Progress in Essential Oils

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Himalayan Cedarwood Oil

Cedrus deodara (Roxb.), a member of the Pinaceae family, is a graceful evergreen tree with spreading branches that create a natural pyramidal outline. It is native to the northwestern Himalayas where it can be found at altitudes between 1,330 m and 3,300 m. The wood of the Himalayan cedar is the source of this oil, which is produced commercially by steam distillation in ca. 200 metric tonnes annually. The wood of *C. deodara* has been valued as a termite-resistant, easy-to-season, readily workable wood that is used in the construction trade and the production of railway sleepers. Guenther (1952) reported that distillation of the wood yields an oil in 2.5% yield that possesses a balsamic aroma.

Sood (1964) reported that steam distillation of the dust and shavings of this deodar cedarwood for 7–8 hrs generated an oil in 3.0% yield that contained 50–70% sesquiterpenes.

Dev (1966) reported that Himalayan cedarwood oil was a complex mixture of sesquiterpenoid compounds. In the hydrocarbon part of this oil he isolated and structurally elucidated new skeletal type compounds for the first time, which he named α-himachalene and β-himachalene. He further structurally elucidated a mono-olefinic, bicyclic, secondary sesquiterpenoid alcohol that he named allo-himachalol. A ketone isolated from the oil that is structurally related to allo-himachalol was named allo-himachalone.

Pande and Dev (1968) isolated and characterized ar-himachalene as a minor constituent of *C. deodara* wood oil.

Joseph and Dev (1968) presented their complete structural elucidation of α- and β-himachalenes and determined that they were the major hydrocarbons in the oil.

Bisarya and Dev (1968a) used the structural elucidation date of the himachalene skeleton to characterize the related himachalol as a constituent of the alcohol fraction of *C. deodara* oil. They also identified longiborneol and allo-himachalol in the same alcohol fraction. A full study on the isolation and structural elucidation of allo-himachalol was reported in a follow-up report of Bisarya and Dev (1968b).

Pande et al. (1971) noted that *cis*- and *trans*-atlantone were thought to be constituents of *C. deodara* oil. As a result, they fractionated the oil and unequivocally isolated and characterized pure *trans*-α-atlantone (also known as (E)-α-atlantone) as the major isomer in the oil with *cis*-α-atlantone (also known as (Z)-α-atlantone) being only a minor constituent.

Shankaranarayan et al. (1973) used a combination of IR, UV and chemical studies to determine that *C. deodara* oil contained a novel sesquiterpene tetrahydro-pyrone that they named deodarone (0.15%).

Adams et al. (1974, 1975) determined that an oil of *C. deodara* contained 0.15% of a C12 ketone [4-(4-methylcyclohex-3-enyl)pent-3-en-2-one].

Kulshreshtha and Rastogi (1975) and Puri et al. (1975) reported that *C. deodara* oil contained himachalol, allo-himachalol, himadarol, centdarol and isocentdarol. They showed through the use of H1-NMR and derivatization studies that centdarol was 2β,7β-dihydroxy-himachal-3-ene. In a follow-up report, Kulshreshtha and Rastogi (1976) structurally elucidated isocentdarol (4α,7β-dihydroxy-himachal-2-ene).

Shankaranarayan et al. (1977a) continued with their studies on *C. deodara* oil and characterized a new bicyclic sesquiterpene ketone, which they named isohimachalone.

Shankaranarayan et al. (1977b) characterized and structurally elucidated a new sesquiterpenoid hydroxyl-ketone, which they named atlantolone. In addition they determined that the compound known as deodarone was chemically correlated with (E)-α-atlantone.

Shankaranarayan et al. (1977c) isolated and elucidated the structure of a cyclic ether oxide of himachalene in *C. deodara* oil and named it oxidohimachalene.

Krishnappa and Dev (1978) determined that limonene carboxylic acid and a sesquiterpenoid diosphenol were minor constituents of *C. deodara* oil.

Bajaj et al. (1980) confirmed the structural elucidation of allo-himachol using crystallography.

Agarwal and Rastogi (1981) isolated and characterized a novel new phenolic sesquiterpenoid compound that they named himasecolone.

Khan and Naheed (1990) examined a petroleum ether extract of the stem bark of *C. deodara* and found that it contained some saturated straight and branched chain C14-C20 hydrocarbons and four sesquiterpene hydrocarbons (α-himachalene, β-himachalene, γ-himachalene and δ-himachalene).

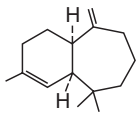
Lawrence (1990) used GC/MS and GC-FID to determine that the main components of commercial samples of Himalayan cedarwood oil were:

α-cedrene (12.0–16.0%)
β-cedrene (0.5–1.5%)
α-himachalene (20.0–30.0%)
β-himachalene (8.0–13.0%)
cedrol (1.0–2.0%)
himachalol (1.0–2.0%)
allo-himachal (0.5–1.5%)
deodarone (4.0–6.0%)
(Z)-α-atlantone (2.0–3.0%)
(E)-α-atlantone (5.0–7.0%)

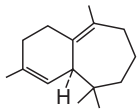
Nigam et al. (1990) analyzed an oil produced in 2.1% yield by hydrodistillation from the sawdust of *C. deodara* using GC/MS. In this oil they characterized the following constituents:

α-pinene (0.1%)
limonene (0.2%)
p-methylacetophenone (0.3%)
β-caryophyllene (0.3%)

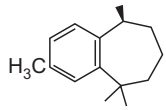
F-1. Structures of Himalayan cedarwood oil components



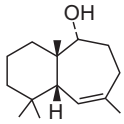
α-Himachalene



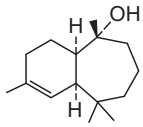
β-Himachalene



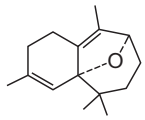
ar-Himachalene



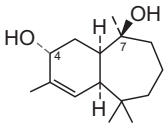
Himachalol
(2-himachalen-7-ol)



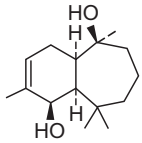
allo-Himachalol



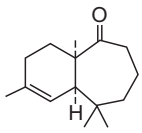
Isohimachalone
(7-oxo-2-himachalene)



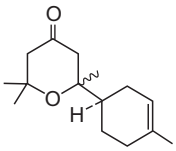
Centdarol
(3-himachaene-2,7-diol)



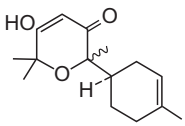
Isocentdarol
(2-himachalene-4,7-diol)



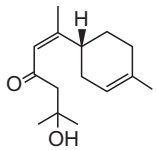
Oxidohimachalene
(1,8-epoxy-2,6-himachaladiene)



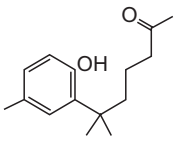
Deodarone



Deodardione



α-Atlantolone
(Z- and E-)



Himasecolone

δ-cadinene (0.7%)
β-cedrene (1.4%)
α-cedrene (15.8%)
β-himachalene (12.3%)
α-himachalene (30.8%)
cedrenol (2.4%)
deodarone (5.4%)
cedrol (1.4%)
himachalol (1.3%)
(Z)-atlantone (2.4%)
(E)-atlantone (6.5%)

Two other sesquiterpene hydrocarbons, three other sesquiterpene alcohols and two other sesquiterpene ketones were found but not characterized. The structures of these uncommon essential oil constituents can be seen in **F-1**.

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Ginger Oil

Koroch et al. (2007) reported the main component composition of two samples of Madagascan ginger oil (no specific raw material state and origin or production details were given), one sample of Ghanaian ginger oil (no specific raw material state and origin or production details were given) and three commercial samples of ginger oil (origins unknown). The results of this report are shown in **T-1**.

T-1. Comparative main component percentage composition of ginger oil from different origins

Compound	1	2	3	4	5	6
α-pinene	-	7.4	0.1	3.1	1.7	2.6
camphene	0.2	22.8	1.0	10.4	5.7	8.1
β-phellandrene	0.4	8.2	0.9	9.1	5.4	7.3
1,8-cineole	0.9	8.7	2.0	4.1	2.2	3.2
neral	11.2	2.4	6.4	-	0.1	-
geranial	17.8	4.2	14.6	-	0.2	0.1
geranyl acetate	-	-	8.3	-	-	-
ar-curcumene	4.5	15.3	7.7	8.2	9.1	4.5
zingiberene	18.1	5.2	22.9	42.2	39.7	18.1
β-bisabolene	6.4	7.4	8.5	11.5	11.3	6.4
β-sesquiphellandrene	6.8	6.3	6.5	13.5	10.9	6.8

1 = Ghanaian ginger oil; 2 = Madagascan ginger oil type 1; 3 = Madagascan ginger oil type 2; 4–6 = commercial ginger oils of undetermined origins

T-2. Comparative percentage composition of the main components of some oils produced from Ghanaian ginger and one commercial ginger from the United States

Compound	Accession-2 types		Commercial	
	Oil 1	Oil 2	Oil 3	Oil 4
1,8-cineole	5.9	10.6	7.6	6.7
borneol	8.3	4.7	5.2	2.1
α-terpineol	3.2	2.3	2.3	2.2
neral	10.2	6.9	10.4	23.4
geranial	16.0	10.7	17.0	34.6
ar-curcumene	1.8	-	4.0	2.4
zingiberene	8.1	5.3	16.4	7.1
β-bisabolene	2.5	-	5.7	2.6
β-sesquiphellandrene	2.9	2.1	6.2	2.4
zerumbone	18.3	28.6	-	3.1

Juliani et al. (2007) examined the chemical composition as related to the quality of Ghanaian ginger (*Zingiber officinale* Ros.). The authors collected rhizome samples from Gyankobe (accession-11), Krabonso (accession-1), Oframanse (accession-1), Gyankobe (accession-2), Krabonso (accession-2) and Oframanse (accession-2). The authors measured the dry weight and dimensions of the rhizomes although they failed to note the age of the ginger plants from which the rhizomes were obtained. The dry weight and dimensions were compared with a commercial sample obtained in New Jersey and only the samples noted as accession-1 from Krabonso had a relatively comparable weight and size.

Oils were produced by hydrodistillation of 200–300 g of rhizomes (state not given) for 2 hours from each accession. The oils were analyzed for main components using GC/MS as the only method. The authors found that all accession-1 types (irrespective of location) were abnormal gingers as the main constituents of their oils were 1,8-cineole (0.9–2.7%) and zerumbone (84.5–86.9%), this latter compound being the major component of the oil of *Zingiber zerambet* not *Z. officinale*. The main components characterized in the oils of all accession-2 types (irrespective of location were compared to an oil produced from commercial ginger rhizomes under the same conditions as Ghanaian ginger. The results of this study are shown in **T-2**. It should be noted that the oils rich in zerumbone are not produced from *Z. officinale*.

Nirmala Menon (2007) reported that the composition of Indian ginger oil was as follows:

α-pinene (1.3%)
camphene (3.5%)
β-pinene (0.8%)
limonene (1.2%)
β-phellandrene (2.9%)
1,8-cineole (1.1%)
linalool oxide* (0.9%)
linalool (1.0%)
neral (1.7%)
undecanone* (5.2%)
α-copaene (0.6%)
β-elemene (9.4%)
thujopsene (0.9%)
β-caryophyllene (0.6%)
ar-curcumene (7.0%)
zingiberene (29.1%)
β-bisabolene (6.1%)
γ-cadinene (3.0%)
β-sesquiphellandrene (11.3%)
nerolidol* (1.8%)
caryophyllene oxide (0.7%)
elemol (0.6%)
eudesmol* (1.3%)
cedrol (1.0%)
cubenol (0.9%)
farnesol epoxide* (1.7%)
farnesol* (0.5%)

* correct isomer not identified

Trace amounts (<0.05%) of p-cymene, citronellal, linalyl acetate, geranial and allo-aromadendrene were also found in this oil.

An oil from mature, healthy rhizomes that were purchased from a Gorakhpur market (Uttar Pradesh, India), produced by hydrodistillation by Singh et al. (2008), was analyzed using GC/MS only. The constituents characterized in this oil were as follows:

2-heptanol (0.1%)
α-pinene (0.8%)
camphene (3.0%)
β-pinene (0.1%)
6-methyl-5-hepten-2-one (0.1%)
myrcene (0.5%)
α-phellandrene (0.1%)
p-cymene (0.1%)
limonene (0.5%)
β-phellandrene (1.4%)
1,8-cineole (1.9%)
terpinolene (0.1%)
linalool (0.9%)
citronellal (0.3%)
borneol (2.1%)
terpinen-4-ol (0.1%)
cryptone (0.1%)
α-terpineol (0.9%)
citronellol (0.7%)
neral (7.4%)
geraniol (3.4%)
geranial (25.9%)
bornyl acetate (0.3%)
2-undecanone (0.2%)
α-copaene (0.2%)
geranyl acetate (0.6%)
β-elemene (0.2%)
cis-α-bergamotene (0.1%)
(Z)-β-farnesene (0.4%)
(E)-β-farnesene (0.2%)
trans-cadina-1(6),4-diene (0.1%)
γ-muurolene (0.5%)
ar-curcumene (6.6%)
δ-selinene[a] (0.6%)
trans-muurola-4(14),5-diene (0.9%)
zingiberene (9.5%)
(E,E)-α-farnesene (7.6%)
7-epi-α-selinene (0.3%)
δ-cadinene (0.1%)
β-sesquiphellandrene (5.1%)
(E)-γ-bisabolene (0.2%)
elemol (0.5%)
germacrene B (0.3%)
(E)-nerolidol (1.5%)
trans-sesquisabinene hydrate (0.7%)
zingiberenol[b] (1.7%)
guaiol (0.6%)
β-eudesmol (1.0%)
α-eudesmol (0.7%)
acorenone B (0.3%)
(E,E)-farnesal (0.2%)

[a] also known as selina-4,6-diene
[b] also known as bisabola-1,10-dien-3-ol

Trace amounts (<0.05%) of tricyclene, sabinene, octanal, δ-3-carene, 2-nonanone and camphor were also found in this oil.

Rana et al. (2008) collected fresh rhizomes of *Z. officinale* from the Thoubal area (Manipur, India). The fresh rhizomes were cut into small pieces and 1,000 g were hydrodistilled for 4 hrs to yield an oil in 1.1% yield. Analysis of this oil was performed using GC-FID and GC/MS. The composition of the oil was found to be as follows:

2-heptanol (0.4%)
α-pinene (0.6%)
camphene (2.6%)
β-pinene (0.1%)
6-methyl-5-hepten-2-one (1.1%)
myrcene (0.9%)
octanal (0.1%)
α-phellandrene (0.1%)
p-cymene (0.1%)
limonene (0.1%)
β-phellandrene (4.1%)
1,8-cineole (2.0%)
2-heptyl acetate (0.1%)
terpinolene (0.2%)
2-nonanone (0.4%)
linalool (1.8%)
camphor (0.2%)
camphene hydrate (0.1%)
citronellal (0.4%)
isoborneol (0.1%)
borneol (3.2%)
terpinen-4-ol (0.2%)
α-terpineol (0.9%)
myrtenol (0.2%)
citronellol (2.4%)
neral (10.6%)
geraniol (4.7%)
geranial (15.0%)
bornyl acetate (0.6%)
2-undecanone (0.7%)
2-undecanol (0.1%)
geranic acid (0.1%)
cyclosativene (0.1%)
α-copaene (0.2%)
geranyl acetate (1.4%)
β-elemene (0.4%)
7-epi-sesquithujene (0.1%)
(E)-β-farnesene (0.3%)
allo-aromadendrene (0.1%)
ar-curcumene (5.0%)
β-selinene (0.1%)
zingiberene (8.2%)
α-farnesene* (6.1%)
(E)-β-bisabolene (0.2%)
β-sesquiphellandrene (4.6%)
α-cadinene (0.2%)
elemol (0.6%)
germacrene B (0.2%)
(E)-nerolidol (0.8%)
sabinene hydrate[a] (0.6%)
γ-eudesmol (0.1%)
β-eudesmol (0.4%)
α-eudesmol (0.3%)
α-bisabolol (0.1%)
nuciferal* (0.1%)
hexadecanoic acid (0.1%)

* correct isomer not identified
[a] should be *trans*-sesquisabinene hydrate

Trace amounts (<0.1%) of sabinene, γ-terpinene, *cis*-p-menth-2-en-1-ol, *cis*-piperitol and β-caryophyllene were also found in this oil.

The main components of a commercial sample of ginger oil obtained in Poland were determined by Golebiowski et al. (2008) to be:

α-pinene (2.5%)
camphene (8.1%)
β-phellandrene (3.9%)
ar-curcumene (12.2%)
zingiberene (35.9%)
β-bisabolene (16.3%)
β-sesquiphellandrene (11.6%)

Omanakutty and Joy (2009) purchased some fresh ginger rhizomes from a local market in Trivandrum (Kerala, India)

and subjected them to cold grinding with ice with a recommended ratio of rhizomes to ice of 1:1.06 (temp. 2°–5°C). Hydrodistillation of the cold ground rhizomes for 3–4 hrs produced an oil in 0.35% yield (versus 0.25% yield if the fresh rhizomes were ground at ambient temperature). Analysis of this fresh ginger rhizome oil using GC-FID and GC/MS revealed that it possessed the following composition:

α-pinene (0.3%)
camphene (1.3%)
sabinene (3.3%)
borneol (0.5%)
neral (1.3%)
nerol (0.2%)
geranial (6.1%)
α-fenchyl acetate (0.1%)
α-terpinyl acetate (0.4%)
cyclosativene (0.2%)
α-copaene (0.5%)
β-elemene (0.6%)
zingiberene[†] (0.2%)
β-caryophyllene (0.1%)
α-bergamotene[*] (0.1%)
β-farnesene[*] (0.5%)
allo-aromadendrene (0.5%)
eremophilene (0.6%)
ar-curcumene (8.0%)
zingiberene (39.3%)
α-farnesene[*] (11.5%)
1-epi-bicyclosesquiphellandrene (0.8%)
β-gurjunene (0.5%)
β-sesquiphellandrene (14.3%)
α-patchoulene[†] (0.4%)
but-2-en-4-one[†] (0.1%)
elemol (0.1%)
germacrene[*] (1.0%)
(E)-nerolidol (1.0%)
epi-globulol (0.4%)
azulene[†] (0.2%)
β-cedrene[†] (0.1%)
α-bisabolol[†] (0.7%)
eudesmol[*] (0.4%)
longifolenaldehyde[†] (0.5%)
α-bisabolol[†] (0.6%)
β-eudesmol (0.4%)
selin-7(11)-4α-ol[a] (0.3%)
globulol[†] (0.2%)

[*] correct isomer not identified
[†] incorrect identification based on GC elution order
[a] also known as juniper camphor

In addition, the author misidentified a further seven compounds.

Padmakumari et al. (2009) collected fresh rhizomes from ginger plants cultivated in Coktak, Kamtong and Chandel (Manipur, India. Oils produced separately from these rhizomes in amounts of 0.30–0.50% (fresh wt basis) were analyzed by GC-FID and GC/MS. The range in composition of these oils can be seen as follows:

α-thujene (t–0.1%)
α-pinene (0.6–1.2%)
camphene (2.0–4.2%)
β-pinene (0.1–0.3%)
myrcene (0.7–0.9%)
α-phellandrene (t)
limonene (2.0–3.5%)
cis-linalool oxide[f] (0.2–0.3%)
linalool (0.7–1.2%)
isoborneol (0.2–1.0%)
α-terpineol (0.3–0.6%)
neral (3.9–5.6%)
linalyl acetate (0–0.2%)
geranial (6.5–9.9%)
anethole (0–0.1%)
α-terpinyl acetate (0.1%)
dodecanal (0.7–1.0%)
α-copaene (0.3%)
β-caryophyllene (0.2–0.8%)
thujopsene[+] (0.9–1.2%)
α-humulene (0.4–0.7%)
ar-curcumene (8.9–11.6%)
zingiberene (19.4–24.5%)
bisabolene[*] (7.1–10.6%)
germacrene D (4.5–6.4%)

β-sesquiphellandrene (0.4–11.4%)
δ-cadinene (0–0.5%)
elemol (0.2–1.1%)
caryophyllene oxide (0.1–0.4%)
cedrene epoxide+ (0.5–0.7%)
cedrol+ (1.1–1.5%)
T-cadinol (1.8–2.2%)
eudesmol* (1.5–2.2%)
bulnesol+ (0–0.3%)
(Z,E)-farnesol (0–0.9%)

* correct isomer not identified
+ identification in error
f furanoid form

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M. Omanakutty and B. Joy, *Cold grinding for retention of fresh flavor components in ginger oil.* Indian Perfum.,**53**(1), 35–37 (2009).

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Caraway Oil

Lawrence (1979) compared the composition of oils produced from vegetative plant (pre-flowering), umbels and fruit (seeds) of *Carum carvi* L. The results of this study are shown in **T-3**.

Janssen (1989) screened caraway oil for its antimicrobial properties. The composition of the oil used in this screening study was determined to be as follows:

T-3. Percentage composition of oils produced from different parts of *Carum carvi*

Compound	Vegetative plant oil	Umbel oil	Seed oil
α-thujene	-	0.1	t
α-pinene	t	0.1	t
β-pinene	t	t	t
sabinene	t	0.2	0.1
myrcene	t	0.3	0.5
α-phellandrene	-	t	t
α-terpinene	-	t	t
limonene	0.8	25.5	48.6
β-phellandrene	-	0.1	t
γ-terpinene	t	0.2	0.1
p-cymene	0.1	0.8	0.1
terpinolene	-	t	t
octanal	t	-	t
nonanal	t	-	t
cis-limonene oxide	-	-	0.1
α-copaene	0.1	0.1	1.8
β-bourbonene	0.2	0.2	t
β-elemene	6.3	2.9	t
β-caryophyllene	8.8	1.2	0.2
trans-dihydrocarvone	0.1	1.1	0.8
cis-dihydrocarvone	t	0.2	0.1
α-humulene	0.5	0.3	0.1
germacrene D	79.5	9.5	1.5
β-selinene	0.2	0.1	t
carvone	0.8	49.6	47.3
dihydrocarveol	-	t	0.1
γ-cadinene	0.3	t	t
δ-cadinene	0.2	t	t
cis-p-mentha-2,8-dien-1-ol	-	t	t
trans-p-mentha-2,8-dien-1-ol	-	t	t
trans-carveol	t	0.1	0.4
germacrene B	1.0	0.2	t
caryophyllene oxide	-	t	0.1

*major constituent
t = trace (<0.1%)

sabinene (0.06%)
myrcene (0.39%)
limonene (46.65%)
limonene 1,2-epoxide* (0.06%)
limonene 1,2-epoxide* (0.05%)
linalool (0.07%)
cis-dihydrocarvone (0.48%)
trans-dihydrocarvone (0.16%)
α-terpineol (0.12%)
neodihydrocarveol (0.09%)
carvone (50.02%)
dihydrocarveol (0.12%)
isodihydrocarveol (0.12%)
perillaldehyde (0.14%)
neoisodihydrocarveol (0.29%)
trans-carveol (0.26%)
cis-carveol (0.12%)

* correct isomer not identified

Ghannadi (2003) determined that an oil of *C. carvi* that was produced by hydrodistillation of the ripe fruit harvested from caraway cultivated in Kerman province (Central Iran) contained the following main constituents:

tricyclene (0.1%)
α-pinene (0.7%)
sabinene (2.1%)
myrcene (0.6%)
limonene (17.4%)
γ-terpinene (17.2%)
terpinolene (0.2%)
linalool (0.1%)
cis-dihydrocarvone (0.5%)
trans-dihydrocarvone (1.2%)
carvone (32.7%)

carvenone (4.6%)
perillyl alcohol (3.1%)
carvacrol (4.4%)
dihydrocarvyl acetate (9.8%)
cis-pinocarvyl acetate (1.0%)

The occurrence of such high levels of γ-terpinene, dihydrocarvyl acetate and carvacrol in caraway oil is highly unusual.

Iacobellis et al. (2005) screened an atypical caraway oil produced in the laboratory by hydrodistillation of ground dried fruits (sees) for its antibacterial activity, particularly those genera responsible for plant and cultivated mushroom diseases. Using a combination of GC-FID and GC/MS, the oil was found to possess the following composition:

octanal (1.2%)
limonene (18.2%)
nonanal (0.3%)
linalool (0.3%)
trans-limonene oxide (0.1%)
(Z)-tagetone[†] (0.2%)
dihydrocarveol (4.5%)
cis-dihydrocarvone (0.4%)
trans-dihydrocarvone (14.0%)
trans-carveol (0.1%)
cis-carveol (0.1%)
carvone (23.3%)
(Z)-2-decenal (0.4%)
(E)-2-decenal (0.2%)
cis-carvone oxide (0.3%)
(E)-anethole (3.3%)
carvacrol (6.7%)
β-caryophyllene (6.1%)
germacrene D (16.2%)
δ-cadinene (0.5%)
germacrene B (3.8%)

[†] unusual caraway oil constituent requires collaboration

A trace amount of *cis*-limonene oxide (<0.5%) was also characterized in this oil. In addition, the fact that the oil had such a low level of carvone and a high level of germacrene D would indicate that the fruits (sees) used in this study were probably immature as it is well-known that young caraway plants possess an oil rich in germacrene D.

Simic et al. (2008) screened a commercial sample of caraway oil for its antimicrobial properties. The composition of this oil was found to be as follows:

p-cymene (0.1%)
limonene (45.5%)
trans-p-mentha-2,8-dien-1-ol (0.3%)
cis-p-mentha-2,8-dien-1-ol (0.3%)
camphor (0.1%)
α-terpineol (0.1%)
dihydrocarveol (0.5%)
cis-dihydrocarvone (1.0%)
trans-dihydrocarvone (0.2%)
isodihydrocarveol (0.4%)
trans-carveol (0.5%)
cis-carveol (1.1%)
carvone (46.6%)
perillaldehyde (0.2%)
safrole (1.4%)
eugenol (0.7%)

It should be noted that perillaldehyde, safrole and eugenol are not constituents of caraway oil. The authors either misidentified the two compounds, their oil was contaminated or, more likely, their oil was adulterated as it was obtained commercially.

Pank et al. (2008) determined that over the years, recurrent selection of annual cultivars of caraway have resulted in an increase of oil content of 3.4% to 7.4%. The authors also screened the most commonly grown cultivars in Germany for fruit yield per hectare and resistance to fruit

shattering. The cultivars screened were 'Selca,' Sprinter,' 'Karzo' and 'SZK-1.' The five major components of the oils were compounded for the four cultivars as shown in **T-4**.

Seo et al. (2009) determined that the enantiomeric ratio of the two major caraway oil components were:

(4S)-(-)-limonene (100%)
(4S)-(+)-carvone (100%)

The authors also noted that *cis*-carveol and *trans*-carveol were characterized as minor constituents in levels of 0.4% and 0.3%, respectively.

Laribi et al. (2009) examined the effect of water deficit on growth and essential oil composition of caraway grown in Tunisia. It was found that the weight of the fruit and the fruit yield per plant was reduced from 2.36–3.05 g/1,000 seeds and 0.70–1.33 g/plant, respectively. The effect of a water deficit on the oil composition is shown in **T-5**.

Laribi et al. (2010) further examined the composition of oils produced (in yields from 0.86–1.2%) from two ecotypes of caraway growing in Haouaria, Menzel Temime and Souassi (Tunisia). The results of this study are presented in **T-6**. In addition, trace amounts (<0.05%) of camphene, β-pinene, (E)-β-pinene, (E)-β-ocimene, p-cymene, terpinolene, camphor, β-elemene, terpinen-4-ol, germacrene D, cuminaldehyde, nerol, *cis*-carveol, perillyl alcohol, eugenol, nonadecane and spathulenol were also found in this oil.

An oil of caraway that was produced from mature caraway fruits grown in Serbia by hydrodistillation was analyzed by Samojlik et al. (2010) using GC-FID and GC/MS. The components characterized in the oil were as follows:

limonene (10.1%)
1,8-cineole (0.6%)
cis-limonene oxide (1.8%)
menthone† (1.2%)
menthol† (0.4%)
dihydrocarvone* (0.8%)
trans-carveol (1.3%)
cis-carveol (0.6%)
carvone (78.8%)
cis-carvone oxide (0.3%)
(E)-anethole (0.4%)
isomenthone† (0.1%)
caryophyllene oxide (0.3%)

* correct isomer not identified
† misidentified constituents

T-4. Comparative percentage composition of the main components of the oils of four annual caraway cultivars

	'Selca' oil	'Sprinter' oil	'Karzo' oil	'SZK-1' oil
limonene	45.3	45.7	47.8	45.7
myrcene	0.6	0.5	0.5	0.5
trans-dihydrocarvone	0.1	0.1	0.2	0.2
carvone	53.3	52.9	50.6	52.9
trans-carveol	0.2	0.2	0.1	0.1
Oil content	**6.57**	**3.98**	**2.23%**	**2.49%**

T-5. Comparative percentage composition of the effect of a water deficiency on the oils of caraway produced in Tunisia

Compound	**Oil 1**	**Oil 2**
α-pinene	0.5	0.3
camphene	0.4	0.4
myrcene	0.1	0.1
limonene	7.5	19.3
γ-terpinene	0.2	0.2
(E)-β-ocimene	0.2	0.2
Terpinolene	0.1	0.1
(Z)-3-hexenol	0.1	0.1
trans-limonene oxide	0.1	0.1
linalyl acetate	0.2	t
β-elemene	0.3	0.2
terpinen-4-ol	0.1	0.1
trans-dihydrocarvone	0.2	0.2
cis-dihydrocarvone	0.2	0.3
allo-aromadendrene	0.2	0.2
germacrene D	0.4	0.3
dihydrocarveol	0.2	0.1
carvone	83.8	72.6
β-selinene	0.6	0.7
α-selinene	0.3	0.4
α-farnesene*	0.3	0.3
citronellol	0.1	0.1
δ-cadinene	0.4	0.4
γ-cadinene	0.5	0.6
cuminaldehyde	0.1	t
perillaldehyde	0.2	0.2
nerol	t	0.1
trans-carveol	1.2	1.0
cis-carveol	0.2	0.3
spathulenol	0.2	0.1
eugenol	0.2	0.1
thymol	0.3	0.2
carvacrol	0.1	0.1
Oil yield	**0.47**	**0.60**

Oil 1 = control
Oil 2 = severe water deficit
t = trace (<0.05%)
*correct isomer not identified

T-6. Comparative percentage composition of the oils of three ecotypes of caraway growing in Tunisia

Compound	Haouaria oil	Menzel Temime oil	Souassi oil
α-pinene	0.1	0.1	0.1
myrcene	0.1	0.2	0.1
limonene	16.2	20.3	13.1
γ-terpinene	t	t	1.2
(Z)-3-hexenol	t	t	0.1
trans-limonene oxide	0.1	0.1	t
linalool	0.1	t	0.1
linalyl acetate	0.1	t	t
β-caryophyllene	0.1	0.1	0.1
trans-dihydrocarvone	0.2	0.2	0.1
cis-dihydrocarvone	0.3	0.1	0.1
allo-aromadendrene	0.2	0.1	0.1
α-terpineol	0.1	t	t
dihydrocarveol	0.2	0.2	1.5
carvone	80.3	76.8	80.5
β-selinene	0.2	0.2	0.8
α-selinene	0.2	0.2	0.4
α-farnesene*	0.3	0.3	0.2
citronellol	0.1	t	0.1
δ-cadinene	0.2	0.1	0.2
γ-cadinene	0.5	0.3	0.3
perillaldehyde	0.2	0.1	0.1
trans-carveol	0.1	0.1	0.1
thymol	0.1	0.1	0.2
carvacrol	t	t	0.7

* correct isomer not identified
t = trace (<0.05%)

T-7. Comparative percentage composition of caraway oil produced by two different isolation procedures in the laboratory

Compound	1	2
α-pinene	0.1	0.1
β-pinene	0.2	0.2
α-phellandrene	1.3	1.4
limonene	43.5	48.4
γ-terpinene	0.1	0.1
p-cymenene	0.2	0.2
limonene oxide*	0.1	0.2
trans-verbenol	0.1	0.1
α-terpineol	0.2	0.2
cis-dihydrocarvone	2.3	2.0
trans-carveol	0.2	0.2
dihydrocarveol	0.3	0.2
carvone	32.6	31.1
(E)-anethole	3.0	2.7
methyl chavicol	0.1	t
β-selinene	0.1	t
cubebol	0.1	0.1
apiole	15.1	12.3
Oil yield	**4.7**	**4.2**

1 = hydrodistilled oil
2 = microwave hydrodistilled oil

A comparison of methods of essential oil isolation in the laboratory was performed by Jiang et al. (2011) using caraway (fruit) seeds (10 g only) as the charge. Typical hydrodistillation (3 hrs) was compared with microwave hydrodistillation (1 hr) and the resultant oils were analyzed by GC/MS, the results of which are shown in **T-7**. As can be seen, the method of isolation had only a very minor effect on the oil yield and composition. However, it is interesting to see that the oil of this Chinese clone of caraway contained apiole, a compound not normally found in caraway oil. The authors also listed a number of trace constituents in the oils; however, as many were highly unusual and questionable, they are not included in this review.

Raal et al. (2012) purchased 20 commercial caraway samples from pharmacies and health shops from a variety of European countries between 2000 and 2008. The oils, which were produced by hydrodistillation, ranged in yield from 0.6% to 5.4%. GC-FID analysis of the oils revealed that their compositions ranged as follows:

a-pinene (0–0.2%)
sabinene (0–0.3%)
myrcene (0–0.4%)
octanal (0–0.6%)
limonene (1.5–51.3%)
(E)-b-ocimene (0–0.1%)
g-terpinene (0–0.1%)
linalool (0–0.2%)
cis-limonene oxide (t–0.3%)
trans-limonene oxide (0–0.4%)
cis-dihydrocarvone (0–0.4%)
trans-dihydrocarvone (0–0.5%)
trans-carveol (0–0.2%)
cis-carveol (0–0.3%)
carvone (44.5–95.9%)
perillaldehyde (0.1–0.4%)
(E)-anethole (0–2.2%)
b-caryophyllene (0–0.3%)

t = trace (<0.05%)

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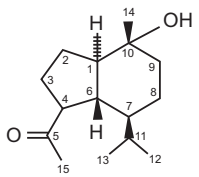
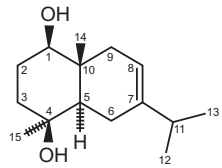
Errata

The structures appearing in F-1 on page 48 of the October 2012 edition of *P&F* magazine were inadvertently misprinted by the publisher (Progress in Essential Oils, "Sugandh Mantri Gandhi Roots Oil"); we regret the error. The correct figure appears below.

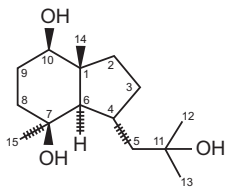
F-1. Uncommon sesquiterpenoids found in *Homalomena aromatica* rhizomes



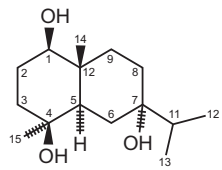
Oplopanone



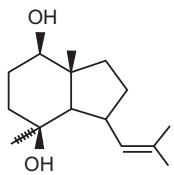
Oplodiol



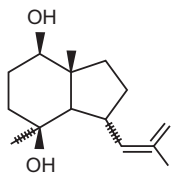
Bullatantriol



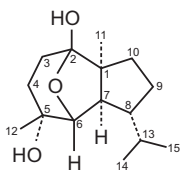
1β,4β,7α-Trihydroxyeudesmane



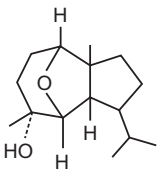
Homalomenol A



Homalomenol B



Homalomenol C



Homalomenol D