Progress in Essential Oils

Brian M. Lawrence, Consultant

Nigella sativa Oil

Although black cumin (*Nigella sativa* L.) is used across numerous countries as a condiment, small quantities of oil are also produced for commercial sale.

El-Alfy et al. (1975) found that a crystalline substance precipitated when an Egyptian oil of *N. sativa* was subjected to refrigeration. Using a combination of spectroscopic techniques, the structure of the compound was elucidated and found to be thymohydroquinone.

Aboutabl et al. (1986) determined that a lab-distilled oil of *N. sativa* contained the following components:

α-pinene (9.3%)
camphene (0.1%)
hexanal (0.1%)
β-pinene (2.2%)
sabinene (0.8%)
myrcene (0.1%)
α-terpinene (0.1%)
limonene (1.6%)
1,8-cineole (0.1%)
γ-terpinene (0.5%)
p-cymene (31.7%)
terpinolene (0.1%)
2-heptenal* (0.1%)
artemisia ketone (0.1%)
ethyl octanoate (0.1%)
trans-sabinene hydrate (0.1%)
longipinene* (0.2%)
camphor (0.1%)
linalool (0.1%)
longifolene + bornyl acetate (0.8%)
2-undecanone (0.1%)
terpinen-4-ol (0.6%)
carvone (0.2%)
thymoquinone (24.5%)
(E)-anethole (0.1%)
p-cymen-8-ol (0.1%)
ethyl tetradecanoate (0.2%)
carvacrol (1.1%)
methyl hexadecanoate (0.1%)
ethyl hexadecanoate (2.8%)
methyl oleate (0.1%)
ethyl octadecanoate (0.2%)
ethyl oleate (2.7%)
methyl linoleate (0.2%)
ethyl linoleate (9.4%)
ethyl linolenate (0.1%)
hexadecanoic acid (0.2%)
thymohydroquinone (0.6%)

*correct isomer not identified

The authors also characterized the following disulphides in this oil:

ethylpropyl disulphide (0.05%)
ethylbutyl disulphide (0.05%)
propylbutyl disulphide (0.13%)
dibutyl disulphide (0.08%)
dipropyl disulphide (0.01%)

In addition, trace amounts (< 0.1%) of β-phellandrene, β-thujone, ethyl nonanoate, *cis*-sabinene hydrate, ethyl decanoate, a 2-dodecenal isomer, p-mentha-1,8-dien-4-ol, carvotanacetone, borneol, 2-tridecanone, ethyl dodecanoate, p-anisaldehyde, 4-hydroxy-4-methyl-2-cyclohexenone, ethyl pentadecanoate, thymol, ethyl heptadecanoate and methyl octadecanoate were found in this same oil.

Bourrel et al. (1993) produced oils of *N. sativa* from two lots of seed purchased in France, the specific geographic origin of which was unknown. Analyses of these two oils resulted in the characterization of the following components:

α-thujene (10.2–17.0%)
α-pinene (2.8–3.7%)
sabinene (0.8–1.5%)
β-pinene (3.3–3.8%)
p-cymene (50.4–62.3%)
limonene (2.5–2.9%)
α-terpinene (0.4–1.1%)
sabinene hydrate* (0.1–0.6%)
linalool (0.2–0.8%)
camphor (0.1–0.2%)
terpinen-4-ol (1.3–2.1%)
carvone (0.2–0.4%)
thymoquinone (t–7.0%)
bornyl acetate (0.1–1.3%)
thymol (1.2–1.8%)
longifolene (0.5–1.0%)
β-longipinene (0–1.2%)
ethyl hexadecanoate (0–0.3%)
linoleic acid (0.2%)
oleic acid (0.1%)

*correct isomer not identified

Trace amounts of methyl tetradecanoate and tetradecanoic acid were also characterized in this oil.

Mozaffari et al. (2000) determined that water stress affected both the yield of oil and quantitative composition of its components. With the use of irrigation over 12 days, the oil produced was found to possess a low p-cymene content and a high thymoquinone content, shown as follows:

α-thujene (1.3%)
α-pinene (0.2%)
sabinene (0.2%)
β-pinene (0.4%)
p-cymene (14.7%)
limonene (0.7%)
γ-terpinene (0.2%)
thymoquinone (54.8%)
bornyl acetate (< 0.1%)
carvacrol (4.2%)
α-cubebene (3.0%)
longifolene (10.2%)

Other irrigation regimens yielded oils with the following ranges for p-cymene (24.8–38.0%) and thymoquinone (26.8–39.8%).

Benyoussef et al. (2001) determined that a steam-distilled oil of *N. sativa* of Algerian origin contained the following constituents:

α-thujene (14.6%)
α-pinene (3.2%)
sabinene (1.5%)
β-pinene (3.5%)
α-terpinene (0.2%)
p-cymene (46.4%)
1,8-cineole (0.2%)
limonene (2.2%)
linalool (1.1%)
camphor (0.2%)
terpinen-4-ol (0.7%)
thymol (0.1%)
carvacrol (2.3%)
alkanes (24.5%)

It was a surprise that the authors did not find any thymoquinone in the oil.

An oil of *N. sativa* was analyzed by D'Antuono et al. (2002) and found to contain the following constituents:

α-thujene (3.27%)
α-pinene (0.70%)
sabinene (0.53%)
β-pinene (1.12%)
myrcene (0.29%)
α-terpinene (0.64%)
o-cymene (3.26%)
p-cymene (33.75%)
limonene (1.13%)
γ-terpinene (2.40%)
trans-sabinene hydrate (1.05%)
thujyl alcohol (7.43%)
thymoquinone (3.80%)
myrtenol (2.44%)
thymol (26.78%)
β-elemene (5.47%)
longifolene (3.11%)
β-selinene (0.37%)
α-selinene (2.17%)
7-epi-α-selinene (0.28%)

El-Ghorab (2003) analyzed the composition of a supercritical fluid CO_2 extract of *N. sativa* seeds of Egyptian origin. The constituents characterized in this extract were as follows:

tricyclene (0.79%)
α-thujene (5.92%)
α-pinene (1.90%)
camphene (0.10%)
sabinene (1.72%)
β-pinene (2.00%)
p-cymene (10.64%)
m-cymene (7.28%)
γ-terpinene (0.59%)
trans-sabinene hydrate (4.04%)
linalool (0.23%)
camphor (6.26%)
pinocarvone (0.25%)
terpinen-4-ol (0.50%)
borneol (3.61%)
terpineol* (0.03%)
trans-dihydrocarvone (0.83%)
α-terpineol (4.49%)
isobornyl formate (0.08%)
(E)-tagetenone (0.22%)
thymoquinone (41.05%)
bornyl acetate (0.68%)
carvacrol (1.41%)
longipinene* (0.31%)
α-thujaplicin (0.13%)
isocaryophyllene† (1.89%)
thymohydroquinone (1.15%)
2-hydroxy-5-methoxyacetophenone (0.01%)
hexadecanoic acid (0.11%)
octadecanoic acid (0.07%)
methyl linoleate (0.03%)
linoleic acid (0.08%)

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

Comparative chemical composition (%) of two oils and an extract of *Nigella sativa* **T-1**

Compound	Water-distilled oil	Steam-distilled oil	Extract
α-thujene	17.3	4.9	7.3
α-pinene	4.1	1.4	1.8
camphene	0.1	t	t
sabinene	1.9	0.7	0.9
β-pinene	4.4	1.7	2.0
α-terpinene	0.6	0.2	0.1
p-cymene	56.4	30.1	33.9
limonene	3.7	1.3	1.7
cis-sabinene hyrate	0.8	1.0	1.1
trans-p-menth-2-en-1-ol	4.4	6.1	5.3
trans-verbenol	0.1	0.3	0.3
terpinen-4-ol	0.5	0.6	0.6
trans-p-mentha-2,8-dien-1-ol	0.3	0.5	0.7
thymoquinone	2.8	48.2	42.8
thymol	0.1	0.2	0.1
α-longipinene	0.2	0.5	0.2
longifolene	0.8	2.1	1.1

t = trace (< 0.03%)

The composition of an oil produced by water distillation was compared to an oil produced by steam distillation and a hexane extract of *N. sativa* seeds produced from plants grown in Bulgaria (Stoyanova et al., 2003). The components characterized in the two oils and extract are shown in **T-1**. Trace amounts (< 0.03%) of pulegone and carvacrol were also found in both oils and the extract.

Moretti et al. (2004) repeated the same results on the composition of *N. sativa* oil as those presented by D'Antuono et al. (2002).

An oil and a chloroform extract of *N. sativa* seeds of Moroccan origin were the subject of analysis by Rchid et al. (2004). The results of this study are shown in **T-2**.

Using the technique of microwave hydrodistillation, oils of *N. sativa* were produced from seeds obtained in Algeria, Syria, Jordan, Iran and

Comparative percentage composition of an oil and extract of *Nigella sativa* **T-2**

Compound	Oil	Extract
α-thujene	8.9	6.0
α-pinene	1.9	1.3
camphene	0.3	–
sabinene	0.6	0.6
β-pinene	2.1	1.6
p-cymene	47.4	49.0
limonene	1.5	1.4
γ-terpinene	1.1	0.8
terpinen-4-ol	0.4	0.3
p-cymen-8-ol	–	0.5
thymoquinone	20.8	20.6
carvacrol	4.3	3.8
thymohydroquinone	–	1.8

Ethiopia by Benkaci-Ali et al. (2006). Analysis of the oils using GC and GC/MS revealed some variations as can be seen in **T-3**. In addition, trace amounts of myrcene, α-phellandrene, linalool, (Z)-myroxide, *cis*-limonene oxide, *cis*-β-terpineol, β-pinene oxide, methyl chavicol, p-cymen-7-ol, α-ylangene, γ-elemene, α-himachalene, α-patchoulene, *cis*-muurola-4(14),5-diene, β-thujaplicin, γ-thujaplicine, germacrene B, 1,10-di-epi-cubenol, 2,3-dihydrofarnesol and selin-7(11)-en-4-yl acetate were found in one or more of the oils.

Percentage composition of *Nigella sativa* oils produced from seeds of different geographic origin **T-3**

Compound	A	S	J	I	E
α-thujene	16.5	6.5	12.4	11.4	10.7
α-pinene	–	2.1	3.2	t	1.9
camphene	0.1	–	t	–	–
sabinene	7.5	–	1.7	0.2	–
β-pinene	0.2	–	3.8	1.4	–
α-terpinene	–	–	0.8	t	–
p-cymene	36.5	73.0	36.8	64.6	66.5
limonene	–	–	0.2	–	–
γ-terpinene	1.9	0.4	3.0	0.9	1.0
cis-sabinene hydrate	0.1	–	–	–	–
α-p-dimethylstyrene	0.2	–	–	t	t
terpinolene	–	0.6	t	0.9	0.5
trans-sabinene hydrate	2.2	–	1.2	–	–
α-thujone	0.1	–	–	–	–
p-mentha-1,3,8-triene	0.4	t	0.2	t	t
trans-limonene oxide	t	–	–	0.3	t
camphor	0.1	t	t	–	0.2
karahanaenone	0.7	0.2	0.5	–	–
terpinen-4-ol	0.6	0.3	0.7	0.3	0.3
p-cymen-8-ol	–	–	6.2	–	–
thuj-3-en-10-al	0.1	–	–	–	–
trans-dihydrocarvone	–	–	–	1.0	–
isodihydrocarveol	–	0.7	–	–	0.4
cis-sabinene hydrate acetate	–	0.1	0.1	0.1	t
cuminaldehyde	–	t	t	0.1	–
carvone	0.1	t	0.1	0.1	t
thymoquinone	14.7	6.2	18.4	9.7	9.6
carvenone	–	–	–	–	1.9
trans-sabinene hydrate acetate	–	0.2	0.1	0.1	t
geranial	–	0.2	–	–	0.2
(E)-anethole	–	–	–	t	0.2
bornyl acetate	0.5	0.5	–	0.2	–
isobornyl acetate	–	–	0.2	0.3	–
2-undecanone	0.2	t	–	–	–
carvacrol	1.9	–	0.3	–	0.6
α-longipinene	1.1	0.5	0.7	0.2	0.2
carvacryl acetate	–	0.4	t	0.3	–
longicyclene	0.1	t	–	–	–
α-copaene	0.2	–	–	t	–
β-patchoulene	0.1	–	–	–	–
isolongifolene	0.4	–	–	–	–
β-longipinene	–	–	0.1	t	t
longifolene	3.1	1.7	2.4	0.4	0.9
dodecanal	0.1	–	–	–	–
β-caryophyllene	0.1	0.1	0.2	t	0.1
p-cymen-7-yl acetate	–	0.1	–	–	–
cis-thujopsene	0.1	–	–	–	–
(E)-isoeugenol	–	0.1	–	–	–
α-humulene	0.1	0.1	t	–	–
6-methyl-α-ionone	0.1	–	–	–	–
γ-muurolene	0.2	–	–	–	–
2-tridecanone	0.1	–	–	–	–
β-bisabolene	0.1	–	–	t	–

continued on next page →

T.S. El-Afy, H.M. El-Fatatry and M.A. Toama, *Isolation and structure assignment of an anti-microbial principle from the volatile oil of* Nigella sativa *L. seeds.* Pharmazie, **30**, 109–111 (1975).

E.A. Aboutabl, A.A. El-Azzouny and F-J. Hammerschmidt, *Aroma volatiles of* Nigella sativa *L. seeds.* In: *Progress in Essential Oil Research.* Edit. E-J. Brunke, pp. 48–55, Walter de Gruyter, New York, NY (1986).

C. Bourrel, G. Vilarem and F. Perineau, *Etude des composes aromatiques des graines de Nigelle (*Nigella sativa *L.); Evaluation des proprietes antibacteriennes et antifongiques.* Rivista Ital. EPPOS, (10), 21–27 (1993).

F.S. Mozaffari, M. Ghorbanli, A. Babai and M. Farzami Sepehr, *The effect of water stress on the seed oil of* Nigella sativa *L.* J. Essent. Oil Res., **12**, 36–38 (2000).

E.H. Benyoussef, N. Zouaghi, R. Belabbes and J-M. Bessiere, *Etude botanique des graines de Nigelle d' Algerie et analyse de leur huile essentielle.* Rivista Ital. EPPOS, (31), 15–19 (2001).

L.F. D'Antuono, A. Moretti and A.F.S. Louato, *Seed yield, yield components, oil content and essential oil content and composition of* Nigella sativa *L. and* Nigella damascena *L.* Indust. Crops Prods., **15**, 59–69 (2002).

A.H. El-Ghorab, *Supercritical fluid extraction of the Egyptian rosemary (*Rosmarinus officinalis*) leaves and* Nigella sativa *L. seeds volatile oils and their antioxidant activities.* J. Essent. Oil Bear. Plants, **6**, 67–77 (2003).

A. Stoyanova, E. Georgiev, A. Wajs and D. Kalemba, *A comparative investigation on the composition of the volatiles from seeds of* Nigella sativa *L. from Bulgaria.* J. Essent. Oil Bear. Plants, **6**, 207–209 (2003).

A. Moretti, L.F. D'Antuono and S. Elementi, *Essential oils of* Nigella sativa *and* Nigella damascene *L. seed.* J. Essent. Oil Res., **16**, 182–183 (2004).

H. Rchid, R. Nmila, J.M. Bessiere, Y. Sauvaire and M. Chokraïri, *Volatile components of* Nigella damascena *L. and* Nigella sativa *L. seeds.* J. Essent. Oil Res., **16**, 585–587 (2004).

Continued from previous page **T-3**

δ-cadinene	0.1	–	0.2	0.1	–
γ-dehydro-ar-himachalene	0.1	–	–	–	–
citronellyl butyrate	0.1	–	–	–	–
thymohydroquinone	0.3	0.5	0.3	t	0.7
tridecanal	0.2	–	–	–	–
himachalol	–	–	0.2	–	–
2-pentadecanone	0.1	–	–	–	–
isolongifolol	0.2	t	–	–	–
pimaradiene	0.1	t	t	t	–
methyl linoleate	0.2	0.1	0.3	t	–

t = trace (< 0.03%); A = Algerian oil; S = Syrian oil; J = Jordanian oil; I = Iranian oil; E = Ethiopian oil

F. Benkaci-Ali, A. Baaliouamer, J-P. Wathelet and M. Marlier, *Etude comparative de la composition chimique de la* Nigella sativa *Linn. de quelques regions du Monde, extraites par micro-ondes.* Rivista Ital. EPPOS, (41), 23–32 (2006).

Coriander Seed Oil

Diederichsen (1996) reported that the main components of the oil of coriander produced from 237 plants grown in Gatersleben (Germany) were:

linalool (67.7%)
α-pinene (10.5%)
γ-terpinene (9.0%)
geranyl acetate (4.0%)
camphor (3.0%)
geraniol (1.9%)

In addition, a number of minor constituents (< 2%) such as β-pinene, camphene, myrcene, limonene, p-cymene, α-terpinene, decanal, borneol and some unnamed acetates were also characterized in this oil.

Li et al. (2001) used a combination of GC(FID) and GC/MS to analyze a lab-distilled oil of *C. sativum* seeds grown in Laifeng County (China). The constituents characterized were as follows:

α-pinene (2.06%)
camphene (0.60%)
β-pinene (0.37%)
1,4-cineole (0.11%)
p-cymene (4.26%)
limonene (0.90%)
1,8-cineole (0.32%)
cis-linalool oxide[f] (6.86%)
trans-linalool oxide[f] (6.37%)
linalool (56.82%)
borneol (0.29%)

[f] = furanoid form

A number of other compounds were erroneously listed as components of the oil; however, these are not included in this review as they are meaningless. Also, please note that the high levels of both linalool oxide isomers and the lower than expected level of linalool indicates that the oil analyzed was oxidized.

The main components of seven lab-distilled samples of coriander seed oil (ex. *Coriandrum sativum* L.) were determined (Braun and Franz 2001) to be as follows:

α-pinene (7.09–9.37%)
limonene (1.85–2.46%)
γ-terpinene (4.53–9.21%)
p-cymene (0.94–4.55%)
camphor (2.88–4.68%)
linalool (65.19–70.15%)
geranyl acetate (2.35–3.36%)

In addition, the authors also examined 11 samples of coriander oil that were available commercially in Germany. The results of these analyses are shown in **T-4**.

In the past, it had been reported (Frank et al. 1995) that the enantiomeric ratio for linalool in genuine coriander oil was as follows: (3R)-(-)-linalool (10%):(3S)-(+)-linalool (90%).

Braun and Franz (2000) used chiral GC to examine the enantiomeric ratio of linalool in the 11 samples of coriander oil and found that it ranged as follows: (3R)-(-)-linalool (12.7–35.2%):(3S)-(+)-(64.8–87.3%). From this data it can be concluded that all of the commercial samples were adulterated, particularly samples 9–11 whose (-)-linalool contents were 30.3%, 35.2% and 23.1%, respectively. Let this be a warning to all users of coriander seed oil because there is definitely a different odor specificity and threshold for each enantiomer of linalool (Sugawara 2001).

An oil of *C. sativum* produced in the laboratory that was screened for its antimicrobial properties was analyzed by Lo Cantore et al. (2004).

Comparative percentage composition of the main constituents of 11 commercial coriander seed oil samples **T-4**

Compound	1	2	3	4	5	6	7	8	9	10	11
α-pinene	7.81	8.48	8.35	4.16	7.23	3.02	5.38	5.43	4.13	3.42	5.28
limonene	2.52	2.69	2.60	2.33	2.62	1.51	2.13	2.48	4.64	9.42	2.31
γ-terpinene	3.59	3.95	4.35	1.15	3.32	5.61	0.70	4.46	2.28	1.55	2.15
p-cymene	2.50	2.26	1.73	6.24	3.93	0.70	5.46	2.34	2.60	1.10	4.21
camphor	4.52	4.49	4.41	4.87	4.84	3.86	5.23	4.97	4.02	1.91	5.34
linalool	68.85	67.42	68.13	71.29	69.13	78.43	72.56	72.38	70.96	74.25	71.14
geranyl acetate	3.24	3.68	3.46	2.52	2.82	1.67	2.32	2.25	2.16	1.80	2.35

The composition of the oil was found to be as follows:

α-pinene (5.1%)
camphene (0.8%)
β-pinene (0.5%)
myrcene (0.8%)
p-cymene (6.3%)
1,8-cineole (0.1%)
limonene (3.6%)
γ-terpinene (0.3%)
linalool (64.5%)
camphor (6.4%)
α-terpineol (0.8%)
nerol (4.6%)
geraniol (0.4%)
(E)-2-decenal (0.1%)
(E)-anethole (0.3%)
thymol (0.1%)
eugenol (0.2%)
geranyl acetate (0.4%)

Trace amounts (< 0.1%) of α-thujene, sabinene, α-terpinene, borneol, geranial, β-caryophyllene and caryophyllene oxide were also found in this same oil.

Benyoussef et al. (2004) determined that the yield of oil, hexane extract and ethanolic extract of coriander seed of Algerian origin was 0.05%, 3.20% and 8.23%, respectively. The authors compared the composition of the oil with the two extracts and the results of this comparative study can be seen in **T-5**. Furthermore, Benyoussef et al. (2004) subjected the exhausted seed from the hexane extraction to hydrodistillation and found that from an oil yield of 0.04%, the composition was as follows:

α-pinene (0.31%)
myrcene (0.16%)
p-cymene (0.13%)
1,8-cineole (0.21%)
γ-terpinene (0.08%)
linalool (80.33%)
camphor (1.36%)
terpinen-4-ol (0.60%)
α-terpineol (0.42%)
octanal (3.07%)
dodecane (0.53%)
geranyl acetate (1.75%)
β-caryophyllene (0.24%)
α-humulene (0.33%)
nerolidol* (0.15%)
tetradecanoic acid (4.04%)

*correct isomer not identified

Telci et al. (2006) compared the composition of lab-distilled oils of *C. sativum* var. *vulgare* Alef and *C. sativum* var. *microcarpum* DC. grown in two different locations in

Comparative percentage composition of an oil and two extracts of coriander seed **T-5**

Compound	Oil	Hexane extract	Ethanol extract
α-pinene	0.1	–	t
myrcene	0.2	–	0.5
p-cymene	0.2	–	t
γ-terpinene	0.6	–	t
1,8-cineole	0.1	–	0.5
terpinolene	–	–	–
linalool	70.2	–	62.6
camphor	1.8	–	1.8
terpinen-4-ol	0.5	–	0.3
α-terpineol	0.3	–	t
octanal†	2.2	–	t
dodecane	0.5	–	0.2
geranyl acetate	1.6	–	2.3
dodecanal	0.5	–	0.3
β-caryophyllene	0.2	t	0.2
α-humulene	0.8	–	0.5
nerolidol*	0.5	–	t
tetradecanoic acid	5.9	63.2	7.8

*correct isomer not identified; t = trace (< 0.05%); † incorrect identification based on GC elution order

Turkey. Using a combination of GC and GC/MS, the authors characterized the composition of the two oils as can be seen **T-6**. Furthermore, the authors showed that the oils from the two varieties of *C. sativum* varied depending upon the location in which they were grown. The differences in major constituents of the two varieties grown at different locations can be seen in **T-7**.

Singh et al. (2006) analyzed a lab-distilled oil of coriander seed that was purchased at a local market in Gorakhpur (India). The composition of this oil was as follows:

α-pinene (4.09%)
camphene (0.05%)
sabinene (0.24%)
β-pinene (0.86%)
myrcene (0.32%)
α-phellandrene (0.07%)
p-cymene (0.45%)
limonene (0.63%)
1,8-cineole (0.43%)
(E)-β-ocimene (0.06%)
γ-terpinene (0.65%)
octanol (0.11%)
cis-linalool oxide[f] (0.51%)
terpinolene (0.20%)
linalool (75.30%)
trans-pinocarveol (0.08%)
camphor (0.14%)
citronellal (0.09%)
borneol (0.30%)
terpinen-4-ol (0.18%)
α-terpineol (0.42%)
verbenone (0.13%)
nerol (0.17%)
citronellol (0.10%)
cuminaldehyde (0.58%)
geraniol (0.81%)
undecanal (0.13%)
citronellyl acetate (0.29%)
neryl acetate (0.14%)
geranyl acetate (8.12%)
β-caryophyllene (0.39%)
α-humulene (0.09%)
ar-curcumene (0.11%)
zingiberene (0.14%)
β-bisabolene (0.09%)
β-sesquiphellandrene (0.17%)
elemol (0.09%)
caryophyllene oxide (0.05%)
ar-turmerone (0.62%)
β-turmerone (0.57%)
α-turmerone (0.33%)

[f] = furanoid form

Trace amounts (0.01%) of isovaleraldehyde, α-thujene, verbenene, 6-methyl-5-hepten-2-one, δ-3-carene, α-terpinene, (Z)-β-ocimene, *trans*-linalool oxide (furanoid), α-campholenal, α-ylangene and δ-cadinene were also found in this oil.

In contrast, the composition of an oleoresin of the same batch of coriander seed produced with acetone using a Soxhlet system was found by Singh et al. to be as follows:

geranyl acetate (1.03%)
dodecanal (0.36%)
(E)-2-dodecenal (2.05%)
β-turmerone (0.91%)
α-turmerone (0.25%)

Comparative percentage composition of the oils of two varieties of *Coriandrum sativum* **T-6**

Compound	var. *vulgare* oil	var. *microcarpum* oil
β-pinene	0.2	0.3
sabinene	0.2	0.1
myrcene	0.2	0.3–0.4
limonene	0.3–0.4	0.5–0.6
1,8-cineole	t–0.2	t–0.1
γ-terpinene	4.5–4.8	0.9–1.1
p-cymene	2.9–3.5	0.6–1.0
terpinolene	t–0.1	0.1
nonanal	–	t–0.1
cis-linalool oxide[f]	t–0.1	0.1
citronellal	t–0.1	–
decenal*	0.1–0.2	0.1–0.3
camphor	0.5–0.7	1.7
linalool	42.1–52.7	63.5–71.0
octanol	0.2	0.1–0.4
cis-dihydrocarvone	t–0.1	0.1
α-terpineol	0.1–0.2	0.3
borneol	0.2–0.3	–
carveol*	t–0.1	–
carvone	0.6–1.2	0.7
dihydrocarveol	t–0.1	–
geranyl acetate	2.0–2.3	3.1–3.2
decanol	t–0.8	–
citronellol	0.2	0.1
(E)-2-decenol	t–0.2	–
(E)-anethole	–	t–0.2
geraniol	1.1–1.2	1.9–2.5
2-dodecenal*	0.5–0.8	0.1–0.2
caryophyllene oxide	–	t–0.1
octanoic acid	t–0.1	0.1
nonanoic acid	0.1–0.2	0.1–0.2
2-methoxy-4-vinylphenol	–	t–0.1
2-methyl-5-phenol	t–0.1	t–0.1
myristicin	0.1–1.0	0.4–0.9
decanoic acid	0.3–1.2	0.4–0.8
(Z)-isoapiole + dillapiole	2.3–2.5	1.1–2.7
undecanoic acid	0.2–0.4	0.2
dodecanoic acid	0.4–0.8	0.4
pentacosane	–	t–0.1
tridecanoic acid	0.2–0.3	0.1–0.2
tetradecanoic acid	7.9–10.5	3.4–7.6
pentadecanoic acid	0.9–1.1	0.4–0.7
hexadecanoic acid	11.3–15.9	6.0–6.1
octadecanoic acid	0.4–1.1	t–0.1

*correct isomer not identified; t = trace (< 0.1%); [f] = furanoid form

decylcyclopentane (0.12%)
tetradecanoic acid (2.04%)
pentadecanoic acid (0.03%)
hexadecanoic acid (11.05%)
linoleic acid (33.21%)
oleic acid (36.52%)
octyl octadecanoate (0.30%)
squalene (0.14%)
nonacosane (0.19%)
stigmasterol (0.42%)
γ-sitosterol (0.53%)
β-amyrin (0.25%)

Trace amounts (< 0.1%) of β-caryophyllene, isovanillin, undecanoic acid, ar-curcumene, β-bisabolene, β-sesquiphellandrene, 5-phenyl-dodecane, 4-phenyl-dodecane, α-tocopherol, ergost-5-en-3-ol and stigmast-4-en-3-one were also characterized as constituents of this coriander seed oleoresin.

C. Frank, A. Dietrich, U. Kremer and A. Mosandl, *GC-IRMS in the authenticity control of the essential oil of* Coriandrum sativum *L.* J. Agric. Food Chem., **43**, 1634–1637 (1995).

A. Diederichsen, *Coriander*—Coriandrum sativum *L.* International Plant Genetic Resources Institute, 83 p., IPGRI, Rome (1996).

M. Braun and G. Franz, *Chirale säulen decken verfalschungen auf.* Pharm. Ztg., **146**, 2493–2499 (2001).

Y. Sugawara, *Odor distinctiveness between enantiomers of linalool.* Curr. Topics Anal. Chem., **2**, 201–210 (2001).

C-M. Li, J. Shan, Y-H. Ren and C-M. Xu, *Analysis of chemical constituents of coriander seed oil from Laifeng county.* Xiangliao Xiangjing Huazhuangpin, (6), 1–2 (2001).

P. LoCantore, N.S. Iacobellis, A. DeMarco, F. Capasso and F. Senatore, *Antibacterial activity of* Coriandrum sativum *L. and* Foeniculum vulgare *Miller var.* vulgare *(Miller) essential oils.* J. Agric. Food Chem., **52**, 7862–7866 (2004).

E-H. Benyoussef, N. Beddek, N. Zouaghi, R. Belabbes and J.M. Bessiere, *Isolation of coriander oils by different processes.* J. Essent. Oil Bear. Plants, **7**, 129–135 (2004).

I. Telci, O.G. Toncer and N. Sahbaz, *Yield essential oil content and composition of* Coriandrum sativum *varieties (var.* vulgare *Alef and var.* microcarpum *DC.) grown in two different locations.* J. Essent. Oil Res., **18**, 189–193 (2006).

G. Singh, S. Maurya, M.P. de Lampasona and C.A.N. Catalan, *Studies on essential oils. Part 41. Chemical composition, antifungal, antioxidant and sprout suppressant activities of coriander (*Coriandrum sativum*) essential oil and its oleoresin.* Flav. Fragr. J., **21**, 472–479 (2006).

Cilantro Oil

The leaf oils of three Indian cultivars (Bangalore, Jaipur and IIHR Sel-1) of coriander were analyzed by co-injection GC (Shivashankara et al. 2003). The results obtained can be seen in **T-8**.

Rao et al. (2004) analyzed the oils produced from the whole herb at its vegetative stage, the whole herb at the flowering stage and the leaf oil from six coriander cultivars. A summary of these results can be found in **T-9**.

Comparative percentage composition of the main components of two varieties of *Coriandrum sativum* grown in two different locations in Turkey **T-7**

Compound	var. *vulgare* oil		var. *microcarpum* oil	
	1	2	1	2
linalool	42.1	52.7	63.5	71.0
hexadecanoic acid	15.9	11.3	6.0	6.1
tetradecanoic acid	10.5	6.0	7.7	3.4
γ-terpinene	4.8	4.5	1.1	1.0
p-cymene	3.5	2.9	1.0	0.6
(Z)-isoapiole + dillapiole	2.3	2.5	2.7	1.2
geranyl acetate	2.0	2.3	3.2	3.1
geraniol	1.1	1.2	1.9	2.5
camphor	0.5	0.7	1.7	1.7
limonene	0.4	0.3	0.5	0.6

Comparative percentage leaf oil composition of three Indian coriander cultivars **T-8**

Compound	Bangalore leaf oil	Jaipur leaf oil	IIHRSel-1 leaf oil
nonane	0.1	0.3	0.3
octanal	0.4	0.8	0.9
(Z)-3-nonenal	0.1	–	–
nonenal*	0.4	–	0.2
(E)-2-nonenal	0.2	0.3	–
(Z)-4-decenal	0.2	0.5	0.2
decanal	3.6	6.6	6.1
(E)-2-decenal	0.7	0.6	0.6
2-decenol*	23.1	16.6	24.9
decanol	30.5	32.1	38.3
undecenal*	0.4	2.2	0.3
(E)-2-undecenal	2.9	–	1.5
undecanol	0.2	1.9	0.9
pentadecanol†	0.1	0.5	–
dodecanal	1.6	1.8	2.2
tetradecane	0.1	–	–
(E)-2-dodecenal	5.8	5.6	6.9
pentadecane	0.1	–	0.2
tridecanol	0.2	–	0.2
hexadecane	0.7	0.7	1.9
pentadecanal	0.1	0.4	–
dodecanol†	0.1	–	0.1
tetradecanol	0.1	0.3	–
nonadecane	0.4	0.7	0.5

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

The volatiles of coriander leaf were reported by Kubo et al. (2004) to be decanal, (E)-2-decenal, (E)-2-dodecenal, nonane, linalool, tetradecanal, (E)-2-undecenal, dodecanal, (E)-2-tridecenal, octanal, undecanal, nonanal, (E)-2-hexenal and geraniol. (E)-2-Dodecenal was found to be most effective against the food-borne bacterium *Salmonella choleraesuis*.

A sample of cilantro oil that was produced in Prince Albert, Saskatchewan (Canada) was screened against a few *Listeria* strains by Delaquis and Stanich (2004). The composition of this oil was determined to be as follows:

nonane (2.5%)
α-pinene (2.7%)
limonene (1.8%)
γ-terpinene (0.9%)
p-cymene (3.5%)
(Z)-3-hexenol (0.3%)
decanal (8.4%)
camphor (1.9%)
linalool (25.9%)
octanol (0.3%)
(E)-2-decenal (20.2%)
carvone (1.2%)
decanol (3.9%)
(E)-2-decenol (7.9%)

The authors found that (E)-2-decenal was the most active constituent against *Listeria*.

Using a combination of GC-GC-time-of-flight mass spectrometry, Eyres et al. (2005) characterized the following compounds in an oil of coriander leaves of Fijian origin:

nonane (1.53%)
decane (0.14%)
undecane (0.09%)
tridecane (0.03%)
hexanol (0.05%)
nonanol (0.12%)
decanol (19.64%)
undecanol (0.32%)
dodecanol (0.19%)
(E)-2-hexenol (0.58%)
(E)-2-nonenol (0.04%)
(E)-2-decenol (26.00%)
(E)-2-undecenol (2.01%)
(E)-2-dodecenol (4.60%)
(E)-2-tridecenol (0.14%)
(E)-2-tetradecenol (0.89%)
(E)-3-hexenol (0.02%)
(Z)-3-hexenal (1.04%)
(Z)-2-hexenol (< 0.01%)
1-octen-3-ol (< 0.01%)
heptanal (0.04%)
octanal (0.84%)
nonanal (0.20%)
decanal (6.56%)
undecanal (0.98%)
dodecanal (2.99%)
tridecanal (0.31%)
tetradecanal (0.96%)
pentadecanal (0.09%)
hexadecanal (0.07%)
(E)-2-hexenal (0.29%)
(E)-2-nonenal (0.04%)
(E)-2-decenal (9.12%)
(E)-2-undecenal (1.20%)
(E)-2-dodecenal (5.37%)
(E)-2-tridecenal (0.41%)
(E)-2-tetradecenal (7.03%)
(E)-2-pentadecenal (0.74%)
(E)-2-hexadecenal (0.39%)

Percentage composition of cilantro oil produced from vegetative and flowering forms of six Indian coriander cultivars **T-9**

Compound	1V	1F	2V	2F	3V	3F	4V	4F	5V	5F	6V	6F
(E)-2-hexenal	0.29	0.85	0.17	0.05	0.21	0.25	0.18	0.13	0.19	0.78	0.26	1.56
nonane	0.45	1.01	0.62	1.74	0.79	0.98	1.61	0.91	0.99	2.41	1.74	2.76
octanal	0.16	0.04	1.27	–	0.12	–	0.21	0.08	0.16	0.25	0.28	0.05
nonanal	0.14	0.25	–	0.12	0.13	–	0.24	–	0.16	0.27	0.12	0.23
undecane	0.21	0.16	0.42	0.19	0.13	0.19	0.07	0.32	0.09	0.08	0.35	0.39
(E)-2-nonenal	0.06	0.12	–	0.09	0.05	–	0.06	–	0.04	0.07	0.04	0.11
decanal	2.02	7.43	6.21	9.64	2.67	4.11	3.18	7.63	3.37	7.21	4.13	10.35
(E)-2-decenal	0.16	0.56	1.86	0.21	0.16	0.24	0.17	0.64	0.17	0.27	0.16	0.42
(E)-2-decenol	5.98	19.25	8.69	7.17	5.88	8.86	6.77	19.23	5.92	9.27	5.28	13.97
decanol	54.03	33.77	26.49	33.75	53.17	42.99	52.84	32.81	55.19	42.21	59.14	40.91
undecanal	0.39	1.43	0.69	1.08	0.46	1.79	0.92	1.32	0.66	1.75	0.67	1.59
(E)-2-undecenal	1.38	3.42	0.41	1.11	1.21	3.27	1.88	3.68	1.23	2.55	0.87	1.91
(E)-2-undecenol	7.06	3.41	1.63	2.71	5.98	8.04	8.76	4.31	6.25	5.59	4.47	2.56
undecanol	0.62	0.75	0.94	0.68	0.87	1.59	1.06	0.29	0.91	1.64	1.05	0.79
dodecanal	0.93	1.54	2.44	2.54	1.12	1.96	1.29	1.41	1.12	1.98	1.04	1.87
(E)-2-dodecenal	3.26	6.11	4.05	5.88	3.11	4.97	2.49	5.95	2.75	4.51	2.54	4.42
(E)-2-dodecenol	7.98	3.17	9.27	5.54	6.85	6.44	6.39	3.12	7.12	5.51	6.86	3.21
pentadecane	0.09	0.11	0.21	0.26	0.09	0.25	0.16	0.21	0.11	0.15	0.09	0.13
(E)-2-tridecenal	0.42	0.64	0.62	0.94	0.31	0.92	0.43	0.49	0.33	0.49	0.31	0.45
tridecanol†	0.12	0.18	0.17	0.29	0.11	0.18	0.09	0.21	0.11	0.14	0.08	0.14
dodecanol†	0.27	0.58	0.41	1.16	0.29	0.16	0.33	0.56	0.31	0.48	0.22	0.48
(E)-2-tetradecenal	3.94	6.13	5.75	12.61	3.09	5.34	2.71	6.98	3.05	4.57	2.36	3.95
(E)-2-tetradecenol	1.28	0.38	1.58	1.32	0.89	0.93	0.89	4.56	0.96	0.66	0.69	0.34
pentadecanal	0.11	0.12	0.16	0.17	0.11	0.12	0.14	0.19	0.14	0.21	0.11	0.11
(E)-2-pentadecenal	0.49	0.52	0.95	1.74	0.38	0.76	0.34	0.69	0.34	0.45	0.38	0.56
(E)-2-pentadecenol	0.23	0.29	0.43	0.91	0.27	0.26	0.13	0.28	0.21	0.28	0.16	0.26

1 = Jaipur local; 2 = Surabhi; 3 = Banglore local; 4 = LC-12; 5 = LC-13; 6 = LC-21; V = vegetative plants; F = flowering plants; †incorrect identification based on GC elution order

(Z)-2-decenal (0.16%)
(Z)-2-undecenal (0.02%)
(Z)-2-dodecenal (0.07%)
(Z)-2-tetradecenal (0.06%)
(Z)-4-decenal (0.16%)
(Z)-4-undecenal (0.02%)
(Z)-4-dodecenal (0.09%)
(Z)-4-tetradecenal (0.08%)
tridecenal* (0.01%)
phenylacetaldehyde (< 0.01%)
α-thujene (0.10%)
α-pinene (0.07%)
sabinene (0.28%)
β-pinene (0.16%)
myrcene (0.06%)
2-pentylfuran (< 0.01%)
δ-3-carene (0.02%)
(Z)-3-hexenyl acetate (0.11%)
p-cymene (0.70%)
limonene (0.10%)
1,8-cineole (1.08%)
γ-terpinene (0.32%)
trans-linalool oxide[f] (0.04%)
terpinolene (0.02%)
1-undecene (< 0.01%)
cis-linalool oxide[f] (0.04%)
2-hexylfuran[t] (< 0.01%)
2-nonanone (0.02%)
linalool (0.17%)
1-octen-3-yl acetate (< 0.01%)
3-octyl acetate (0.01%)
camphor (0.02%)
pentylbenzene (0.01%)
trans-2-caren-4-ol[t] (0.02%)
terpinen-4-ol (0.13%)
α-terpineol (0.01%)
cyclodecanol[t] (0.06%)
tridecene* (0.01%)
decyl acetate (0.03%)
α-amorphene (0.02%)
β-ionone* (0.02%)
2-tridecanone (0.01%)

*correct isomer not identified; [f] = furanoid form; [t] = tentative identification

K.S. Shrivashankara, T.K. Roy, B. Valaralakshmi, V. Venkateshwarlu and Y. Selvaraz, *Leaf essential oils of cultivar (*Coriandrum sativum *L.) cultivars.* Indian Perfum., **47**, 35–37 (2003).

V.K. Rao, T.K. Roy, K.S. Shrivashankara and B. Valaralakshmi, *A comparative study of whole herb and leaf essential oils of coriander.* J. Essent. Oil Bear. Plants, **7**, 49–55 (2004).

I. Kubo, K-I. Fujita, A. Kubo, K-I. Nihel and T. Ogura, *Antibacterial activity of coriander volatile compounds against* Salmonella choleraesuis. J. Agric. Food Chem., **52**, 3329–3332 (2004).

P.J. Delaquis and K. Stanich, *Antilisterial properties of cilantro essential oil.* J. Essent. Oil Res., **16**, 409–414 (2004).

G. Eyres, J-P. Dufour, G. Hallilfax, S. Sotheeswaran and P.J. Marriot, *Identification of character-impact odorants in coriander and wild coriander leaves using gas chromatography-olfactometry (GCO) and comprehensive two-dimensional gas chromatography-time-of-flight mass spectrometry (GC x GC-ToFMS).* J. Sep. Sci., **28**, 1061–1074 (2005).

I. Telci, O.G. Toncer and N. Sahbaz, *Yield, essential oil content and composition of* Coriandrum sativum *varieties (var.* vulgare *Alef and var.* microcarpum *DC.) grown in two different locations.* J. Essent. Oil Res., **18**, 189–193 (2006).