Progress in Essential Oils

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Maté Extract

Maté is also known as yerba mate, erva mate, Paraguay tea, St. Bartholomew's tea or Jesuits tea. The terms refer to the leaves of *Ilex paraguarensis* St. Hilaire, an evergreen member of the Aquifoliaceae family. The leaves of maté are important natural products from which a tisane (tealike beverage) is made. This beverage is widely consumed throughout South America, particularly Paraguay, Argentina and Brazil. Maté is also used as a component of beverages such as *chimarrao*, *tereré* and some soft drinks (Viera et al., 2008). Because maté is rich in caffeine, it acts as a stimulant (tonic) and a diuretic (Wichtl, 1994).

The volatile components of both green and toasted (the typical tea leaf process) leaves of *I. paraguarensis* were analyzed by Kawakami and Kobayashi (1991) using GC/MS. The components characterized in the hydrodistilled oils of both types of leaves are presented in **T-1**. In addition, trace amounts (<0.1%) of butanal, 2-butanone, 3-buten-2-one, 2-methyl-3-pentanone, toluene, α-phellandrene, (E)-3-hexen-2-one, (E,E)-2,4-octadienal, undecanal, nonanol, 2-dodecanone, dodecanal, 4-methylguaiacol and T-cadinol were also found in the oil obtained from green leaves. Trace amounts (<0.1%) of (E)-3-hexen-2-one, 3-octanone, 6-methyl-(Z,Z)-3,5-heptadien-2-one and 2-dodecanone were characterized in the oil obtained from roasted leaves.

Kubo et al. (1993) determined that the main 10 volatile compounds found in maté leaves were linalool, α-ionone, β-ionone, α-terpineol, octanoic acid, geraniol, octanol, nerolidol, geranyl acetone and eugenol.

Triterpenoid saponins are both bitter and very water-soluble; as a result, they could play an important role in the bitterness principles of maté tea, Gosmann et al. (1995) examined the triterpenoid saponin content of maté leaves.

A more detailed discussion on the saponin content, the ursolic and danolic moieties named maté saponins, and their anti-inflammatory and hypocholesterolemic properties can be seen in a comprehensive review by Heck and Meija (2007).

Saldana et al. (1999) used supercritical CO$_2$ extraction of the purine (methylxanthine) alkaloids from *I. paraguarensis* leaves. The authors found that they could successfully isolate caffeine, theobromine and theophylline from the leaf extract using HPLC; however, they noted that the solubility of caffeine in supercritical CO$_2$ was ca. 2 orders of magnitude higher than for theobromine or theophylline.

Filip et al. (2001) noted that maté leaves or their infusions had a bitter taste attributed to the phenolic components found in the leaves. As a result, Filip et al. developed an HPLC method to quantify the caffeoyl derivatives and flavonoids in a range of *Ilex* species. They found that the leaves of *I. paraguarensis* contained the following non-volatile components:

chlorogenic acid (2.800%)
caffeic acid (0.023%)
3,4-dicaffeoylquinic acid (0.855%)
3,5-dicaffeoylquinic acid (3.040%)
4,5-dicaffeoylquinic acid (2.890%)
rutin (0.060%)
quercitin (0.003%)
kampferol (0.001%)

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[a] dry wt percent

Chandra and Meija (2004) showed that maté tea possessed a good antioxidant activity.

Esmelindro et al. (2004) extracted 25 g x 4 of comminuted maté leaves using supercritical CO$_2$ pumped at a rate of 2 g/min at 30°C and 175 bar for 300 min. The compounds characterized were caffeine, theobromine, phytol, vitamin E (α-tocopherol), squalene and stigmasterol. In this study, the authors showed that the age of the leaves and their exposure to direct sunlight affected the compositions of the above-listed components. The range in composition of the various components was found to be as follows:

caffeine (9.8–53.5)[a]
theobromine (trace–7.1)
phytol (1.1–33.5)
squalene (9.5–85.8)
α-tocopherol (21.7–63.3)
[a]mg/gm extract

Scherer et al. (2006) noted that the caffeine and theobromine contents of maté leaves were 0.5–2.5% and 0.3–0.7%, respectively.

Araujo et al. (2007) analyzed the headspace volatiles of the ground leaves and twigs of *I. paraguarensis* using a divinylbenzene-carboxen-polydimethylsiloxane fiber SPME coupled with GC/MS. Using GC-FID for quantitation, the headspace volatiles were found to comprise:

acetaldehyde (0.3%)
propanal (1.4%)
acetic acid (0.2%)
(E)-2-butenal (0.4%)
1-penten-3-ol (1.0%)
1-penten-3-one (0.6%)
valeraldehyde (0.8%)
2-ethylfuran (0.2%)
(E)-2-pentenal (2.0%)
(Z)-2-pentenal (1.0%)
hexanal (2.8%)
furfural (0.3%)
(E)-2-hexenal (1.2%)
1-acetyl-1-cyclohexene (0.1%)
(Z)-4-heptenal (0.6%)
heptanal (0.3%)
(E,E)-2,4-hexadienal (0.2%)
α-pinene (0.1%)
benzaldehyde (1.2%)
5-methylfurfural (0.2%)
β-pinene (0.2%)

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T-1. Comparative percentage composition of maté oils produced from green and roasted leaves

Compound	Green leaf	Roasted leaf
propanal	t	0.3
isovaleraldehyde	0.1	t
ethanol	0.1	0.2
2-ethylfuran	0.5	-
butane-2,3-dione	0.1	t
valeraldehyde	0.8	0.2
1-penten-3-one	0.4	0.3
2-methyl-3-buten-2-ol	0.5	0.3
(E)-2-butenal	0.1	-
α-pinene	t	0.1
pentane-2,3-dione	0.2	0.1
1,4-dioxane	0.2	t
hexanal	1.2	0.4
2-methyl-2-butenal	0.1	t
β-pinene	0.3	0.2
(E)-2-pentenal	0.8	0.3
4-methyl-3-penten-2-one	t	0.1
butanol	0.2	0.3
ethylbenzene	t	0.1
1-penten-3-ol	2.5	0.9
2-methyl-2-pentenal	0.5	t
myrcene	0.2	-
2-heptanone	0.2	0.3
heptanal	0.4	0.3
4-methyl-2,3-dihydrofuran	0.3	0.3
isoamyl alcohol	t	0.3
limonene	0.5	0.5
(E)-2-hexenal	1.1	0.5
ethylmethylbenzene	t	0.1
2-pentylfuran	0.4	0.2
6-methyl-2-heptanone	0.3	0.4
amyl alcohol	0.7	0.7
γ-terpinene	0.2	-
2-methyl-3-oxotetrahydrofuran	t	0.2
methyl pyrazine	0.1	0.3
p-cymene	0.2	0.4
acetoin	0.3	t
2-octanone	0.2	0.2
octanal	0.4	0.3
terpinolene	0.1	-
(Z)-2-pentenol	0.2	0.1
4-methylpentanol	-	0.1
(E)-2-pentenol	1.1	0.8
2,6,6-trimethylcyclohexanone	0.2	0.3
2,5-dimethylpyrazine	0.1	0.1
2,6-dimethylpyrazine	t	0.2
ethylpyrazine	t	0.1
6-methyl-5-hepten-2-one	1.5	1.3
2,3-dimethylpyrazine	-	0.1
hexanol	0.3	0.4
3,3,5-trimethylcyclohexanone	0.2	0.1
6-methyl-2-heptanol	t	0.1
2-acetoxypropanal	-	0.1
(Z)-3-hexenol	0.2	0.4
2-ethyl-5-methylpyraxine	-	0.1
2-nonanone	0.4	0.4
(E,E)-2,4-hexadienal	0.2	0.2
nonanal	0.4	t
2-butoxyethanol	9.5	1.2
2,6,6,-trimethyl cyclohex-2-en-1-one	0.4	0.4
2,3-dihydro-2,5-dimethylfuran	0.2	0.2
acetic acid	0.2	0.2
1,2-dichlorobenzene[a]	-	0.2
cis-linalool oxide[f]	0.8	2.2
1-octen-3-ol	0.1	-
3,5,5-trimethylcyclohex-3-en-1-one	0.2	-
heptanol	1.3	1.5
furfural	0.6	3.2
(E,Z)-2,4-heptadienal	0.4	0.3
trans-linalool oxide[f]	0.5	1.3
2-ethylhexanol	0.4	0.4
(E,E)-2,4-heptadienal	1.3	1.0
2-decanone	0.3	0.5
2-acetylfuran	0.3	0.5
decanal	0.2	-
benzaldehyde	0.4	0.9
(E,Z)-3,5-octadien-2-one	0.8	0.4
1-acetyl-2-propionyloxyethane	-	0.4
propionic acid	0.1	0.7
(E)-2-nonenal	0.3	0.2
2,10,10-trimethyl-6-methylidene-1-oxaspiro-[4,5]dec-7-ene*	-	1.0
2,10,10-trimethyl-6-methylinene-1-oxaspiro-[4,5]dec-7-ene*	-	1.5
linalool	7.5	0.9
octanol	1.4	1.5
5-methylfurfural	0.6	4.3
(E,E)-3,5-octadien-2-one	0.4	0.8
2-cyclopentene-1,4-dione	0.1	0.1
(E,Z)-2,6-nonadienal	0.1	0.1
6-methyl-(E)-3,5-heptadien-2-one	1.6	1.0
2,6,6-trimethyl-2-hydroxycyclohexanone	1.5	1.1
2-undecanone	-	0.2
3,7-dimethyl-1,5,7-octatrien-3-ol	0.1	-
2-methyl-5-acetylfuran	0.1	0.4
1-methylformylpyrrole	-	0.2
butyric acid	0.2	1.0
1,4-dimethyl-3-cyclohexen-1-acetaldehyde	t	0.1
β-cyclocitral	0.4	0.3
safranal	0.2	0.2
(E)-2-decenal	0.6	0.3
phenylacetaldehyde	0.1	t
furfuryl alcohol	0.2	0.5
isovaleric acid	0.1	-
2-methylbutyric acid	0.1	1.0
4-methyl-5-hexen-4-olide	0.4	0.4
neral	0.4	0.3
2,6,6-trimethylcyclohex-2-ene-1,4-dione	0.4	0.7
6,10-dimethylundecanone	0.5	0.6
α-terpineol	1.9	0.4

T-1. Comparative percentage composition of maté oils produced from green and roasted leaves (cont.)

Compound	Green leaf	Roasted leaf
1-phenylpropanone	0.3	0.7
benzyl acetate	-	0.2
valeric acid	0.3	0.8
geranial	0.5	0.6
naphthalene	0.2	0.3
cis-linalool oxide[p]	-	0.7
1,3,5-trimethyl-2-(1,3-butadienyl)-benzene	0.1	0.5
(E)-2-undecenal	0.5	0.2
trans-linalool oxide[p]	0.1	0.7
decanol	0.4	0.2
1-(2-furyl)-1,2-propanedione	t	0.2
methyl salicylate	0.2	0.8
nerol	0.7	0.1
4-heptanolide[a]	-	0.1
(E,E)-2,4-decadienal	0.3	0.2
2-tridecanone	0.1	t
hexanoic acid	2.8	3.2
geraniol	1.7	0.3
guaiacol	0.2	0.6
α-ionone*	1.5	0.7
geranyl acetone	3.4	1.8
undecanol	0.2	0.1
benzyl alcohol	0.3	0.9
2-phenethanol	-	0.2
4-octanolide[b]	0.2	0.2
benzyl cyanide	0.1	0.1
2-tetradecanone	0.1	-
heptanoic acid	0.7	1.2
β-ionone*	1.4	1.0
dodecanol	0.3	0.1
2-vinylnaphthalene	t	0.2
phenol	0.6	0.9
5,6-epoxy-β-ionone*	1.4	1.3
1,2-dimethylnaphthalene	-	0.2
1-indanone	-	0.1
2-formylpyrrole	t	0.3
4-ethylguaiacol	-	0.3
4-nonanolide[c]	0.2	0.2
2,3-dihydro-2-methylbenzofuran	0.1	0.6
2-pentadecanone	0.1	-
nerolidol*	0.3	t
6,10-dimethylundeca-3,5,9-trien-2-one	0.3	0.1
octanoic acid	2.8	3.5
o-cresol	0.6	0.5
m-cresol + p-cresol	0.1	0.3
tridecanol	0.4	0.1
4-propylguaiacol	0.1	0.2
6,10,17-trimethylpentadecanone	1.3	1.7
4-decanolide[d]	0.1	0.1
bovolide	0.3	0.4
nonanoic acid	1.7	2.0
eugenol	-	2.5
3-ethylphenol	-	0.3
4-ethylphenol	0.1	0.1
1,6,7-trimethylnaphthalene	t	0.1
dihydrobovolide	0.4	0.2
tetradecanol	0.2	-
2,4-dihydroacetophenone	-	0.2
methyl hexadecanoate	0.2	-
T-cadinol	t	-
decanoic acid	0.8	0.6
phytol	0.2	0.1
1-(2,3,6-trimethylphenyl)-3-buten-2-one	-	0.2
geranic acid	0.1	0.1
isoeugenol*	-	0.3
dihydroactinodiolide	0.5	0.4
undecanoic acid	0.1	0.1
4-vinylphenol	0.1	-
indole	0.2	-
dodecanoic acid	0.1	0.1

t = trace (<0.1%)
* correct isomer not identified
[a] syn. γ-heptalactone
[b] syn. γ-octalactone
[c] syn. γ-nonalactone
[d] syn. decalactone
[f] furanoid form
[p] pyranoid form

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1-octen-3-ol (0.2%)
6-methyl-5-hepten-2-ol (1.4%)
2-pentylfuran (0.4%)
(E,Z)-2,4-heptadienal (7.0%)
octanal (0.6%)
(E,E)-2,4-heptadienal (7.8%)
p-cymene (0.2%)
limonene (0.5%)
benzyl alcohol (0.2%)
phenylacetaldehyde (0.3%)
(E)-β-ocimene (0.1%)
(E)-2-octenal (0.6%)
cis-linalool oxidef (0.5%)
(E,Z)-octa-3,5-dien-2-one (5.2%)
trans-linalool oxidef (0.7%)
(E,E)-octa-3,5-dien-2-one (0.8%)
linalool (0.5%)
6-methyl-3,5-heptadien-2-one[*] (1.3%)
4-ketoisophorone (0.3%)
(E)-2-nonenal (0.3%)
naphthalene (0.2%)
α-terpineol (0.1%)
methyl salicylate (0.2%)
dodecane (0.3%)
decanal (0.8%)
β-cyclocitral (1.2%)
3-ethyl-4-methyl-1H-pyrrole-2,5-dione (2.5%)
neral (0.2%)
geraniol (0.3%)
geranial (0.3%)
methylnaphthalene[*] (0.5%)
methylnaphthalene[*] (0.6%)
(E,E)-2,4-decadienal (0.3%)
eugenol (0.2%)
α-copaene (0.5%)
vanillin (0.1%)
tetradecane (0.1%)
β-caryophyllene (0.3%)
α-ionone[*] (2.1%)
geranylacetone (4.4%)
β-ionone[*] (2.9%)
pentadecane (0.2%)
dihydroactinodiolide (1.8%)
(Z)-nerolidol (0.1%)
(E)-nerolidol (0.2%)
hexadecane (0.1%)
caffeine (2.3%)
6,1014-trimethyl-2-pentadecanone (0.5%)
(E,E)-farnesylacetone (0.2%)

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[*] correct isomer not identified

Jacques et al. (2007) showed that leaf drying methods and agronomic variables had a marked effect on the caffeine, hexadecanoic acid, phytol, octadecanoic acid, squalene and α-tocopherol content of harvested maté leaves.

Three samples of maté tea were brewed by Lozano et al. (2007). The hot water tea extract was removed by filtration and subjected to dynamic headspace dilution analysis using Tenax traps solvent-assisted flavor evaporation, solvent extraction and aroma extract dilution analysis coupled with GC/MS. The components characterized as odorants of maté tea were geraniol, guaiacol, a β-damascenone isomer, δ-octalactone, skatole, 1,8-cineole, linalool, butyric acid, a β-ionone isomer, γ-nonalactone, p-cresol, eugenol, 1-penten-3-one, (E)-2-octenal, (E)-2-decenal, valeric acid, citronellol, geranial, hexanoic acid, isovaleraldehyde, 2,3-butanedione and 1-hexen-3-one. In addition, the authors tentatively identified 1-octen-3-ol, skatole, 2-acetylthiazole, 2-acetyl-1-pyrroline, methional, p-vinylguaiacol, furaneol, wine lactone, 2,3-butanedione, 2,3-pentanedione, (Z)-3-hexenal, (E)-2-nonenal, (E,Z)-2,6-nonadienal, (Z)-4-heptenal and (E,E)-2,4-hexadienal as maté tea odorants.

Heck et al. (2008) also examined the effect of agronomic practice and leaf drying conditions on the phenolic composition of dried maté leaves. They found that the concentration range of the phenolic constituents was as follows:

theobromine (1.5–7.6)[a]
caffeine (3.9–16.6)
rutin (2.6–11.5)
neochlorogenic acid (6.9–33.0)
chlorogenic acid (6.6–24.9)
cryptogenic acid (4.6–41.3)

[a] mg/leaf dry wt

In addition, 3,4-dicaffeoylquinic acid, 3,5-dicaffeoylquinic acid, 4,5-dicaffeoylquinic acid and luteolin diglycoside were found as dry leaf components.

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Litsea cubeba Oil

Williams (2008) reported that a commercial sample of *Litsea cubeba* oil possessed the following composition:

α-pinene (1.1%)
camphene (0.3%)
6-methyl-5-hepten-2-one (1.2%)
sabinene (0.9%)
6-methyl-5-hepten-2-ol + β-pinene (0.9%)
myrcene (1.2%)
limonene (12.5%)
1,8-cineole (1.3%)
linalool (1.2%)
citronellal (1.0%)
citronellol (0.1%)
nerol (0.4%)
α-terpineol (0.4%)
neral (30.3%)
geraniol (0.9%)
geranial (39.0%)
β-caryophyllene (1.0%)

Trace amounts of α-phellandrene, γ-terpinene, terpinolene, borneol, terpinen-4-ol, piperitone and α-humulene were also characterized in this oil.

Although *L. cubeba* is normally associated with China, Choudhury et al. (2009) reported that this evergreen shrub of the Lauraceae family can also be found growing in its natural environment in the eastern Himalayan areas of Assam, Manipur and other autonomous regions of northeastern India. The authors collected 144 samples of leaves and fruit (300–500 g each) from the Indian states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram and Nagaland. Hydrodistillation of each of the samples revealed that the leaf oil yield ranged from 0.01–3.00% with samples from Tuli (Nagaland, 125 m asl) and Zoram and Potin (Aranchal Pradesh, 1,660 m and 1,160 m) containing 3.0%, 2.1% and 2.0%, respectively. Fruit oils were also found to vary in yields from 0.01–4.01% with Arunchal Pradesh samples from Potin (1,660 m), Ziro (1,580 m), Umiam (1,000 m) and Borapani (1,000 m) possessing 3.5–4.0%, 3.9%, 3.3% and 3.1%, respectively. Furthermore, the authors found that the fruit oil yield varied irrespective of the collection altitude. Analysis of the fruit oils for their major components revealed that there were four chemotypes characterized, e.g.:

- Chemotype 1. Oils rich in neral and geranial (citral) which ranged from 36.0–40.8% and 44.1–48.8%, respectively.
- Chemotype 2. Oils rich in linalool (62.0%).
- Chemotype 3. Oils rich in sabinene (61.3–62.1%).
- Chemotype 4. Oils rich in citronellal (75.3–83.1%).

The authors concluded that altitude appeared to have an influencing effect on the fruit oil composition. They found that oils rich in neral + geranial and sabinene were found at altitudes around 1,660 m, while linalool-rich oils were found at 125 m, and citronellal-rich oils at 1,000 m.

An ethanolic extract of *L. cubeba* fruits was analyzed by Hu et al. (2011). Using

GC-FID and GC/MS as their method of analysis, the authors found that the extract possessed the following constituents:

α-pinene (0.6%)
camphene (0.5%)
β-pinene (0.2%)
6-methyl-5-hepten-2-one (t)
1,8-cineole (t)
limonene (8.5%)
γ-terpinene (0.6%)
linalool (1.4%)
cis-limonene oxide (0.9%)
sabinene hydrate[*] (1.0%)
trans-p-menth-2-en-1-ol (0.7%)
citronellal (0.9%)
borneol (0.2%)
terpinen-4-ol (0.3%)
α-terpineol (0.6%)
citronellol (0.5%)
neral (26.2%)
nerol (1.0%)
geranial (33.2%)
bornyl acetate (4.0%)
eugenol (1.2%)
β-caryophyllene (3.5%)
ethyl myristate (1.9%)
palmitic acid (1.2%)
ethyl palmitate (2.3%)
methyl oleate (0.6%)
ethyl linoleate (1.3%)
ethyl oleate (1.7%)

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[*] correct isomer not identified
t = trace (<0.1%)

Analysis of an oil produced in the laboratory from dried fruits of *L. cubeba* from Jiangxi Province (China) by Wang et al. (2012) using GC-FID and GC/MS was found to contain:

α-thujene (0.2%)
α-pinene (3.8%)
camphene (0.8%)
β-phellandrene[a] (4.5%)
β-pinene (6.2%)
dehydro-1,8-cineole (0.1%)
α-phellandrene (0.1%)
limonene (26.3%)
1,8-cineole (1.6%)
γ-terpinene (0.1%)
cis-β-terpineol[*] (0.1%)
terpinolene (0.1%)
linalool (1.4%)
cis-limonene oxide (0.1%)
trans-limonene oxide (0.2%)
citronellal (0.5%)
cis-verbenol (0.5%)
trans-verbenol (1.0%)
terpinen-4-ol (0.5%)
α-terpineol (0.5%)
cis-carveol (0.1%)
nerol (0.5%)
neral (21.9%)
geraniol (0.6%)
geranial (26.0%)
α-terpinyl acetate (0.1%)
α-copaene (0.1%)
β-elemene (0.1%)
β-farnesene[**] (0.1%)
β-caryophyllene (0.8%)
caryophyllene oxide (0.2%)
farnesol[**] (0.1%)
ethyl geranate[*]

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[a] should be sabinene
[*] incorrect identification based on GC elution order
[**] correct isomer not identified

Trace amounts (<0.05%) of neryl acetate, α-selinene and a cadinene isomer were also found in this oil.

D.G. Williams, *The chemistry of essential oils.* 2nd edn., pp. 196–197, Micelle Press, Port Washington, NY (2008).

S.N. Choudhury, D.K. Deka, A.K.S. Baruah, P.G. Rao, M.F. Duke and A. Riggins, *Constituents of essential oil of* Litsea cubeba *from north Indian germplasm.* Indian Perfum., **53**, 38–43 (2009).

L.S. Hu, H.-D. Wang, M.-H. Du and J.-P. Zhang, *Characterization of the volatiles and active components in ethanol extracts of fruits of* Litsea cubeba *(Lour.) by gas chromatography-mass spectrometry (GC-MS) and gas chromatography-olfactometry (GC-O).* J. Med. Plants Res., **5**, 3298–3303 (2011).

Y. Wang, Z.-T. Jiang and R. Li, *Antioxidant activity, free radical scavenging potential and chemical composition of* L. cubeba *essential oil.* J. Essent. Oil Bear. Plants, **15**, 134–143 (2012).

Cumin Oil

A lab-distilled cumin seed oil (*Cuminum cyminum*) was screened for its antibacterial activity against microbes known to cause plant and cultivated mushroom diseases by Iacobellis et al. (2005). Using GC-FID and GC/MS as their method of analysis, this lab-distilled oil was found to contain the following constituents:

tricyclene (0.1%)
α-pinene (0.6%)
sabinene (0.5%)
β-pinene (11.4%)
myrcene (0.9%)
α-phellandrene (1.3%)
o-cymene (3.1%)
p-cymene (5.7%)
limonene (3.1%)
β-phellandrene (2.2%)
γ-terpinene (12.8%)
cuminaldehyde (16.1%)
cumin alcohol (0.4%)
p-mentha-1,3-dien-7-al (8.7%)
p-mentha-1,4-dien-7-al (27.4%)
perillaldehyde (0.6%)
perillyl alcohol (0.3%)
eugenol (0.7%)
geranyl acetate (1.7%)
β-caryophyllene (1.3%)

Kan et al. (2007) used a combination of GC-FID and GC/MS to examine the composition of oils, produced by hydrodistillation from cumin seed (fruit) harvested at different maturity stages from plants grown on an experimental farm in the Konya region of Turkey. The results of this comparative study can be seen in **T-2**. As can be seen, the oils were quite similar except that the ripe seeds were richest in oil and total aldehydes.

The effect of row distance on the fruit (seed) and oil yield of cumin grown in Turkey was the subject of study by Kizil et al. (2008). Using a sowing rate of 25 kg/ha, five row distances (20, 30, 40, 50 and 60 cm) and a randomized block design, the row distances were examined for plant height, number of branches, number of umbels, number of seeds per umbel, seed yield per plant, weight of a thousand seeds, seed yield, essential oil content and oil composition over a two-year period. Oil analyses were performed using GC/MS only. The components found in amounts >0.1% in the seed oils that were obtained from the most productive plants from the 20 and 30 cm row distances were as follows:

α-thujene (0.4%)
α-pinene (0.9%)
sabinene (0.1–0.2%)
β-pinene (12.2–12.4%)
myrcene (1.0%)
α-phellandrene (1.6–1.9%)
α-terpinene (0.1–0.2%)
p-cymene (6.8–10.1%)
β-phellandrene (1.0–1.1%)
γ-terpinene (13.7–16.5%)
linalool (<0.1–0.8%)
terpinen-4-ol (0.3–0.4%)
α-terpineol (0.1%)
pulegone (0.7–0.9%)
cuminaldehyde (18.9–23.3%)
p-mentha-1,3-dien-7-al (6.7–7.8%)
p-mentha-1,4-dien-7-al (16.5–27.0%)
carvacrol (0.1%)
p-mentha-1,4-dien-7-ol (0.3–0.4%)
β-gurjunene (0.4%)
β-caryophyllene (0.3–0.5%)
cuminic acid (<0.1–0.4%)
α-bergamotene[*] (0.1%)
β-farnesene[*] (0.5–0.6%)
γ-cadinene (0.2–0.3%)
α-cedrene (0.3–0.4%)
germacrene A (0.1–0.2%)

β-bisabolene (0.1%)
caryophyllene oxide (0.1–0.2%)
carotol (0.8–0.9%)

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[*] correct isomer not identified

Lesser amounts (<0.1%) such as camphene, δ-3-carene, p-menth-1-ene, 1,8-cineole, terpinolene, α-fenchyl alcohol, terpinen-1-ol, *trans*-pinocarveol, pinocarvone, pinocamphone, furfuraldehyde, *cis*-sabinol, *cis*-piperitol, p-menth-1-en-7-al, 2-acetylcyclopentanone, a dimethylphenol isomer, germacrene D, α-humulene, zingiberene, β-sesquiphellandrene, α-chamigrene, a γ-bisabolene isomer, a nerolidol isomer, α-caryophyllene alcohol, α-eudesmol and α-cedrol were also listed as constituents of the oils. Finally, the essential oil yield ranged from 2.8–3.2% for the 20 and 30 cm row distances and slightly lower for the other row distances.

T-2. Comparative percentage composition of cumin seed oil produced from seeds of different maturity

Compound	Unripe seed oil	Ripe seed oil	Overripe seed oil
α-pinene	0.4	0.3	0.4
α-thujene	0.2	0.1	0.2
β-pinene	8.7	7.4	9.0
sabinene	0.4	0.3	0.1
α-phellandrene	8.5	4.1	5.4
α-terpinene	0.1	0.1	0.2
limonene	1.0	0.8	1.0
1,8-cineole	0.1	0.1	0.1
β-phellandrene	1.2	0.8	1.0
γ-terpinene	10.3	11.5	13.6
p-cymene	7.7	9.6	11.6
terpinolene	0.1	0.1	0.2
daucene	0.5	0.7	0.6
2-acetylfuran	0.1	0.1	0.2
trans-p-menth-2-en-1-ol	0.1	0.1	t
cis-isopulegone	0.4	0.3	0.3
bornyl acetate	0.1	0.1	0.1
trans--beragamotene	0.1	0.2	0.2
terpinen-4-ol	0.1	0.1	0.2
β-caryophyllene	0.3	0.4	0.4
cis-p-menth-2-en-1-ol	0.1	0.1	t
myrtanal	0.1	0.1	0.1
(Z)-β-farnesene	0.7	0.8	0.8
trans-p-pinocarveol	0.1	0.1	0.1
α-terpineol	0.1	t	0.5
β-acoradiene	0.8	0.7	0.3
valencene	0.2	0.2	0.1
β-bisabolene	0.2	0.2	0.2
phellandral	0.1	0.1	0.1
cuminaldehyde	19.9	23.6	20.4
p-mentha-1,3-dien-7-al	14.1	17.5	11.4
p-mentha-1,4-dien-7-al	16.9	13.9	16.0
caryophyllene oxide	0.1	0.2	0.1
carotol	1.5	1.4	1.2
(E)-nerolidol	0.1	0.1	t
p-mentha-1,4-dien-7-ol	0.5	0.4	0.4
cumin alcohol	0.2	0.2	0.3
spathulenol	0.5	t	0.1
β-eudesmol	0.1	0.1	0.1
hexadecanoinc acid	0.1	0.1	0.1
oil yield (%)	**1.9**	**2.4**	**2.3**

t = trace (<0.1%)

Hashemi et al. (2008) showed that for studies such as the effect of fertilization treatments on essential oil composition they believed that SPME-GC/MS was a fast and accurate way to determine compositional differences in the oil or crushed seed headspace. However, they were not able to unequivocally show that nitrogen fertilization had an effect on oil composition and yield.

Sowbhagya et al. (2008) determined that to obtain the highest yield of oil from cumin seed, the authors recommended that the seed be flaked rather than ground in a hammer mill or some other size reducing processes. Oil yields of 2.8% and 3.3% were obtained from powdered and flaked seed, respectively. There were minimal differences in the amount of cuminaldehyde and p-mentha-1,4-dien-7-al found in each oil. Analysis of the distillation water revealed that it possessed 0.2% oil. Unfortunately, the authors did not report on the composition of this distillate oil (hydrosol).

Hashemi et al. (2009) that an ultrasound assisted SPME method using a nanoporous SBA-15 fiber functionalized with 3-[bis(2-hydroxyethyl)aminopropyltrimethoxysilane] was a more efficient fiber for cumin oil headspace analysis that a polydimethylsiloxane (PDMS) fiber.

Wang et al. (2009) used a similar ultrasonic extraction system in conjunction with a single drop of solvent (heptadecane containing 0.01% dodecane as an internal standard) coupled to GC/MS to analyze the headspace of cumin oil. The process is known as UNE-HS-SDME (ultrasonic nebulization extraction headspace single drop micro-extraction). A comparison between the analytical results of a hydrodistilled oil versus a UNE-HS-SDME can be seen in **T-3**. Although the authors claim that this is an improved method to obtain headspace volatiles, it seems to be a bit of overkill from this reviewer's point of view as SPME is very easy from which comparable results can be readily obtained.

Cumin seed oil produced by hydrodistillation of seeds cultivated in central Sudan that were purchased at a local market in Omduran (Sudan). Analysis of this oil by GC/MS only by El-Kamali et al. (2009) revealed that the oil contained cuminaldehyde (32.7%). As many of the other constituents were misidentified, this data will not be presented, but was included for review completeness.

Romagnoli et al. (2010)reported that they used GC-FID and GC/MS to analyze an oil of cumin seed (fruit) of Indian origin. However, according to a description of their methid, they actually analyzed a soxhlet, methanolic extract of the ground cumin seeds. As a result, the methanolic extract was determined to contain the following:

α-pinene (0.2%)
β-pinene (3.5%)
p-cymene (4.4%)
1,8-cineole (0.6%)
γ-terpinene (0.8%)
α-fenchyl alcohol (0.3%)
borneol (0.2%)
terpinen-4-ol (0.2%)
p-cymen-8-ol (0.3%)
α-terpineol (1.6%)
p-cymenol[**] (1.0%)
cuminaldehyde (61.7%)
p-mentha-1,3-dien-7-al (7.3%)
p-mentha-1,4-dien-7-al (12.3%)
cumin alcohol (0.5%)
thymol (0.2%)
carvacrol (0.4%)
4-hydroxy-cryptone[*] (1.0%)
β-farnesene[**] (0.2%)
caryophyllene oxide (0.3%)
carotol (0.2%)
dillapiole (0.7%)
apiole (0.5%)
hexadecanol (0.3%)
eicosene[**] (0.3%)

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[*] incorrect identification
[**] correct isomer not identified

Bankar et al. (2011) compared the oil composition of cumin seed (fruit) obtained from local markets in Delhi and Karpur using GC-FID and GC/MS. The composition of the two lab-distilled oils (3.7–3.9% yield) can be seen in **T-4**.

Finally, Owlia et al. (2010) screened a number of essential oils against *Pseudomonas aeruginosa.* A lab distilled oil of the whole plants of *C. cyminum* grown in an experimental garden of the Research Institute of Forests and Rangelands (Tehran, Iran) was analyzed by GC-FID and GC/MS. The whole plant oil composition, which is dissimilar to the seed oil, was determined to possess the following composition:

isobutyl isobutyrate (0.8%)
α-thujene (0.3%)
α-pinene (29.1%)
sabinene (0.6%)
myrcene (0.2%)
δ-3-carene (0.2%)
limonene (21.5%)
1,8-cineole (17.9%)
(E)-β-ocimene (0.1%)
γ-terpinene (0.6%)
terpinolene (0.3%)
linalool (10.4%)
terpinen-4-ol (0.5%)
α-terpineol (3.2%)
trans-carveol (0.4%)
cis-carveol (0.1%)
geraniol (1.1%)
linalyl acetate (4.8%)
methyl geranate (0.2%)
α-terpinyl acetate (1.3%)
methyl eugenol (1.6%)
β-caryophyllene (0.2%)
α-humulene (0.2%)
spathulenol (0.1%)
caryophyllene oxide (0.1%)
acetocyclohexane-2-dione[*]

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[*] incorrect identification

In addition, trace amounts (<0.1%) of α-campholenal, *trans*-pinocarveol, δ-terpineol, neryl acetate and humulene epoxide II were also found in this cumin whole plant oil.

N.S. Iacobellis, P. Lo Cantore, F. Capasso and F. Senatore, *Antibacterial activity of* Cuminum cyminum *L. and* Carum carvi *L. essential oils.* J. Agric. Food Chem., **53**, 57–61 (2005).

Y. Kan, M. Kartal, T Ozek, S. Aslan and K.H.C. Baser, *Composition of essential oil* Cuminum cyminum *L. according to harvesting times.* Turkish J. Pharm. Sci., **4**(1), 25–29 (2007).

S. Kizil, S. Kirici and O. Sönmez, *Effect of different row distances on some agronomical characteristics and essential oil composition of cumin* (Cuminum cyminum *L.).* Die Bodenkultur, **59**, 77–83 (2008).

H.B. Sowbhagya, B.V. Sathyendra Rao and N. Krishanamurthy, *Evaluation of size reduction and expansion on yield and quality of cumin* (Cuminum cyminum) *seed oil.* J. Food Engineer., **84**, 595–600 (2008).

T-3. Comparative percentage composition of a hydrodistilled oil and the headspace volatiles of cumin seed by UNE-HS-SDME

Compound	Hydrodistilled oil	Headspace
	0.6	0.4
α-pinene	1.3	1.3
camphene	t	t
sabinene	2.0	2.0
β-pinene	11.1	18.9
myrcene	1.8	1.7
α-phellandrene	0.3	0.2
δ-3-carene[*]	0.2	0.1
δ-4-carene[*a]	0.3	0.1
α-terpinene	7.1	10.4
limonene	1.5	1.3
1,8-cineole	0.5	0.4
(Z)-β-ocimene	t	t
p-cymene	14.3	22.1
terpinolene	0.2	0.1
cis-β-terpineol[*]	0.4	0.2
trans-pinocarveol	0.2	t
terpinen-1-ol[*]	0.5	t
α-terpineol	0.2	t
pulegone[*]	1.6	0.4
nopol[*]	0.2	-
cuminaldehyde	22.8	16.3
trans-p-menth-2-en-7-ol[*]	0.2	t
phellandral	0.2	t
2-caren-10-al[c]	8.6	1.0
cumin alcohol	21.9	22.3
4-(1-methylethyl)-benzene methanol[b]	0.2	0.1
p-mentha-1,4-dien-7-ol	0.8	-

t = trace (<0.05%)
[*] incorrect identification based on GC elution order

[a] δ-4-carene = δ-2-carene
[b] 4-(1-methylethyl)-benzenemethanol = cumin alcohol
[c] *trans*-p-mentha-1,4-dien-7-al

P. Hashemi, A. Yarahmadi, K. Azizi and B. Sabouri, *Study on the effects of N. fertilization and plant density on the essential oil composition and yield of* Cuminum cyminum *L. seeds by HS-SME.* Chromatographia, **67**, 253–257 (2008).

P. Hashemi, M. Shamizadeh, A. Badiei, A. Rezi Ghiasvand and K. Azizi, *Study of the essential oil composition of cumin seeds by an amino ethyl functionalized nanoporous SPME fiber.* Chromatographia, **70**, 1147–1151 (2009).

H.H. El-Kamali, S.I.Y. Adam, A.S. Adam, F.M. Abbakar and I.I. Babikir, *Aromatic plants from Sudan: Part I. Chemical composition and antibacterial activity of* Cuminum cyminuma *L. essential oil.* Adv. Nat. Appl. Sci., 1–4 (2009).

L. Wang, Z.-M. Wang, H.-H. Zhang, X.-Y. Li and H.-Q. Zhang, *Ultrasonic nebulization extraction coupled with headspace single drop microextraction and gas chromatography-mass spectrometry for analysis of the essential oil in* Cuminum cyminum *L.* Anal. Chim. Acta, **647**, 72–77 (2009).

P. Owlia, L. Moein Najafabodi, S. Mousavi Nadoshan, I. Bazoli and H. Saderi, *Effects of sub-minimal inhibitory concentrations of some essential oils on virulence factors of* Pseudomonas aeruginosa. J. Essent. Oil Bear. Plants, **13**, 465–476 (2010).

C. Romagnoli, E. Adreotti, S. Maietti, R. Mahendra and D. Mares, *Antifungal activity of essential oil from fruits of Indian* Cuminum cyminum. Pharaceut. Biol., **48**, 834–838 (2010).

R. Bankar, A. Kumar and S. Puri, *Comparative studies of the major components present in the essential oil of Indian cumin (*Cuminum cyminum *L.) from different origin.* Indian Perfum., **55**, 38–39 (2011).

Coriander Seed Oil

Lawrence (1979) examined the composition of a lab-distilled oil of coriander seed (fruit) obtained from a commercial source in the former U.S.S.R. The components characterized in this oil were:

heptanal (0.2%)
α-pinene (3.4%)
β-pinene (0.3%)
myrcene (0.1%)
octanal (0.2%)
p-cymene (0.4%)
limonene (0.1%
γ-terpinene (0.3%)
octanol (0.2%0
linalool (84.0%)
α-terpineol (0.1%)
decanal (0.5%)
geraniol (0.8%)
(E)-2-decenal (0.3%)
(E)-2-decenol (0.1%)
decanol (0.1%)
(E)-anethole (3.5%)
geranyl acetate (2.5%)
dodecanal (0.1%)
β-caryophyllene (0.1%)
(E)-nerolidol (0.2%)

In a follow-up study, Lawrence (1980) examined 16 different commercial samples of coriander oil. The main constituents characterized in these oils were:

α-pinene (1.5–9.0%)
camphene (0.2–1.3%)
β-pinene (0.2–0.9%)
sabinene (0.1–0.5%)
myrcene (0.2–1.4%)
α-terpinene (t–0.1%)
limonene (1.3–4.9%)
β-phellandrene + 1,8-cineole (t–0.2%)
(E)-β-ocimene (t–0.2%)
γ-terpinene (3.1–9.3%)
p-cymene (0.8–3.2%)
terpinolene (0.1–0.6%)
cis-linalool oxide[f] (t–0.3%)
trans-linalool oxide[f] (t–0.4%)
decanal (t–0.2%)
camphor (3.6–5.6%)
linalool (65.9–76.0%)
β-caryophyllene (t–1.5%)
terpinen-4-ol (t–0.7%)
α-humulene (t–0.3%)
α-terpineol (t–2.6%)
borneol (t–0.4%)
geranyl acetate (0.6–2.8%)
nerol (t–0.4%)
geraniol (0.1–2.3%)
(E)-nerolidol (t–0.3%)

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[f] furanoid form
t = trace (<0.05%)

Viable coriander seeds were obtained from 100 different seed sources (mainly from Botanic Garden collections) mostly of European origin. Each of the accessions were grown in an experimental garden in eastern North Carolina. Ripe seeds (ca 100 g) were harvested from each accession and subjected to steam distillation (Lawrence 1980). The oil contents were found to range from 0.1–1.5%; the highest oil yielding accessions originating from the former Soviet Block countries, mainly via East Germany, Hungary, Lithuania and Latvia. Analysis of the 100 oils revealed that the main components ranged as follows:

α-pinene (0.1–6.7%)
camphene (t–0.9%)
β-pinene (t–0.6%)
sabinene (t–0.5%)
myrcene (0.1–1.0%)
α-terpinene (t–0.1%)
α-phellandrene (0–0.3%)
limonene (0.1–2.4%)
β-phellandrene + 1,8-cineole (0–0.2%)
(E)-β-ocimene (0–t)
γ-terpinene (0.1–10.7%)
p-cymene (t–2.7%)
terpinolene (t–0.6%)
nonanal (0–0.1%)
cis-linalool oxide[f] (t–0.3%)
trans-linalool oxide[f] (t–0.3%)
decanal (t–1.2%)

T-4. Comparative percentage composition of the oils of cumin seed from Delhi and Kapar

Compound	Delhi seed oil	Kapar seed oil
α-pinene	0.8	0.9
sabinene	0.4	0.2
β-pinene	12.9	13.1
myrcene	1.0	0.7
β-phellandrene[*]	0.3	0.3
limonene	0.7	0.3
γ-terpinene	26.3	26.3
p-cymene	17.9	21.8
phellandral	1.0	0.4
terpinen-4-ol	0.4	0.1
α-terpineol	0.6	0.2
cumin alcohol	0.6	0.3
carvone	0.1	0.3
cis-pinocarveol[*]	0.1	0.1
cuminaldehyde	18.0	25.1
2-caren-10-al[a]	16.3	7.2
p-mentha-1,4-dien-7-al	0.4	0.1
apiole	0.6	0.4

[a] should be p-mentha-1,3-dien-7-al
[*] incorrect identification based on GC elution order

camphor (0.5–5.2%)
linalool (62.8–90.0%)
β-caryophyllene (t–0.5%)
terpinen-4-ol (t–0.4%)
undecanal (0–0.2%)
α-humulene (t–0.3%)
α-terpineol (t–3.7%)
borneol (t–0.2%)
dodecanal (0–0.1%)
geranyl acetate (0.2–4.3%)
nerol (t–0.2%)
geraniol (1.1–5.7%)
(E)-nerolidol (t–0.4%)

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[f] furanoid form
t = trace (<0.05%)

Msaada et al. (2007) compared the composition of coriander fruit (seed) harvested at three different maturity stages from plants grown in the region of Mezel Temine (northwestern Tunisia). Using a combination of GC-FID and GC/MS, the oil compositions can be seen summarized in **T-5.** Trace amounts (<0.05%) of heptanal, α-thujene, α-pinene, sabinene, α-terpinene, p-cymene, limonene, γ-terpinene, terpinen-4-ol, (Z)-3-hexenyl butyrate, geraniol and neryl acetate were also found in this oil.

T-5. Comparative percentage composition of coriander fruit (seed) oils from three different maturity stages

Compound	**1**	**2**	**3**
β-pinene	t	0.2	0.1
δ-3-carene	0.1	0.1	t
1,8-cineole	0.2	0.1	0.2
(Z)-β-ocimene	0.1	t	t
cis-linalool oxide[f]	0.3	0.3	0.3
terpinolene	t	0.2	0.2
linalool	11.0	76.3	87.5
trans-linalool oxide[f]	0.3	t	t
camphor	0.9	0.1	0.2
borneol	0.1	0.3	0.3
menthol[*]	0.1	0.2	0.1
p-cymen-8-ol	1.4	t	t
α-terpineol	0.4	t	0.1
cis-dihydrocarvone[*]	t	3.2	2.4
nerol	1.5	t	t
citronellol	0.1	t	0.5
neral[*]	1.4	0.1	0.1
carvone	0.1	0.1	0.1
geranial[*]	0.7	t	t
(E)-anethole	0.1	1.4	t
thymol	t	1.0	1.9
carvacrol	1.0	0.1	0.5
δ-elemene	t	0.1	t
eugenol[*]	0.1	t	t
geranyl acetate	46.3	2.9	0.8
β-caryophyllene	t	0.1	t
α-humulene	0.1	t	t
germacrene D	t	0.2	0.1
eugenyl acetate	t	t	0.1

1 = immature fruit (green)
2 = intermediate mature fruit (green-brown)
3 = fully mature fruit (brown)
t = trace (<0.05%)
[f] furanoid form
[*] questionable identity

Lopez et al. (2008) screened fruit (seed) oils from 60 accessions of coriander using GC-FID and GC/MS. The oils were found to range in composition as follows:

α-thujene (0–0.2%)
α-pinene (2.0–9.1%)
camphene (t–0.8%)
hexanal (0–t)
β-pinene (0.3–1.1%)
sabinene (t–0.3%)
myrcene (0–0.2%)
α-phellandrene (0.1–0.7%)
heptanal (t–0.2%)
limonene (t–1.6%)
1,8-cineole (0–1.0%)
γ-terpinene (0.2–3.8%)
terpinolene (0.3–5.9%)
octanal (0–0.3%)
nonanal (t–0.4%)
1-octen-3-ol (t–0.5%)
linalool oxide[°f] (0.2–2.8%)
decanal (0–0.1%)
camphor (0.1–5.7%)
linalool (49.3–83.2%)
octanol (0.1–0.4%)
myrtenal (0.1–0.7%)
(E)-2-decenal (0.1–0.4%)
β-terpineol[°] (0.2–5.9%)
α-humulene (0–0.2%)
neral (0–0.2%)
borneol (t–0.2%)
α-terpinyl acetate (0–0.2%)
neryl acetate (t–0.1%)
geranial (0.1–0.2%)
geranyl acetate (1.0–8.6%)
myrtenol (t–0.2%)
nerol (0–1.5%)
citronellol (0.6–3.6%)
geraniol (0.1–7.4%)

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t = trace (<0.05%)
[f] furanoid form
[°] correct isomer not identified

The composition of a bulked oil of coriander seed (fruit) produced by hydrodistillation in the laboratory from land races cultivated in Iran was reported by Nadjafi et al. (2009). The constituents characterized in this oil by GC-FID and GC/MS were:

α-thujene (0.1%)
α-pinene (5.9%)
sabinene (0.2%)
β-pinene (0.5%)
myrcene (0.4%)
p-cymene (1.2%)
limonene (0.2%)
γ-terpinene (7.6%)
linalool (77.6%)
camphor (0.1%)
citronellal (0.2%)
borneol (0.1%)
terpinen-4-ol (0.1%)
decanal (0.3%)
nerol (0.2%)
(E)-2-decenal (0.2%)
undecanal (0.5%)
neryl acetate (2.6%)
dodecanal (0.1%)
(E)-2-dodecenal (0.6%)
(Z)-2-dodecenal (0.1%)
tetrahydro-ionol[°] (0.1%)

[°] does not occur naturally

T-6. Comparative percentage composition of the oil and supercritical fluid CO_2 extract (SFE) of coriander seed (fruit)

Compound	Oil	SFE
α-pinene	2.5	1.5
camphene	0.3	0.2
sabinene	0.1	0.1
β-pinene	0.4	0.2
myrcene	2.8	1.0
p-cymene	1.3	0.8
limonene	3.1	1.4
(E)-β-ocimene	1.7	0.4
γ-terpinene	6.8	5.0
trans-sabinene hydrate	t	0.1
terpinolene	0.9	0.5
linalool	67.6	75.9
camphor	3.0	3.1
citronellal	0.1	0.1
borneol	0.1	0.1
terpinen-4-ol	0.2	0.2
α-terpineol	0.4	0.1
geraniol	2.7	2.9
geranyl acetate	2.8	3.5

t = trace (<0.05%)

T-7. The percentage composition of coriander oils produced from Canadian and Tunisian seed (fruit)

Compound	Canadian seed oil	Tunisian seed oil
tricyclene	0.1	0.1
heptanal	0.6	0.3
α-pinene	4.5	3.4
α-thujene	0.5	0.3
camphene	0.5	0.3
sabinene	0.1	0.1
myrcene	1.3	0.6
α-terpinene	0.1	0.1
limonene	2.6	1.4
γ-terpinene	8.9	8.4
p-cymene	2.1	1.4
trans-linalool oxide[f]	0.6	0.2
camphor	6.4	2.9
linalool	57.0	71.6
linalyl acetate	7.1	1.9
terpinen-4-ol	0.5	0.3
menthol	t	0.1
neral	0.2	-
α-terpineol	0.1	0.4
borneol	0.1	0.6
geranial	0.1	0.1
carvone	0.1	0.1
geranyl acetate	2.0	1.8
citronellol	0.2	0.1
nerol	0.1	-
(E)-anethole	0.1	0.1
geraniol	0.1	0.1
p-cymen-8-ol	0.6	0.3

t = trace (<0.05%)
[f] furanoid form
[*] questionable identity

The chemical composition (GC-FID and GC/MS) of a lab-distilled oil of coriander seed (fruit) was compared with a supercritical fluid CO_2 extraction (SFE) of the same batch of coriander seed obtained commercially in Italy by Grosso et al. (2010). The results of the analyses, which were performed by GC-FID and GC/MS, can be seen summarized in **T-6**. The conditions used for production of the SFE were: coriander particle size = 0.6 mm, pressure = 90 bar, temperature = 40°C, CO_2 flow rate = 1.1 kg/hr and amount of CO_2 consumed = 4.4 kg. In addition to the components listed in **T-6**, trace amounts (<0.05%) of α-thujene (Z)-β-ocimene, *cis*-linalool oxide (furanoid form), octanol and citronellol were also characterized in both the oil and SFE.

Sriti et al. (2011) compared the composition of lab-distilled oils of 300 g of fresh coriander seeds (fruit) of Canadian and Tunisian origin. The compositions of the oils of the Canadian coriander (0.44% yield) and Tunisian coriander (0.37% yield) are presented in **T-7**. Trace amounts of β-pinene, decanal, β-caryophyllene, *cis*-dihydrocarvone, neryl acetate, thymol and carvacrol were also characterized in these oils.

Coriander seeds (fruit that were collected from retail pharmacies in different European countries (11 samples), a spice shop in Turkey (one sample) and cultivated in Estonia (five samples) were subjected to oil isolation in the laboratory by hydrodistillation by Orave et al. (2011). The oil contents varied from 3–52 m2/kg with the 'Thuringer' cultivar being the far the richest in essential oil. The range in oil composition as determined by GC-FID was as follows:

α-pinene (0–10.9%)
camphene (0–1.3%)
sabinene (0–0.9%)
β-pinene (0–0.9%)
myrcene (t–1.2%)
p-cymene (0.1–8.1%)
limonene (0.1–3.2%)
γ-terpinene (0.3–11.2%)
linalool (58.0–80.3%)
camphor (1.2–5.3%)
terpinen-4-ol (0.1–1.2%)
α-terpineol (0.2–0.8%)
carvone (0–1.6%)
geraniol (0–3.6%)
linalyl acetate (0–1.1%)
geranial (0–1.3%)

geranyl acetate (0.2–5.4%)
α-humulene (0–1.3%)

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t = trace (<0.05%)

Hadian et al. (2012) obtained fruit from 26 different Iranian land races of coriander that were produced at the Research Institute of Shahidi Behesti University (Evin, Tehran, Iran). Oils produced from each land race were produced by hydrodistillation in the laboratory and were analyzed by GC-FID and GC/MS. The oils, which varied in yield from 0.4–1.6% were found to possess the following range in composition:

nonane (0–0.1%)
α-pinene (0–7.8%)
camphene (0–0.1%)
sabinene (0–0.3%)
β-pinene (0–0.6%)
myrcene (0–0.2%)
p-cymene (0–1.5%)
limonene (0–0.3%)
γ-terpinene (0.1–13.2%)
linalool (69.7–88.1%)
camphor (0–0.3%)
citronellal (0–0.4%)
terpinen-4-ol (0–0.1%)
decanal (0–1.6%)
nerol (0–0.7%)
(E)-2-decenal (0–0.4%)
undecanal (0–0.2%)
myrtenyl acetate (0–0.1%)
citronellyl acetate (0–0.1%)
neryl acetate I1.3–9.1%)
dodecanal (0–0.4%)
β-caryophyllene (0–0.1%)
(E)-2-dodecenal (0–10.6%)
pentadecane (0–0.4%)
hexadecane (0–2.4%)
heptadecane (0–0.4%)
octadecane (0–0.8%)
hexahydrofarnesyl acetone (0–0.8%)\
nonadecane (0–0.9%)
eicosane (0–1.5%)
heneicosane (0–0.2%)
docosane (0–1.6%)
tetracosane (0–0.6%)

A sample of coriander seed oil produced in the United States was screened for its activity against the cotton leaf worm (Pavela, 2012). Analysis of this oil by GC/MS and GC-FID revealed that it possessed the following major components:

α-pinene (4.2%)
β-pinene (2.5%)
p-cymene (2.7%)
limonene (5.6%)
linalool (69.3%)
camphor (3.5%)
α-terpineol (3.2%)
geraniol (3.8%)
geranyl acetate (3.8%)

B.M. Lawrence, Unpublished data (1979).

B.M. Lawrence, unpublished data (1980).

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