1056	1081	1539	octanol [22,81]
984	1003	1398	octanol-3 [22,52,81]
963	983	1428	1-octen-3-ol [22,52,81]
1253	1272	1735	decanol [22,81]
-	-	1342	diacetone alcohol [81]
Monoterpene alcohols:			
1087	-	-	cis-sabinene hydrate [52,81]
1058	1080	1462	trans-sabinene hydrate [52,81]
1087	1102	1547	linalool [22,52,55,81,85]
1211	1231	1747	citronellol [77]
1213	1245	1780	nerol [22,52,81]
-	-	-	isogeraniol [22]
1237	1258	1844	geraniol [22,52,77,81]
1102	-	1585	myrcenol [81]
1085	-	1601	(E)-hotrienol [52,81]
-	-	-	(E)-2,7-dimethyl-1,4,6-octatrien-3-ol [81]
1177	1199	1690	α-terpineol [22,52,77,81]
1122	1160	1616	β-terpineol [83]
1162	1211	-	γ-terpineol [52]
1150	-	1663	δ-terpineol [81]
1165	1185	1602	1-terpinen-4-ol [22,81,83]
1281	1318	2009	perillyl alcohol [22]
1184	-	-	cis-piperitol [81]
1193	-	-	trans-piperitol [81]
-	-	-	trans-carvotan alcohol [81]
1208	1247	1846	cis-carveol [77]
1201	1235	1791	trans-carveol [77]
1166	1206	1836	p-cymen-8-ol [52,81]
-	-	1442	camphene hydrate [81]
1129	-	1683	trans-sabinol [81]
1181	1212	1775	myrtenol [81]
1138	1170	1660	isoborneol [77,81]
-	-	-	isosobrerol [83]
1153	-	1682	lavandulol [22,52,77,83]
1127	1158	1676	trans-pinocarveol [22]
1154	1175	1696	borneol [22,52,77,81,83]
1287	1306	2045	cuminic alcohol [81]
-	-	1525	plinol (isomer 1) [52]
-	-	-	plinol (isomer 2) [52]
-	-	-	plinol (isomer 3) [52]
-	-	-	1,8-epoxy-2-p-menthen-4-ol [81]
-	-	-	cis-1,8-terpin hydrate [81]
-	-	-	2,6-dimethyl-6-methoxy-7-octen-2-ol [81]
-	-	-	exo-1,8-epoxy-p-menthan-2-ol [81]
-	-	-	endo-1,8-epoxy-p-menthan-2-ol [81]
Sesquiterpene alcohols:			
1549	1579	2009	nerolidol (trans) [81]
1644	-	2171	α-cadinol [81]
-	-	-	β-cadinol [81]
1621	1670	2137	δ-cadinol [81]
-	-	-	10-epi-α-cadinol [81]
-	-	2083	viridiflorol [81]
1567	-	2137	spathulenol [81]
1674	-	2218	α-bisabolol [81]
-	-	2018	β-bisabolol [52]
-	-	-	α-photosantalol [22,52]
-	-	-	iso-α-photosantalol [22]
1618	-	-	cubenol [52]
1627	-	2145	cadinol T [52]
Aliphatic and cyclic ethers:			
-	-	-	1-methoxybutane [22]
-	-	-	1-methoxyhexane [52,81]
589	-	866	2-methylfuran [22,81]
-	-	-	3-methylfuran [81]
694	707	944	2-ethylfuran [81]
-	-	-	3-isopropylfuran [81]
Monoterpenoid ethers and oxides:			
1022	1040	1211	1,8-cineole [22,52,81]
-	-	-	ocimene oxide [52]
-	-	-	lavandulyl epoxyde [52]
1061	1084	1432	cis-linalool oxide (furanoid) [52,81]
1075	1098	1462	trans-linalool oxide (furanoid) [52,81]
1141	-	1737	cis-linalool oxide (pyranoid) [52,81]
1156	-	1765	trans-linalool oxide (pyranoid) [52,81]
964	980	1109	2,2,6-trimethyl-6-vinyl-tetrahydropyran [81]
-	-	-	5-isopropyl-2-methyl-2-vinyl-tetrahydrofuran [81]
-	-	-	epoxy-α-santalene [52]
1569	1613	1979	caryophyllene oxide [22,81]
-	-	-	cis-caryophyllene oxide [52]
-	-	-	trans-caryophyllene oxide [52]
Aliphatic sulfides:			
-	-	-	dimethylsulfide [22,52]
Aliphatic and cyclic aldehydes:			
-	-	-	methanal [83]
451	-	732	ethanal [22,81]
481	-	786	propanal [81]
564	596	864	butanal [81]
522	556	800	2-methylpropanal [22,81]
671	702	962	pentanal [52,81]
627	664	918	3-methylbutanal [22,81]
637	675	930	2-methylbutanal [22,81]
775	802	1084	hexanal [22,52,58,81]
876	906	1183	heptanal [22,81]
-	-	-	2-ethyl-3-methylhexanal [81]
980	1006	1276	octanal [22,52,58,81]
1081	1105	1380	nonanal [52,58,81]
1185	1210	1487	decanal [22,58,81]
-	676	-	(E)-2-methyl-2-butenal [81]
-	-	-	2-methyl-2-pentenal [81]
822	863	1212	(E)-2-hexenal [22,58,81]
980	1016	1472	(E,E)-2,4-heptadienal [22,58]
1029	1068	1423	(E)-2-octenal [81]
1133	1158	1543	(E)-2-nonenal [81]
1123	1155	-	(E,Z)-2,6-nonadienal [81]
1187	1325	1175	(E,E)-2,4-decadienal [22,58]
-	-	-	2-methyl-1-cyclopentene-1-carboxaldehyde [81]
780	-	1450	furfural [22,81]
-	-	-	3-methylfurfural [81]
928	-	1562	5-methylfurfural [81]
-	-	-	tetrahydropyranyl-2-ethanal [81]
-	-	-	6-methyl-3(4)-(4-methyl-3-pentenyl)-3-cyclohex-enecarbaldehyde [32]
Monoterpene aldehydes:			
1264	-	-	1,3-p-menthadien-7-al [81]
1260	-	-	1,4-menthadien-7-al [22]
1248	1293	1789	perillaldehyde [22,58,81]
-	-	1603	phellandral [81]
-	1221	-	1-p-menthen-9-al [81]
1133	1157	1462	citronellal [81]
1173	1217	1638	myrtenal [81]
1216	1248	1676	neral [81]
1244	1276	1721	geranial [81]
-	-	-	5,5-dimethyl-2-cyclopenten-1-ethanal [81]
-	-	-	2,2-dimethyl-3-cyclopenten-1-ethanal [81]
-	-	-	5-isopropyl-2-methyl-1-cyclopenten-1-carboxaldehyde [81]

Table XXIV. Compounds identified in *Lavandula* oils (continued)

Retention Indices DB-1	DB-5	CBWX	Compound [Ref]
-	-	-	α-campholenic aldehyde [58,81]
-	-	-	5-isopropenyl-2-methyltetrahydro-furan-2-ethanal [81]
-	-	-	5-methyl-5-vinyltetrahydrofuran-2-(2-methylethanal) [81]
-	-	-	pinone aldehyde [81]
Sesquiterpene aldehydes:			
-	-	-	2Z,6E-farnesal [32]
-	-	-	2E,6E-farnesal [32]
-	-	-	cedrenal [32]
-	-	-	α-santalal [22,32]
-	-	-	teresantalal [32]
-	-	-	tricyclo-eka-santalal [32,52]
-	-	-	nortricyclo-eka-santalal [32]
-	-	-	γ-cadinen-15-al [32]
-	-	-	caryophylla-2(12),5-dien-13-al [32]
Aromatic aldehydes:			
932	974	1509	benzaldehyde [81]
-	-	-	2,5-dimethylbenzaldehyde [81]
1005	1055	1640	phenylacetaldehyde [81]
-	-	-	2-(4-methylphenyl)propanal [32,81]
-	-	-	4-(4-methylphenyl)pentanal [81]
1008	-	1705	salicylaldehyde [81]
1214	1257	1758	cuminaldehyde [22,58,81]
-	-	-	4-isopropenylbenzaldehyde [81]
-	-	-	2-hydroxy-4-isopropylbenzaldehyde [81]
Aliphatic ketones:			
530	-	815	acetone [22,52,81]
563	592	898	butanone [81]
-	-	-	3-buten-2-one [81]
-	-	-	2,3-butanedione [22]
666	691	965	2-pentanone [22,81]
-	-	-	3-pentanone [81]
-	-	-	3-methyl-2-butanone [81]
766	782	1055	2-hexanone [81]
767	788	1055	3-hexanone [81]
-	-	-	4-methyl-2-pentanone [81]
-	-	-	2-methyl-3-pentanone [81]
-	-	-	2,4-dimethyl-3-pentanone [22]
864	891	1172	2-heptanone [81]
-	951	1205	3-octanone [22,52,58,81]
1274	1302	1592	2-undecanone [81]
-	-	-	5-hexen-2-one [81]
-	-	978	4-methyl-3-penten-2-one [81]
-	-	-	6-methyl-3-heptanone [22]
963	996	1335	6-methyl-5-hepten-2-one [22,58,81]
1075	-	-	6-methyl-3,5-heptadien-2-one [22,58,81]
-	-	-	2-methyl-3,6-heptadien-2-one [81]
Monoterpene ketones:			
1152	-	-	cryptone [22,52,58,81]
-	-	1545	nopinone [22,58,81]
1229	1271	1739	piperitone [81]
-	-	-	4-isopropenyl-3-methyl-2-cyclohexen-1-one [81]
1216	1262	1726	carvone [22,52,81]
1142	-	-	pinocarvone [81]
1269	-	1648	carvotanacetone [81]
1133	-	1624	sabina ketone [58,81]
1122	1150	1524	camphor [22,52,58,81]
1183	1230	1730	verbenone [81]
1070	1102	1413	fenchone [52]
-	-	-	isofenchone [52,81]
-	-	-	camphenilone [81]
1091	1119	1435	α-thujone [83]
1100	1228	-	β-thujone [63]
Homocyclic ketones:			
-	-	-	3-isopropylcyclopentanone [81]
-	-	-	3,4,4-trimethyl-2-cyclopenten-1-one [81]
-	-	-	3-methyl-2-cyclohexen-1-one [81]
-	-	-	2-hydroxy-3-isopropyl-2-cyclohexen-1-one [81]
-	-	-	6-hydroxy-3-isopropyl-6-methyl-2-cyclohexen-1-one [81]
-	-	-	2-methoxy-3,5,5-trimethyl-2-cyclohexen-1,4-dione [81]
1428	1460	1842	geranylacetone [81]
1403	1448	1825	α-ionone [81]
1465	1509	1908	β-ionone [32,81]
1471	-	1836	α-methylionone [81]
-	-	-	saturated C-14 ketone [22]
-	-	-	α, β-unsaturated C-14 ketone [22]
Sesquiterpene ketones and homologues:			
-	-	-	α-norsantalenone [32]
-	-	-	α-santalan-12-one [32]
-	-	-	α-santal-13-en-12-one [32]
-	-	-	13-hydroxy-α-santalan-12-one [32]
-	-	-	15-norcedran-8-one [32]
-	-	-	norcadin-5-en-4-one [32]
-	-	-	norcadin-5-en-4-one isomer [32]
-	-	-	cadina-4,10(15)-dien-3-one [32]
-	-	-	kobusone [32]
-	-	-	4,7-dimethyltetralone [32]
-	-	-	4-isopropyl-6-methyl-1-tetralone [32]
-	-	-	12-norcaryophyllen-2-one [32]
-	-	-	caryophylla-2(12),6-dien-5-one [32]
-	-	-	caryophyla-2(12),6(13)-dien-5-one [32]
-	-	-	caryophylla-2(12),5-dien-7-one [32]
-	-	-	11-norbourbonan-1-one [32]
-	-	-	6,10,14-trimethylpentadecan-2-one [32]
-	-	-	methyl cis-3-methyl-2-(3-methyl-2-butenyl)-3-cyclohexenyl ketone [32]
-	-	-	methyl trans-3-methyl-2-(3-methyl-2-butenyl)-3-cyclohexenyl ketone [32]
-	-	-	methyl cis-4-methyl-5-(3-methyl-2-butenyl)-3-cyclohexenyl ketone [32]
-	-	-	methyl trans-4-methyl-5-(3-methyl-2-butenyl)-3-cyclohexenyl ketone [32]
-	-	-	4,t-5-dimethyl t-2(2-methyl-1-propenyl)-3-cyclohexenyl methyl ketone [32]
-	-	-	4,c-5-dimethyl t-2(2-methyl-1-propenyl)-3-cyclohexenyl methyl ketone [32]
-	-	-	4,t-5-dimethyl c-2(2-methyl-1-propenyl)-3-cyclohexenyl methyl ketone [32]
-	-	-	4,c-5-dimethyl c-2(2-methyl-1-propenyl)-3-cyclohexenyl methyl ketone [32]
-	-	-	methyl 3-(4-methyl-3-pentenyl) 3-cyclohexenyl ketone [32]
-	-	-	methyl 4-(4-methyl-3-pentenyl) 3-cyclohexenyl ketone [32]
-	-	-	3-(E)-(4,8-dimethyl-3,7-nonadienyl) 3-cyclohexenyl methyl ketone [32]
-	-	-	4-(E)-(4,8-dimethyl-3,7-nonadienyl) 3-cyclohexenyl methyl ketone [32]
-	-	-	3-(4-methyl-3-pentenyl)-3-cyclohexenyl pentyl ketone [32]
-	-	-	4-(4-methyl-3-pentenyl)-3-cyclohexenyl pentyl ketone [32]
-	-	-	3-(4-methyl-3-pentenyl)-3-cyclohexenyl propyl ketone [32]
-	-	-	4-(4-methyl-3-pentenyl)-3-cyclohexenyl propyl ketone [32]
-	-	-	ethyl 3-(4-methyl-3-pentenyl)-3-cyclohexenyl propyl ketone [32]
-	-	-	ethyl 4-(4-methyl-3-pentenyl)-3-cyclohexenyl propyl ketone [32]
-	-	-	trans-2-(Z)-(1-heptenyl)-3-cyclohexenyl methyl ketone [32]
-	-	-	trans-2-(Z)-(1-heptenyl)-3-cyclohexenyl methyl ketone [32]
-	-	-	trans-2-(E)-(1-heptenyl)-3-cyclohexenyl methyl ketone [32]
-	-	-	cis-2-(Z)-(1-heptenyl)-3-cyclohexenyl methyl ketone [32]
-	-	-	trans-2-(E)-(1-heptenyl)-3-cyclohexenyl methyl ketone [32]
-	-	-	8,9-dinorborn-5-en-2-yl(exo) pentyl ketone [32]
-	-	-	8,9-dinorborn-5-en-3-yl(exo) pentyl ketone [32]
-	-	-	8,9-dinorborn-5-en-2-yl(endo) pentyl ketone [32]
-	-	-	8,9-dinorborn-5-en-3-yl(endo) pentyl ketone [32]
-	-	-	6-methyl-8,9,10-trinorborn-5-en-2-yl-(exo) pentyl ketone [32]
-	-	-	6-methyl-8,9,10-trinorborn-5-en-2-yl-(endo) pentyl ketone [32]
-	-	-	5-methyl-8,9,10-trinorborn-5-en-2-yl-(exo) pentyl ketone [32]
-	-	-	5-methyl-8,9,10-trinorborn-5-en-2-yl-(endo) pentyl ketone [32]
-	-	-	8,9-dinorborn-5-en-3-yl(exo) methyl ketone [32]
-	-	-	8,9-dinorborn-5-en-3-yl(endo) methyl ketone [32]
-	-	-	8,9-dinorborn-5-en-2-yl(exo) methyl ketone [32]
-	-	-	8,9-dinorborn-5-en-2-yl(endo) methyl ketone [32]
-	-	-	methyl 6-methyl-8,9,10-trinorborn-5-en-2-yl(exo) ketone [32]
-	-	-	methyl 6-methyl-8,9,10-trinorborn-5-en-2-yl(endo) ketone [32]
-	-	-	methyl 5-methyl-8,9,10-trinorborn-5-en-2-yl(exo) ketone [32]
-	-	-	methyl 5-methyl-8,9,10-trinorborn-5-en-2-yl(endo) ketone [32]
Aromatic ketones:			
1151	-	1770	4-methylacetophenone [22,58,81]
-	-	-	4-isopropylacetophenone [22]
-	-	-	2-hydroxyacetophenone [81]
-	-	2185	2-hydroxy-4-methylacetophenone [81]
-	-	-	2-hydroxy-5-methylacetophenone [81]
-	-	-	2-hydroxy-6-methylacetophenone [81]
-	-	-	1(2H)-naphthalenone-3 [58]
-	-	-	6-methyl-5-(3-methylphenyl)-heptan-2-one [32]
-	-	-	2-methyl-6-(4-methylphenyl)-hept-1-en-3-one [32]
-	-	-	2-methyl-6-(4-methylphenyl)-heptan-3-one [32]
Aliphatic acids:			

Table XXIV. Compounds identified in *Lavandula* oils (continued)

Retention indices DB-1	DB-5	CBWX	Compound [Ref]
-	-	-	formic acid [83]
827	-	1412	acetic acid [22,81]
846	-	1592	propanoic acid [81]
891	-	1600	butanoic acid [22,81]
-	-	1550	isobutanoic acid [81]
917	-	1707	pentanoic acid [81]
-	-	1648	2-methylbutanoic acid [81]
-	860	1639	3-methylbutanoic acid [81]
-	-	-	2,3-dimethylpropanoic acid [81]
985	-	1821	hexanoic acid [22,81]
-	-	-	2,3-dimethylbutanoic acid [81]
-	-	-	3,3-dimethylbutanoic acid [81]
-	-	-	2-methylpentanoic acid [81]
-	-	-	3-methylpentanoic acid [81]
-	-	-	4-methylpentanoic acid [81]
-	1083	1913	heptanoic acid [81]
-	-	-	2-ethyl-3-methylbutanoic acid [81]
-	-	-	4-methylhexanoic acid [81]
-	-	-	5-methylhexanoic acid [81]
1174	1198	2025	octanoic acid [81]
-	1273	2131	nonanoic acid [81]
1352	-	2256	decanoic acid [81]
-	-	-	(E)-2-methyl-2-butenoic acid [81]
-	-	-	3,3-dimethylpropenoic acid [81]
-	-	-	4-methyl-3-pentenoic acid [81]
-	-	-	malonic acid [81]
-	-	-	maleic acid [81]
-	-	-	succinic acid [81]
-	-	-	tartaric acid [83]
-	-	-	citric acid [83]
-	-	-	2-isopropylsuccinic acid [81]
-	-	-	2-isopropylglutaric acid [81]
-	-	-	3,3-dimethyl-1,6-hexanedioic acid [81]
-	-	-	3-isopropyl-1,6-hexanedioic acid [81]
Monoterpene acids:			
1316	-	-	nerylic acid [81]
1347	-	2294	geranic acid [81]
-	-	-	myrtenic acid [81]
-	-	-	α-campholenic acid [81]
-	-	-	γ-campholenic acid [81]
-	-	-	α-campholitic acid [81]
Cyclic acids:			
-	-	-	lilic acid [81]
-	-	-	3-carboxy-4,4-dimethyl-cyclobutane-1-acetic acid [81]
-	-	-	1-oxo-4,4,5-trimethylcyclopentane-3-acetic acid [81]
-	-	-	2-furancarboxylic acid [81]
Aromatic acids:			
-	-	2431	benzoic acid [81]
-	-	-	salicyclic acid [81]
-	-	2564	phenylacetic acid [81]
-	-	-	3-phenylpropanoic acid [81]
-	-	-	3-(2-methoxyphenyl)propanoic acid [81]
-	-	-	cinnamic acid [81]
-	-	-	4-propylbenzoic acid [81]
-	-	-	4-isopropylbenzoic acid [81]
Aliphatic esters:			
-	-	-	2-propyl formate [81]
-	-	-	hexyl formate [81]
995	1022	1282	hexyl acetate [81]
1088	-	1326	hexyl propionate [81]
1180	-	1407	hexyl butyrate [52,81]
1135	-	1336	hexyl isobutanoate [52,81]
1310	-	1621	hexyl tiglate [52,81]
1222	-	1425	hexyl 2-methylbutanoate [81]
1228	1242	1433	hexyl 3-methylbutanoate [81]
1370	-	1595	hexyl hexanoate [81]
1555	-	2066	hexyl benzoate [81]
598	614	875	ethyl acetate [81]
-	-	-	allyl acetate [81]
-	-	-	2-butyl acetate [81]
1187	1220	1465	octyl acetate [81]
1283	-	1536	octyl propionate [81]
1422	-	1615	octyl 2-methylbutanoate [81]
-	-	-	octyl 3-methylbutanoate [81]
-	-	-	methyl butanoate [81]
1087	-	1273	3-methylbutyl 2-methylbutanoate [81]
Monoterpene esters:			
1206	-	1570	linalyl formate [22]
1241	1265	1554	linalyl acetate [22,52,81]
1394	-	1689	linalyl butanoate [22]
1582	-	1843	linalyl hexanoate [52]
-	-	-	epoxylinalyl acetate [22,52]
1282	1311	1687	geranyl formate [81]
1361	1393	1750	geranyl acetate [81]
1449	1482	1799	geranyl propionate [81]
1536	-	1880	geranyl butanoate [81]
1593	-	1919	geranyl 3-methylbutanoate [81]
1343	1374	1715	neryl acetate [52,81]
1436	-	1773	neryl propionate [81]
1515	-	1841	neryl 2-methylbutanoate [81]
1574	-	1890	neryl 3-methylbutanoate [81]
1709	-	2021	neryl hexanoate [81]
1272	-	1604	lavandulyl acetate [22,52]
-	-	-	lavandulyl propanoate [81]
-	-	-	lavandulyl butanoate [22]
-	-	-	lavandulyl isobutanoate [81]
-	-	-	lavandulyl 2-methylbutanoate [22,81]
-	-	-	lavandulyl 3-methylbutanoate [81]
-	-	-	lavandulyl hexanoate [22]
-	-	-	lavandulyl benzoate [22]
1271	1298	1572	bornyl acetate [22,52,81]
-	-	-	bornyl propanoate [81]
-	-	-	bornyl isobutanoate [81]
-	-	-	bornyl 2-methylbutanoate [81]
-	-	-	bornyl 3-methylbutanoate [81]
1279	-	1584	isobornyl acetate [83]
1332	-	1699	α-terpinyl acetate [22,81]
-	-	-	3,7-dimethyl-6,7-epoxy-1-octene-3-ol acetate [58]
-	-	-	2,6-dimethyl-3,7-octadiene-2,6-diol 6-acetate [58]
-	-	-	2,6-dimethyl-1,7-octadiene-3,6-diol 6-acetate [58]
-	-	-	6-methyl-3,7-octadien-2-one-6-hydroxy acetate [58]
-	-	-	2,6-dimethyl-2,7-octadienal-6-hydroxy acetate [58]
-	-	-	5-isopropenyl-2-methyl-2-heptenal-7-hydroxy acetate [58]
-	-	-	2,6-dimethyl-3-acetoxymethyl-1,4-heptadien-6-ol [22]
-	1668	-	methyl jasmonate [32]
-	-	-	2,6-dimethyl-3-acetoxymethyl-1,6-heptadien-5-ol [22]
-	-	-	3,7-dimethyl-1,7-octadien-3,6-diol-6-acetate [22]
-	-	-	5,7-epoxy-2,6-dimethyl-3-acetoxymethyl-1-heptene [22]
-	-	-	1,7-octadien-3-one-6-ol-6-methyl acetate [22]
-	-	-	7-octen-3-one-6-ol-6-methyl acetate [22]
-	-	-	2,6-dimethyl-3-acetoxymethyl-1,6-heptadien-5-one [22]
-	-	-	2,6-dimethyl-3-acetoxymethyl-1-hepten-5-one [22]
Aromatic esters:			
1347	-	1841	butyl benzoate [52]
1723	1795	2496	benzyl benzoate [81]
1165	-	1748	methyl salicylate [81]
Lactones:			
835	-	1632	4-butanolide [15,22,81]
-	-	-	2-methyl-4-butanolide [15,22,81]
-	-	-	4-isopropyl-4-butanolide [15,22,81]
1420	1492	2118	4-hexyl-4-butanolide [15,22,81]
-	-	-	4-methyl-4-vinyl-4-butanolide [15,22,81]
-	-	-	4,4-dimethyl-4-but-2-enolide [15,22,81]
-	-	-	4-methyl-4-vinyl-4-but-2-enolide [14,15,22,81]
1444	1473	2168	5-pentyl-5-pentanolide [15,22,81]
1418	-	2397	coumarin [22,81]
1359	-	2286	dihydrocoumarin [22,81]
-	-	-	7-methoxycoumarin [22,81]
Phenols:			
957	-	1960	phenol [81]
1024	-	2013	o-cresol [81]
-	-	2031	m-cresol [81]
1052	1073	2028	p-cresol [81]
-	-	-	o-ethylphenol [81]
-	-	-	guajacol [81]
1274	1306	2126	thymol [81]
1280	1317	2186	carvacrol [81]
1328	1375	2127	eugenol [22,81]
-	-	-	2,4(5)-dimethylphenol [81]
Aromatic ethers:			
1264	1299	1814	trans-anethole [81]
1222	-	-	thymol methyl ether [81]
1226	-	-	carvacrol methyl ether [81]
1275	1303	1886	safrole [22]
Nitrogen derivatives:			
711	751	1183	pyridine [81]
788	868	-	2-methylpyridine [81]
829	-	-	3-methylpyridine [81]
-	-	-	2-ethylpyridine [81]
-	-	-	3-ethylpyridine [81]
-	-	-	4-ethylpyridine [81]
-	-	-	4-isopropylpyridine [81]
-	-	-	3-sec.butylpyridine [81]
867	-	-	2,6-dimethylpyridine [81]
1045	-	-	5-methyl-2-isopropylpyridine [81]
1068	-	-	2-methyl-5-isopropylpyridine [81]
-	-	-	5-methyl-2-isopropenylpyridine [81]
-	-	-	2-acetylpyridine [81]
-	-	-	3-acetyl-6-methylpyridine [81]
-	-	-	2-acetyl-5-isopropylpyridine [81]
1206	-	-	quinoline [81]
900	-	1322	2,3-dimethylpyrazine [81]
893	-	1301	2,5-dimethylpyrazine [81]
-	-	-	2,4,5-trimethyloxazole [81]
1304	1362	2181	methyl anthranilate [81]
1389	1439	2042	N-methyl methyl anthranilate [81]

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