Progress in Essential Oils

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Cinnamon Leaf, Fruit and Bud Oils

Oils produced from the dried fruit of cinnamon of Karnatakan and Keralan (India) origin were analyzed by GC/MS (Mohan Rao 2000). As can be seen from the data in T-1, the fruit oils were quite different to the commercially available oils obtained either from the leaves (a eugenol-rich oil) or from the inner bark (a cinnamaldehyde-rich oil). The safrole content of cinnamon leaf oil was determined to be 1.3 percent (Anon 2002).

An oil produced in the lab by hydrodistillation from fresh cinnamon buds collected from coastal Karnataka (India) was analyzed by Jayaprakasha et al. (2002) and found to contain the following constituents:

heptanal (1.09 percent)
α-pinene (0.87 percent)
nonanal (1.09 percent)
linalool (0.89 percent)
α-copaene (23.05 percent)
α-bergamotene* (27.38 percent)
(E)-cinnamyl acetate (2.41 percent)
aromadendrene (1.79 percent)
α-cadinene† (0.56 percent)
α-humulene (6.19 percent)
germacrene D (2.10 percent)
valencene (0.66 percent)
viridiflorene (3.29 percent)
α-muurolene (2.70 percent)
cis-calamenene (0.92 percent)
δ-cadinene (5.97 percent)
α-calacorene (0.78 percent)
β-guaiene† (0.91 percent)
ledol (1.29 percent)
spathulenol (2.02 percent)
caryophyllene oxide (0.81 percent)
globulol (1.67 percent)
T-cadinol (t)
T-muurolol (t)
α-muurolol (t)
α-cadinol (t)
β-bisabolol (1.26 percent)
tetradecanol (4.27 percent)
epi-α-bisabolol (2.08 percent)
benzyl benzoate (t)
tetradecanoic acid (t)
hexadecanol (t)
hexadecanoic acid (t)

* correct isomer not identified; † incorrect identity based on elution order; t = trace (< 0.01 percent)

An oil produced from the dried leaves of *Cinnamomum zeylanicum* growing in Cameroon was analyzed by Jirovetz et al. (2002) using GC and GC/MS techniques. The oil composition was determined to be as follows:

α-thujene (0.1 percent)
α-pinene (0.5 percent)
camphene (0.2 percent)
β-pinene (0.2 percent)
myrcene (0.1 percent)
α-phellandrene (0.9 percent)
δ-3-carene (0.1 percent)
α-terpinene (0.1 percent)
p-cymene (0.4 percent)
limonene (0.3 percent)
β-phellandrene (0.1 percent)
(E)-β-ocimene (0.1 percent)
γ-terpinene (0.1 percent)
terpinolene (0.1 percent)
1,8-cineole (0.3 percent)
linalool (2.8 percent)
linalool oxide* (0.1 percent)
borneol (0.1 percent)
terpinen-4-ol (0.1 percent)
α-terpineol (0.1 percent)
eugenol (85.2 percent)
eugenyl acetate (0.1 percent)
(E)-cinnamaldehyde (4.9 percent)
(E)-cinnamyl acetate (0.1 percent)
β-caryophyllene (1.8 percent)
caryophyllene oxide (0.5 percent)

* correct isomer not identified

In addition, trace (< 0.1 percent) amounts of 3-hexenol, 1-octen-3-ol, p-cymenene, linalyl acetate, linalyl propionate, α-thujone, myrtenal, perillaldehyde, geraniol, α-cubebene, β-cubebene, γ-cadinene, neryl acetate, elemol, cedrol, a cadinol, α-muurolol, and a farnesol were also found in the same oil.

An oil produced from the fruit stalks of *C. zeylanicum* was analyzed by Jayaprakasha et al. (2003). Its composition was determined to be as follows:

β-pinene (0.40 percent)
linalool (0.70 percent)
(E)-cinnamaldehyde (0.34 percent)
hydrocinnamyl acetate‡ (1.45 percent)
α-copaene (3.02 percent)
β-caryophyllene (22.36 percent)
(E)-cinnamyl acetate (36.59 percent)
α-humulene (5.49 percent)
germacrene D (0.53 percent)
germacrene B† (0.96 percent)
valencene (0.55 percent)
α-muurolene (1.29 percent)
γ-cadinene (2.27 percent)
(Z)-γ-bisabolene (0.52 percent)
δ-cadinene (4.70 percent)
γ-curcumene† (0.56 percent)
β-guaiene*† (0.73 percent)
ledol (2.55 percent)
nerolidol* (0.30 percent)
spathulenol (0.40 percent)
globulol (0.75 percent)
10-epi-γ-eudesmol (0.65 percent)
cubenol (0.20 percent)
T-cadinol (4.90 percent)
α-muurolol (0.65 percent)
α-cadinol (1.66 percent)
benzyl benzoate (1.46 percent)

* correct isomer not identified; † incorrect identification based on GC elution order; ‡ also known as 3-phenylpropyl acetate

Kaul et al. (2003) investigated the composition of oils produced from tender twigs bearing reproductive parts, bud and flower stalks, buds and flowers, fruit stalks and fruits of *C. zeylanicum* of Indian origin. The comparative composition of these oils can be found in T-2.

Comparative percentage composition of cinnamon fruit oil of Karnatakan and Keralan origin **T-1**

Compound	Karnataka oil	Kerala oil
α-pinene	1.6	0.1
β-pinene	0.6	0.1
myrcene	0.2	-
α-phellandrene	0.7	0.1
β-phellandrene	1.6	0.4
(E)-β-ocimene	0.5	0.2
(Z)-cinnamaldehyde	0.3	0.2
borneol	0.4	0.3
α-terpineol	0.3	0.3
(E)-cinnamaldehyde	4.3	0.6
(E)-cinnamyl alcohol	2.2	2.0
eugenol	0.3	0.2
hydrocinnamyl acetate	2.9	4.3
α-copaene	3.1	1.8
β-caryophyllene	13.7	9.2
(E)-cinnamyl acetate	42.4	54.2
α-humulene	3.1	2.8
germacrene D	0.8	0.7
germacrene B†	2.0	1.7
γ-cadinene	1.6	1.2
δ-cadinene	3.0	2.3
β-guaiene†	0.4	0.4
nerolidol*	0.2	0.4
caryophyllene oxide	0.9	1.1
globulol	0.5	0.6
germacrene D-4-ol	0.3	0.3
10-epi-γ-eudesmol	0.4	0.5
α-muurolol	0.3	0.3
cubenol	0.8	0.5
T-cadinol	2.7	3.4
α-cadinol	1.0	1.5
benzyl benzoate	2.7	2.8
methyl palmitate	0.3	-
methyl oleate	0.3	-

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

L.J. Mohan Rao, *Quality of essential oils and processed materials of selected spices and herbs.* J. Med. Arom. Plant Sci., **22**, 808-816 (2000).

Anon, *Report of the Analytical Methods Committee Application of gas-liquid chromatography to the analysis of essential oils. Part XVIII. Determination of safrole in oils of cinnamon leaf, Litsea cubeba and nutmeg.* Analyst, **127**, 428-429 (2002).

G.K. Jayaprakasha, L.J. Mohan Rao and K.K. Sakariah, *Chemical composition of the volatile oil from Cinnamomum zeylanicum buds. Z. Naturawissenforsch.*, **57c**, 990-993 (2002).

L. Jirovetz, G. Buchbauer, M.B. Ngassoum, J.J. Essia-Ngang, L.N. Tatsadjieu and O. Adjoudji, *Chemical composition and antibacterial activities of the essential oils of Plectranthus glandulosus and Cinnamomum zeylanicum from Cameroon.* Sci. Pharm., **70**, 93-99 (2002).

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P.N. Kaul, A.K. Bhattacharya, B.R. Rajeswara Rao, K.V. Syamasundar and S. Ramesh, *Volatile constituents of essential oils isolated from different parts of cinnamon (Cinnamomum zeylanicum Blume).* J. Sci. Food Agric., **83**, 53-55 (2003).

Palmarosa Oil

Kaul et al. (1998) compared the influence of harvesting date and method of distillation on the composition of palmarosa oil as can be seen from the results presented in T-3.

Rajeswara Rao (2001) reported that palmarosa oil produced in an area of India (Hyderabad, Andhra Pradesh), which experiences a semi-arid tropical climate, possessed the following composition:

Percentage composition of the oils isolated from different plant parts of *Cinnamomum zeylanicum* **T-2**

Compound	1	2	3	4	5
α-thujene	0.2	0.1	-	0.1	0.2
α-pinene	2.3	0.7	0.1	0.8	4.2
camphene	1.0	0.2	-	0.4	1.1
sabinene	0.1	-	-	-	0.1
β-pinene	0.9	0.4	-	0.5	1.9
myrcene	0.4	0.3	-	0.3	0.5
α-phellandrene	3.4	2.2	0.2	1.7	2.3
δ-3-carene	0.1	0.1	-	-	0.1
α-terpinene	0.2	0.1	-	0.1	0.2
p-cymene	0.6	0.4	-	0.2	0.2
limonene	1.6	0.9	-	0.8	1.5
1,8-cineole	0.1	0.1	0.1	0.2	0.2
(Z)-β-ocimene	0.1	0.1	0.2	0.1	0.1
(E)-β-ocimene	0.1	0.1	0.1	0.1	0.2
γ-terpinene	0.1	0.1	-	0.1	0.1
terpinolene	0.3	0.3	-	0.2	0.3
linalool	15.2	11.3	3.6	13.1	27.4
borneol	0.3	0.3	0.2	0.4	0.5
terpinen-4-ol	0.1	0.1	0.2	0.1	0.1
α-terpineol	0.8	0.6	0.5	0.8	1.0
(E)-cinnamaldehyde	4.0	0.8	0.2	0.9	-
eugenol	0.8	0.1	1.0	0.3	0.1
neryl acetate	1.2	2.0	0.6	1.4	0.9
(Z)-cinnamyl acetate	2.0	0.7	6.1	1.5	1.1
β-elemene	0.1	0.1	0.8	0.1	0.1
(E)-cinnamyl acetate	49.4	64.5	22.0	58.1	43.4
β-caryophyllene	8.3	9.6	9.8	11.1	6.9
α-humulene	0.8	0.8	2.2	1.1	0.9
germacrene D	0.1	0.1	0.2	-	0.1
α-muurolene	0.1	0.2	0.9	0.4	0.5
δ-cadinene	0.4	0.3	2.2	0.4	0.3
caryophyllene oxide	0.3	0.2	1.4	0.4	0.2
globulol	-	-	0.4	0.1	0.1
humulene epoxide I	0.1	0.3	5.0	0.3	0.3
α-muurolol	0.2	0.2	4.9	0.4	0.7
α-cadinol	0.2	0.2	2.4	0.3	0.3

1 = tender twig oil, 2 = bud and flower stalk oil, 3 = bud and flower oil, 4 = fruit stalk oil and 5 = fruit oil

myrcene (1.0 percent)
p-cymene (0.1 percent)
limonene (0.5 percent)
(E)-β-ocimene (1.7 percent)
linalool (2.5 percent)
β-terpineol* (0.3 percent)
citronellol (0.1 percent)
geraniol (73.1 percent)
geranyl acetate (15.8 percent)
β-elemene (0.1 percent)
β-caryophyllene (2.0 percent)
geranyl propionate (0.2 percent)
β-selinene (0.1 percent)
β-bisabolene (0.1 percent)
geranyl butyrate (0.2 percent)
caryophyllene oxide (0.1 percent)
geranyl valerate (0.1 percent)
geranyl hexanoate (0.3 percent)
geranyl heptanoate (0.1 percent)

* correct isomer not identified

Trace amounts (< 0.1 percent) of 6-methyl-5-hepten-2-one, α-phellandrene, α-terpinene, α-terpineol, α-terpinyl acetate and α-selinene were also found in this same oil.

Singh et al. (2002) found that the effect of partial shade on oil produced from palmarosa grass grown in India was minimal as can be seen from the variation found in the three major constituents: linalool (1.5-1.7 percent), geraniol (81.6-83.8 percent) and geranyl acetate (8.8-9.7 percent).

Comparative percentage composition of palmarosa oil produced either by water or steam distillation in July or August **T-3**

Compound	July harvest		August harvest	
	WD	SD	WD	SD
(Z)-3-hexenol	0.06	-	-	-
α-pinene	-	0.05	-	-
sabinene	-	0.04	0.12	0.05
β-pinene	-	0.04	-	-
myrcene	2.65	3.09	2.97	3.34
α-phellandrene	0.12	0.09	0.17	0.07
α-terpinene	0.04	0.05	0.06	0.06
p-cymene	0.06	0.05	-	-
limonene	0.84	1.04	0.29	0.26
(Z)-β-ocimene	0.67	1.03	0.82	0.93
(E)-β-ocimene	1.20	2.52	1.86	1.97
γ-terpinene	0.07	0.06	0.15	0.06
terpinolene	0.13	0.09	0.06	0.05
linalool	3.22	2.78	2.52	2.22
citronellal	0.07	-	-	-
terpinen-4-ol	0.08	0.11	-	-
α-terpineol	0.07	-	0.09	-
citronellol + nerol	-	0.10	0.09	0.06
geraniol	63.14	69.91	70.06	75.75
linalyl acetate	0.04	-	-	-
geranyl formate	0.08	-	-	-
citronellyl acetate	0.18	0.09	0.05	0.07
neryl acetate	0.47	-	-	-
geranyl acetate	20.13	15.58	12.45	11.44
β-elemene	0.06	0.03	-	0.04
β-caryophyllene	0.54	0.93	0.85	1.26
geranyl propionate	0.10	0.06	0.06	0.07
geranyl isobutyrate	-	-	0.18	-
geranyl butyrate	0.30	0.11	0.23	0.12
geranyl valerate	0.06	-	0.07	-
geranyl hexanoate	0.81	0.05	0.83	0.71
geranyl heptanoate	0.24	0.05	0.16	0.13

WD = water distilled, SD = steam distilled

An oil of palmarosa of south Indian origin was analyzed by Narayanan (2003). The main components identified in this oil were as follows:

limonene (0.66 percent)
(Z)-β-ocimene (0.76 percent)
linalool (2.58 percent)
citronellol (0.47 percent)
geraniol (76.86 percent)
geranyl acetate (6.72 percent)
β-caryophyllene (1.18 percent)

Futhermore, Narayanan reported that if the oil is stored for a long time period (storage duration not given) then the main components change (degrade) as follows:

limonene (0.40 percent)
linalool (2.53 percent)
citronellol (0.23 percent)
geraniol (44.75 percent)
geranyl acetate (5.30 percent)
β-caryophyllene (0.30 percent)

The high boiling components formed during storage were not identified.

Using solid phase microextraction (SPME) coupled with GC/MS, Sartoratto and Augusto (2003) determined that the headspace volatiles of the dried and ground leaves of palmarosa were:

(Z)-β-ocimene (0.73 percent)
linalool (4.10 percent)
geraniol (68.20 percent)
geranyl acetate (10.30 percent)
β-caryophyllene (2.31 percent)
(Z,Z)-farnesol (1.10 percent)

Comparative percentage composition of palmarosa oil produced in three different locations in India **T-4**

Compound	Hyderabad (Madhya Pradesh)	Lucknow (Uttar Pradesh)	Amarwati (Maharashtra)
isopropyl propionate	-	-	t
isopropyl butyrate	-	t	-
(Z)-3-hexenol	-	0.1	-
1-hepten-3-ol	-	0.1	-
cyclohexanone	-	t	-
2-heptanol	0.1	-	-
sabinene	-	0.1	-
myrcene	0.3	0.1	0.2
α-phellandrene	-	t	t
p-cymene	0.2	-	0.1
limonene	-	0.1	0.1
(Z)-β-ocimene	-	0.1	0.2
m-cymene	t	-	-
(E)-β-ocimene	0.1	0.6	0.7
γ-terpinene	t	0.1	-
terpinolene	0.1	-	-
linalool	1.6	3.4	2.8
trans-p-menth-2-en-1-ol	-	0.1	0.4
cis-verbenol	0.1	0.1	0.5
isoborneol	-	0.1	-
borneol	0.1	-	-
terpinen-4-ol	-	0.1	2.0
α-terpineol	-	t	0.4
2-decanol	0.2	t	0.1
linalyl formate	0.1	-	0.2
citronellol	2.1	-	1.6
geraniol	67.6	74.2	83.6
geranial	8.8	2.0	1.0
neryl formate	0.1	t	-
geranyl formate	0.9	0.1	0.2
undecanol	-	0.1	-
linalyl propionate	0.1	0.3	-
citronellyl acetate	1.1	-	-
neryl acetate	-	0.3	0.2
α-cubebene	0.2	0.1	-
geranyl acetate	10.0	15.8	2.2
β-elemene	0.4	0.1	-
β-caryophyllene	0.1	0.2	1.1
α-cadinene	0.3	-	-
β-farnesene*	-	0.1	0.1
germacrene D	0.1	-	-
geranyl isobutyrate	0.1	-	0.1
β-curcumene	t	-	0.1
δ-cadinene	t	-	-
geranyl butyrate	0.3	0.1	0.1
(E)-nerolidol	0.3	0.1	0.1
caryophyllene oxide	0.9	0.1	0.5
humulene epoxide*	0.1	-	-
geranyl valerate	0.1	-	0.1
geranyl tiglate	0.1	-	0.1
(E,E)-farnesol	0.5	0.7	0.7
geranyl hexanoate	0.6	0.2	0.2
neryl heptanoate	0.3	0.1	-

Comparative percentage composition of palmarosa oil produced in three different locations in India (continued) **T-4**

Compound	Hyderabad (Madhya Pradesh)	Lucknow (Uttar Pradesh)	Amarwati (Maharashtra)
geranyl heptanoate	-	-	0.1
2-heptadecanone	-	0.1	-
nonadecane	0.2	-	-
geranyl octanoate	0.2	0.1	0.1
nonadecanol	0.1	-	-

* correct isomer not identified; t = trace (< 0.1 percent)

Palmarosa oils produced from plants grown in three different locations in India (Hyderabad, Lucknow and Amarwati) were analyzed by Raina et al. (2003) using GC and GC/MS. The results of this comparative study can be seen in T-4.

P.N. Kaul, A.K. Bhattacharya and B.R. Rajeswara Rao, *Influence of method of distillation on quality of palmarosa (Cymbopogon martinii (Roxb.) Wats. var. motia Burk.)* oil. J. Essent. Oil Bear. Plants, **1**(1), 39-44 (1998).

B.R. Rajeswara Rao, *Biomass and essential oil yields of rain fed palmarosa (Cymbopogon martinii (Roxb.) Wats. var. motia Burk.) supplied with different levels of organic manure and fertilizer nitrogen in semi-arid tropical climate.* Indust. Crops Prods., **14**, 171-178 (2001).

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P. Narayanan, *Comparison of quality of essential oils from south India.* FAFAI, **5**(1), 47-56 (2003).

A. Sartoratto and F. Augusto, *Application of headspace solid phase microextraction and gas chromatography to the screening of volatile compounds from some Brazilian aromatic plants.* Chromatographia, **57**, 351-356 (2003).

V.K. Raina, S.K. Srivastava, K.K. Aggarwal, K.V. Syamsundar and S.P.S. Khanuja, *Essential oil composition of Cymbopogon martinii from different places in India*. Flav. Fragr. J., **18**, 312-315 (2003).

Tuberose Extract

A summary of the pre-1955 literature (Gildemeister and Hoffmann 1956) reveals that benzyl alcohol, methyl anthranilate, benzyl benzoate, geraniol, nerol, eugenol, methyl salicylate and farnesol have been previously found as components of extracts of tuberose.

Kaiser and Lamparsky (1976) examined the lactone fraction of a commercial sample of tuberose absolute. In this fraction, they identified trace amounts of δ-undecalactone, δ-dodecalactone, δ-tetradecalactone, γ-octalactone, γ-nonalactone, γ-undecalactone, γ-dodecalactone and coumarin. They also found four other lactones e.g.: tuberolactone (0.01-0.02 percent), δ-decalactone (0.6 percent), massoia lactone (0.005 percent) and a δ-lactone of 5-hydroxy-*cis*-2,*cis*-7-decadienoic acid (1.0 percent).

Petrzilka and Ehret (1991) reported that the major constituents of tuberose absolute were:

methyl palmitate (14.5 percent)
methyl benzoate (12.2 percent)
benzyl benzoate (10.4 percent)
ethyl oleate (5.3 percent)
α-terpineol (4.0 percent)
1,8-cineole (3.8 percent)
methyl salicylate (3.6 percent)
farnesol* (3.5 percent)
methyl anthranilate (2.4 percent)
methyl eugenol (2.2 percent)
benzyl salicylate (2.1 percent)
benzyl alcohol (1.8 percent)
palmitic acid (1.4 percent)
oleic acid (1.3 percent)
δ-decalactone (0.1-1.0 percent)
jasminlactone (0.1-1.0 percent)

* correct isomer not identified

In addition, important trace (< 0.1 percent) constituents that were reported to be also found in tuberose absolute were massoialactone, tuberolactone, δ-undecalactone, δ-dodecalactone, δ-tetradecalactone, γ-valerolactone, γ-octalactone, γ-nonalactone, γ-decalactone, γ-undecalactone, γ-dodecalactone, methyl hydrocinnamate, hexyl methyl ether, phenylacetonitrile, 5-dodeden-4-olide (dihydro-δ-decalactone), 1-nonen-4-ol, α-damascone isomer, (E)-anethole and 6-methyl coumarin.

Zhu et al. (1993) examined the headspace of tuberose flowers. The components identified in the headspace were:

α-pinene (1.22 percent)
benzaldehyde (0.58 percent)
sabinene (1.27 percent)
β-pinene (0.50 percent)
6-methyl-5-hepten-2-one (0.33 percent)

myrcene (0.39 percent)
limonene (1.78 percent)
1,8-cineole (31.96 percent)
methyl benzoate (41.21 percent)
camphor (0.07 percent)
methyl salicylate (11.29 percent)
indole (0.80 percent)
methyl anthranilate (2.79 percent)
methyl eugenol (0.03 percent)
pentadecane (0.80 percent)
benzyl benzoate (0.73 percent)

Reverchon and Della Porta (1997) used supercritical fluid CO_2 to fractionate a commercial sample of tuberose concrete of Indian origin. Unfortunately, the authors stated that the concrete was obtained from *Nepeta tuberosa* L. (Lamiaceae), whereas tuberose concrete is really obtained from *Polyanthes tuberosa* L. (Agavaceae). The fractionation technique used was to warm the concrete to ca. 30°C and mix it with glass beads (2 mm diameter) and charge the extractor with this mixture (1:10 concrete/beads). The discharge of the extractor was set up to exit through two separators. The temperature and pressure of the first separator was -5°C and 80 bar, while the parameters of the second extractor were set at 0°C and 15 bar. Using this system, the authors produced three fractions. The first fraction (F-1) was taken after 20 min, the second fraction (F-2) between 360-480 min and the third fraction (F-3) between 690-750 min. The three fractions and the original concrete were then subjected to analysis by GC/MS. The results of the various analyses can be seen summarized in T-5. It should be noted that the characterizations of nepetalactone and dihydronepetalactone were in error, probably autosuggestive from the misidentification from the incorrect taxonomic origin of the concrete. Also, the lack of characterization of numerous lactones, methyl salicylate and indole combined with the high levels of isoeugenol, eugenyl acetate and (E)-methyl isoeugenol could indicate that this was not a true natural tuberose concrete but one compounded by a supplier.

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Coriander Seed and Leaf Oils

A Polish oil of coriander seed (fruit) was analyzed by Gora et al. (1997). It was found to contain the following four major constituents:

α-pinene (4.5 percent)
p-cymene (6.5 percent)
linalool (69.4 percent)
camphor (6.9 percent)

Bhattacharya et al. (1998) analyzed an oil of coriander seed (fruit) produced experimentally from plants grown in Andhra Pradesh (India) where the annual production of coriander seed is 40,000-55,000 tonnes. The composition of the oil under study was found to be:

myrcene (1.71 percent)
α-terpinene (0.11 percent)
p-cymene (0.16 percent)
limonene + 1,8-cineole (0.44 percent)
(E)-β-ocimene (0.69 percent)
cis-linalool oxide† (0.35 percent)
trans-linalool oxide† (0.18 percent)
linalool (52.26 percent)
camphor (0.57 percent)
borneol (0.10 percent)
terpinen-4-ol (0.26 percent)
α-terpineol (0.36 percent)
decanal (0.51 percent)
citronellol (4.64 percent)
geraniol (9.29 percent)
safrole (2.67 percent)
undecanal (0.21 percent)
α-terpinyl acetate (1.07 percent)
eugenol (0.14 percent)
geranyl acetate (18.07 percent)
β-caryophyllene (0.20 percent)
α-humulene (0.40 percent)
(Z,Z)-farnesol (0.35 percent)

† furanoid form

The authors also tentatively identified chavicol (0.18 percent) in the same oil. Furthermore, it should be noted that prior to this analysis safrole has only ever been found as a trace component in coriander seed oil (Lawrence 1988).

An oil produced from coriander seed grown in Pakistan was the subject of analysis by Ur-Rahman et al. (1999). In this oil, the following components were identified:

α-pinene (2.5 percent)
β-pinene (0.3 percent)
myrcene (0.1 percent)

Comparative chemical composition (%) of tuberose concrete and its fractions **T-5**

Compound	F-1	F-2	F-3	concrete
benzaldehyde	0.42	0.37	0.60	0.03
β-pinene	1.15	0.08	0.18	0.26
p-cymene	0.19	0.04	-	0.13
1,8-cineole	8.22	0.25	0.09	3.41
α-p-dimethylstyrene	0.25	0.05	-	t
methyl benzoate	16.47	0.26	0.12	3.57
2-methylbenzonitrile	1.13	0.11	-	0.24
benzyl acetate	0.35	0.05	-	t
α-terpineol	1.25	0.78	0.15	t
methyl salicylate	6.68	0.22	0.03	3.57
ethyl benzoate	0.49	0.20	0.24	0.17
4-phenylbutyl acetate	0.08	0.05	-	0.22
methyl anthranilate	0.52	1.36	0.76	0.66
benzyl butyrate	0.24	0.07	-	0.07
eugenol	1.13	0.97	0.14	0.48
β-bourbonene	0.31	0.09	t	t
vanillin	t	t	0.24	t
methyl eugenol	2.61	2.00	0.50	1.07
β-caryophyllene	0.31	0.15	0.07	0.11
β-gurjunene	0.17	0.10	0.05	0.04
(Z)-isoeugenol	3.33	7.52	2.03	t
(Z)-methyl isoeugenol	0.46	0.54	0.61	2.73
(Z)-β-farnesene	t	t	t	0.30
valencene	4.93	4.92	1.63	2.87
nepetalactone	4.34	10.10	14.18	4.08
dehydronepetalactone	0.80	2.98	3.23	0.90
(E)-methyl isoeugenol	31.89	44.79	23.88	15.21
α-farnesene*	3.08	2.77	0.85	1.44
farnesol*	-	-	2.33	0.90
eugenyl acetate	8.15	15.75	36.70	6.09
benzyl benzoate	0.40	1.50	4.06	0.72
octadecanol	-	-	-	t
nonadecane	0.11	-	0.09	0.02
eicosane	-	-	-	0.01
heneicosane	0.18	-	0.14	0.08
tricosane	0.31	-	0.34	0.90
tetracosane	-	-	-	0.39
tricosanol	-	-	-	0.36
pentacosane	0.96	-	0.52	10.79
hexacosane	-	-	-	0.98
tetracosanol	-	-	-	1.52
heptacosane	-	-	-	20.25
octacosane	-	-	-	0.61
pentacosanol	-	-	-	1.62
nonacosane	-	-	-	10.91
hentriacontane	-	-	-	1.46

* correct isomer not identified

γ-terpinene (3.4 percent)
p-cymene (1.6 percent)
trans-linalool oxide† (0.4 percent)
cis-linalool oxide† (0.3 percent)
decanal (0.2 percent)
camphor (0.2 percent)
linalool (78.1 percent)
octanol (0.9 percent)
terpinen-4-ol (0.5 percent)
(E)-2-decenal (0.1 percent)
α-terpineol (0.9 percent)
geranyl acetate (3.8 percent)

Comparative percentage composition of coriander oil produced in Europe and Argentina **T-6**

Compound	European oil	Argentinean oil
α-pinene	5.1-5.9	2.1-4.4
camphene	0.8	0.3
β-pinene	0.4-0.5	0.2-0.4
sabinene	0.3	0.1-0.3
myrcene	0.8-0.9	0.3-0.5
limonene	1.9-2.0	0.7-0.9
γ-terpinene	3.9-4.7	2.7-5.6
p-cymene	0.7-1.2	1.0
terpinolene	0.3-0.4	0.2-1.3
linalool	72.2-73.1	77.7-82.9
camphor	4.6-4.9	2.4-3.0
terpinen-4-ol	< 0.1-0.2	0.4-0.5
(E)-2-decenal	0.1-0.2	0.3-0.4
α-terpineol	0.4-0.5	0.2
geranyl acetate	1.7-2.3	1.1-1.4
geraniol	2.7-3.9	1.9-2.3

citronellol (0.3 percent)
cuminaldehyde (0.5 percent)
nerol (0.1 percent)
p-mentha-1,3-dien-7-al (0.2 percent)
geraniol (1.4 percent)
(E)-2-dodecenal (0.5 percent)
decanoic acid (0.2 percent)
tetradecanoic acid (1.5 percent)
hexadecanoic acid (2.1 percent)

† furanoid form

It should be noted that the occurrence of cuminaldehyde and p-mentha-1,3-dien-7-al (normal components of cumin seed oil) could indicate a raw material contamination when the analyzed oil was produced as neither compound has been previously characterized in coriander seed oil.

Shatar and Altantsetseg (2000) produced an oil from ripe coriander seed that was grown in Mongolia. Analysis of this oil by GC and GC/MS revealed that is possessed the following composition:

nonane (0.2 percent)
α-pinene (0.6 percent)
camphene (0.1 percent)
β-pinene (0.1 percent)
sabinene (0.1 percent)
myrcene (0.2 percent)
α-phellandrene (0.3 percent)
α-terpinene (0.1 percent)
limonene (0.8 percent)
β-phellandrene (0.1 percent)
1,8-cineole (0.1 percent)
(Z)-β-ocimene (0.1 percent)
γ-terpinene (2.8 percent)
p-cymene (0.7 percent)
octanal (0.8 percent)
2-hexylfuran (0.2 percent)
nonanal (0.3 percent)
α-thujone (0.1 percent)
cis-linalool oxide† (0.1 percent)
trans-linalool oxide† (0.1 percent)
decanal (8.6 percent)
camphor (3.5 percent)
linalool (45.4 percent)
octanol (0.2 percent)
undecanal (0.8 percent)
terpinen-4-ol (0.2 percent)
α-humulene (0.5 percent)
α-terpineol (0.3 percent)
borneol (0.3 percent)
dodecanol (1.5 percent)
geranyl acetate (0.7 percent)
(E)-2-undecenal (1.0 percent)
tridecanal (2.4 percent)
geraniol (1.8 percent)
pentadecanal (0.2 percent)
(E)-nerolidol (< 0.1 percent)
carvacrol (0.1 percent)
α-cadinol (0.1 percent)
decanoic acid (0.4 percent)

† furanoid form

Recently, Larran et al. (2001) screened coriander oil against the bee chalkbrood fungus. The oil, which was found to be fairly active against the fungus at 700-900 µL/L, possessed the following main components:

α-pinene (0.7 percent)
limonene (0.5 percent)
p-cymene (5.6 percent)
cis-linalool oxide† (4.3 percent)
trans-linalool oxide† (3.7 percent)
linalool (68.4 percent)
camphor (3.9 percent)
geranyl acetate (1.8 percent)
geraniol (1.0 percent)

† furanoid form

Minija and Thoppil (2001) examined the antimicrobial characteristics of coriander seed and herb oils produced in the laboratory by hydrodistillation of plant material grown in Kerala (India). The seed oil was found to possess the following major constituents:

linalool (70.5 percent)
α-terpineol (3.0 percent)
α-terpinyl acetate (10.9 percent)
geraniol (10.4 percent)

It should be noted that the richness of this oil in α-terpinyl acetate is quite unusual and probably an error in identification. The five constituents reported to be found in the herb oil were completely different to any that have been previously found in cilantro oil (coriander herb oil). As a result, their identities will not be included in this review as they are in error.

Gil et al. (2002) compared oils produced from coriander seed of European and Argentinean origin both grown in Argentina over two seasons. A summary of the results of this study is presented in T-6. It should be noted that the constituents listed in Table VI reflect only the main oil constituents. It does not include any minor or trace constituents that were ignored by the authors.

Domokos and Kiss (2002) reported that the main constituents of a Hungarian-produced coriander seed oil were:

α-pinene (3.1 percent)
camphene (0.5 percent)
β-pinene (0.4 percent)
limonene (5.0 percent)
linalool (80.0 percent)
linalyl acetate (3.8 percent)

The occurrence of such high levels of limonene and linalyl acetate is unusual and possibly in error.

Stoyanova et al. (2002) compared the composition of oils produced from whole and ground coriander seed and the distillation water with a hexane extract produced from the same batch of ground coriander seed. The results of this comparative study can be seen in T-7. The oils produced from ground seed were ground to a 2 mesh size. Both oils were produced by hydrodistillation for 60 min (whole seed) and 240 min (ground seed). The oil produced from the distillation water once the solid material had been removed by filtration was obtained by redistillation and oil cohobation. The extract was produced by soxhlet extraction for 8 h using hexane.

Comparative percentage composition of whole and ground coriander seed oil, a distillation water oil and a hexane extract **T-7**

Compound	WSO	GSO	DO	EX
α-pinene	1.8	6.5	-	6.1
camphene	0.2	0.7	-	0.8
sabinene	0.2	0.4	-	0.4
β-pinene	0.2	0.6	-	0.6
myrcene	0.5	0.8	-	0.8
p-cymene	3.4	4.2	-	5.0
limonene	1.1	1.8	-	2.2
γ-terpinene	2.6	4.5	-	4.4
linalool	79.3	69.3	82.7	63.3
camphor	2.6	3.3	4.9	3.5
terpinen-4-ol	0.2	0.2	0.6	0.2
α-terpineol	0.4	0.3	0.8	0.2
citronellol	0.1	0.1	-	0.1
geraniol	3.2	2.0	0.2	1.8
eugenol	0.5	0.3	0.3	0.1
geranyl acetate	1.5	3.6	0.5	2.2
Yield (%)	0.55	0.86	0.02	1.63

WSO = whole seed oil, GSO = ground seed oil, DO = distillation water oil, EX = hexane extract

Percentage composition of the main components of coriander seed oil produced from plants either treated or not with VAM fungi **T-8**

Compound	Control oil	VAM-1 oil	VAM-2 oil
α-pinene	0.40	0.63	3.19
β-pinene	0.48	0.62	0.71
p-cymene	1.33	5.06	1.60
linalool	56.55	44.42	61.72
geraniol	3.93	19.99	1.57
(E)-anethole	8.18	0.02	0.76
β-elemene	1.26	1.04	1.11
β-caryophyllene	1.41	2.17	1.89

VAM-1 treated with Glomus macrocarpum; VAM-2 treated with Glomus fasciculatum

The use of vesicular arbascular mycorrhizal (VAM) fungi (zygomycetes) as biofertilizers has become more popular over the past 20 years because they are inexpensive and are environmentally more acceptable to expensive chemical fertilizers. As a result, Kapoor et al. (2002) examined the use of two VAM fungi during the cultivation of coriander to determine their effect on oil yield and composition for plants grown experimentally in New Delhi (India). A comparison of the compositional data obtained is shown in T-8. It should be noted that the high level of (E)-anethole found in the seed of the control plants was not expected; consequently, it was probably characterized in error. The authors noted that with the use of VAM fungi the seed oil yield increased by up to 4.3 percent. Also, they showed that Glomus fasciculatum was the best VAM to use for coriander.

Coriander seed oil was the subject of analysis by Kubeczka and Formacek (2002). They found that the oil contained the following components:

α-pinene (3.46 percent)
camphene (0.68 percent)
β-pinene (0.72 percent)
sabinene (0.10 percent)
myrcene (0.41 percent)
limonene (6.20 percent)
1,8-cineole + β-phellandrene (3.77 percent)
γ-terpinene (2.72 percent)
p-cymene (3.89 percent)
terpinolene (0.25 percent)
trans-linalool oxide† (0.23 percent)
cis-linalool oxide† (0.19 percent)
camphor (4.12 percent)
linalool (69.33 percent)
terpinen-4-ol (0.10 percent)
(E)-β-farnesene (0.12 percent)
α-terpineol (0.33 percent)

Average percentage composition of the main components of the headspace volatiles of 31 samples of Italian coriander seed **T-9**

Compound	Group 1(9)[a]	Group 2(11)	Group 3(11)
α-thujene	0.29	0.24	0.15
α-pinene	31.36	28.78	19.41
camphene	2.90	2.66	2.14
sabinene	1.15	1.17	0.94
β-pinene	2.39	2.36	1.71
myrcene	1.40	2.11	1.68
α-terpinene	-	0.11	0.09
p-cymene	24.71	3.45	2.15
limonene	6.21	5.89	4.40
γ-terpinene	7.17	23.31	16.40
terpinolene	0.44	0.93	0.89
linalool	18.98	25.91	44.66
camphor	2.99	3.01	5.38
borneol	-	0.05	0.02

[a] = number of samples

α-terpinyl acetate + borneol (0.62 percent)
geranyl acetate (1.01 percent)
nerol (0.04 percent)
geraniol (1.06 percent)

† furanoid form

Carrubba et al. (2002) used Cluster Analysis and Principle Component Analysis to determine whether there were any differences between SPME headspace volatiles of the 31 samples of ground coriander seed obtained from various regions of Italy. The average percentage composition of three groups of volatiles that were grouped using Cluster Analysis can be seen in T-9.

Oliver (2003) showed that pure (3S)-(+)-linalool could be isolated from coriander seed oil by formation of its 3,5-dinitrobenzoate ester followed by regeneration and distillation.

Fan and Sokorai (2002) used SPME and GC/MS to determine the headspace volatiles of cilantro (coriander herb) leaves. The compounds that were characterized were:

(E)-2-hexenal (0.23 percent)
nonane (4.25 percent)
octanal (0.65 percent)
linalool (2.13 percent)
nonanal (0.29 percent)
decanal (51.51 percent)
(E)-2-decenal (31.61 percent)
undecanal (0.59 percent)
(E)-2-undecenal (0.80 percent)
dodecanal (0.74 percent)
(E)-2-dodecenal (4.94 percent)
(E)-2-tridecenal (0.61 percent)
tetradecanal (1.85 percent)

In another SPME headspace study, Deng et al. (2003) examined the headspace volatiles of fresh Chinese cilantro. The main compounds identified were:

(Z)-3-hexenyl acetate (1.06 percent)
hexanol (0.29 percent)
decanal (9.12 percent)
hexadecane (0.59 percent)
(E)-2-decenal (8.41 percent)
decyl acetate (1.77 percent)
dodecanal (1.05 percent)
(E)-8-dodecenyl acetate (5.63 percent)
decanol (16.52 percent)
(E)-2-decenol (13.71 percent)
(E)-2-dodecenal (13.99 percent)
(E)-2-decen-2-ol (0.35 percent)
(E)-2-tridecenal (19.29 percent)
(E)-5-dodecenol (0.65 percent)

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Percentage composition of five chemotypes of *Melaleuca quinquinervia* **T-10**

Compound	Chemotypes				
	1	2	3	4	5
α-thujene	t	1.9	4.5	t	-
β-pinene	1.2	4.8	0.2	0.6	0.3
α-phellandrene	0.1	1.0	-	t	-
myrcene	0.6	0.7	-	0.1	-
α-terpinene	0.2	3.8	0.1	0.1	0.1
limonene	8.2	3.5	0.7	2.2	1.3
1,8-cineole	59.3	10.5	4.1	35.4	1.3
γ-terpinene	0.4	19.0	3.6	1.5	7.1
p-cymene	0.5	1.6	13.6	5.2	27.1
terpinolene	0.2	4.9	0.8	1.0	1.6
linalool	0.2	6.3	0.5	0.2	0.7
linalyl acetate	0.2	-	0.3	t	2.7
terpinen-4-ol	0.8	1.8	3.6	2.1	4.4
β-caryophyllene	0.4	0.5	0.5	0.1	-
viridiflorene	0.3	0.5	0.3	0.7	0.4
α-terpineol	11.1	1.5	3.9	20.3	2.7
α-terpinyl acetate	0.9	-	3.7	0.3	-
caryophyllene oxide	0.2	0.2	0.4	1.1	0.2
(E)-nerolidol	0.5	t	6.3	2.5	4.3
ledol	0.3	0.3	0.2	0.2	0.2
globulol	6.8	18.3	25.5	7.1	17.7
viridiflorol	3.2	3.4	4.1	1.8	2.4
T-cadinol	0.4	0.2	3.5	1.6	0.7
α-cadinol	t	0.1	0.9	0.1	0.2

t = trace (< 0.1 percent)

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Niaouli Oil

Oils of *Melaleuca quinquinervia* (Cav.) S.T. Blake (niaouli) produced in New Caledonia were analyzed by Trilles et al. (1999). A summary of the composition of these oils, which have been grouped into five chemotypes can be seen in T-10.

Hethelyi et al. (2000) determined that the commercially available niaouli oils possessed the following components:

α-pinene (2.1-4.9 percent)
β-pinene (1.2-1.7 percent)
myrcene (1.4-2.6 percent)
1,8-cineole (58.3-63.2 percent)
linalool (1.7-3.8 percent)
camphor (1.1-1.7 percent)
borneol (0.1-1.3 percent)
α-terpineol (16.8-29.1 percent)

Bombarda et al. (2001) synthesized ledol and viridiflorol and unequivocally proved that the major sesquiterpene alcohol found in niaouli oil was viridiflorol.

Ireland et al. (2002) obtained 136 samples of *M. quinquinervia* leaves from Australia and Papua New Guinea and found that there was a distinct difference in oil yield from the north and south of the geographic range from which the samples were obtained. In Australia, latitude 8°S to ca. 25°S the oil yields were all < 0.5 percent w/w, whereas between the latitudes 25°-33°S, the oil yields were all ca. 1.5-3.0 percent. Also, samples of leaves from Papua New Guinea were all above 3.0 percent.

Examination of the analytical data of the 136 oil samples revealed, according to Ireland et al., two chemotypes. One chemotype containing large amounts of (E)-nerolidol, which may or may not be in association with linalool, and the other chemotype containing 1,8-cineole, α-terpineol, viridiflorol and β-caryophyllene, with either 1,8-cineole or viridiflorol being the

major constituent. A typical composition of the (E)-nerolidol-rich chemotype can be seen as follows:

α-pinene (0.1 percent)
limonene (0.1 percent)
γ-terpinene (0.1 percent)
cis-linalool oxide† (0.1 percent)
trans-linalool oxide† (0.1 percent)
benzaldehyde (0.7 percent)
linalool (20.3 percent)
β-caryophyllene (0.5 percent)
cis-p-menth-2-en-1-ol (< 0.1 percent)
α-humulene (0.1 percent)
α-terpineol (0.1 percent)
geraniol (0.1 percent)
palustrol (0.1 percent)
nerolidol oxide*‡ (0.4 percent)
caryophyllene oxide (0.8 percent)
nerolidol oxide*‡ (0.1 percent)
epi-globulol (0.1 percent)
(E)-nerolidol (74.2 percent)
cubeban-11-ol (0.2 percent)
epi-cubenol (0.1 percent)
viridiflorol (0.2 percent)
γ-eudesmol (0.1 percent)
bulnesol (0.2 percent)
β-eudesmol (0.1 percent)
(E,E)-farnesol (0.6 percent)

† furanoid form; * correct isomer not identified; ‡ tentative identification

In contrast, the composition of a typical example of the other chemotype, which is the one generally encountered in commerce, can be seen as follows:

α-pinene (4.7 percent)
α-fenchene (0.1 percent)
β-pinene (1.7 percent)
myrcene (0.6 percent)
α-terpinene (0.1 percent)
limonene (6.7 percent)
1,8-cineole (53.4 percent)
γ-terpinene (0.5 percent)
(E)-β-ocimene (0.2 percent)
p-cymene (0.3 percent)
terpinolene (0.1 percent)
benzaldehyde (0.2 percent)
α-gurjunene (0.1 percent)
β-caryophyllene (0.2 percent)
terpinen-4-ol (0.6 percent)
methyl benzoate (0.1 percent)
α-humulene (0.1 percent)
neral (0.3 percent)
α-terpineol (11.9 percent)
palustrol (0.2 percent)
caryophyllene oxide (0.3 percent)
ledol (3.1 percent)
cubeban-11-ol (0.3 percent)
viridiflorol (10.3 percent)
spathulenol (< 0.1 percent)
γ-eudesmol (0.4 percent)
T-cadinol (0.2 percent)
bulnesol (0.2 percent)
α-eudesmol (0.9 percent)
β-eudesmol (1.3 percent)
citronellic acid (0.1 percent)

In addition, a number of other constituents were found in the oils of the 136 samples. The maximum levels found of these components that were not characterized in the two example chemotypes were as follows:

sabinene (1.8 percent)
α-phellandrene (2.3 percent)
β-phellandrene (1.1 percent)
(Z)-β-ocimene (0.4 percent)
rose oxide* (0.3 percent)
bicycloelemene (1.3 percent)
α-cubebene (1.6 percent)
α-copaene (0.2 percent)
methyl citronellate (0.8 percent)
isopulegol (2.0 percent)
β-elemene (0.5 percent)
α-fenchol (4.0 percent)
hexenyl butyrate* (3.3 percent)
α-bulnesene (0.6 percent)
methyl benzoate (0.5 percent)
allo-aromadendrene (4.5 percent)
citronellyl acetate (1.4 percent)
cis-piperitol (0.4 percent)
δ-terpineol (0.9 percent)
α-terpinyl acetate (4.4 percent)
viridiflorene (1.6 percent)
verbenone (0.7 percent)
β-selinene (3.5 percent)
α-selinene (4.0 percent)
bicyclogermacrene (4.1 percent)
naphthalene (2.8 percent)
trans-piperitol (1.7 percent)
δ-cadinene (0.5 percent)
geranyl acetate (0.7 percent)
citronellol (36.0 percent)
cadina-1,4-diene (0.9 percent)
calamenene* (13.6 percent)
(E,E)-α-farnesene (0.7 percent)
calacorene* (0.4 percent)
guaiol (1.0 percent)
globulol (39.7 percent)
T-muurolol (1.0 percent)
α-muurolol (1.1 percent)
α-cadinol (2.6 percent)

* correct isomer not identified

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